MAJOR PROJECT REPORT
SUBMISSION ON

PRODUCTION OPTIMIZATION OF COAL BED METHANE WELLS IN RANIGANJ FIELD

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Batch 2011-15

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CERTIFICATE

This is to certify that the student **Sagar Nagpal, Steffones K, Robin Sharma** of **University of Petroleum and Energy Studies, Dehradun** has successfully completed the project work on **“Production Optimization of Coal Bed Methane Wells in Raniganj Field”** under Petroleum & Earth Science Department at the University of Petroleum & Energy Studies**.** This project work is the requirement towards awarding the Degree of Bachelor of Technology in Applied Petroleum Engineering, from University of Petroleum and Energy Studies, Dehradun.

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(Course- Coordinator)

Dr. D. K. Gupta
(HOD, Department of Petroleum and Earth Sciences)

DECLARATION

We, hereby declare that the project entitled **PRODUCTION OPTIMISATION OF CBM WELLS IN RANIGANJ FIELD** is a genuine work carried out by us under the supervision of **DR. PUSHPA SHARMA** for the partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in **APPLIED PETROLEUM ENGINNERING with specialization in UPSTREAM**. All the interpretations have been made on the basis of the literature survey being conducted and the information taken from the sources have been acknowledged.

We declare that if any part of the report is found to plagiarized, we shall take the full responsibility

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Date: 25th May'1

ACKNOWLEDGEMENT

We express our deep sense of gratitude to **Dr. Srihari**, Vice Chancellor UPES Dehradun & **Mr. Kamal Bansal**, Dean College of Engineering Studies UPES Dehradun for giving us the opportunity to work on academic major project and providing all the necessary facilities towards the completion of this project. We are thankful to **Dr. D.K Gupta**, HOD (Petroleum & Earth Science) for valuable discussions throughout this project. We are extremely grateful to **Dr. Pushpa Sharma,** Professor Petroleum & Earth Science, who mentored us throughout this project. It was with her invaluable guidance that this work could be completed in time.

We would like to express our sincere regards to **Mr. P.K. Gupta** (VP - Production Operations, ESSAR E&P Ltd., Durgapur) without whose support our project seems impossible. We would like to extend our vote of thanks to our mentor, Mr. Karthik Santhanam (Manager, Workover Operations). A significant course of our project was spent on operational sites with Mr. Fayaz Iqbal, Mr. Anuj, Mr. Chetan Mishra, Mr. Vishnu Gupta Kothuri & Mr. Vipul Keshwani.

Executive Summary

A coal bed methane gas reservoir contains compressible hydrocarbon fluids (methane gas) at a considerable amount of pressure and temperature and as such, the fluid (methane gas) stores up within itself some energy of compression. The efficient production of fluids from a reservoir requires the effective dissipation of this energy through the production system. Optimum utilization of this energy is an essential part of a successful completion design and ultimately of field development economics. Where necessary and economic, this lift process can be supported by artificial lift using pumps or gas lift. The pressure drop across the reservoir, the tubing and choke are rate dependent and these relationships therefore define the means by which we can optimize the production of the fluid from the reservoir. In some cases there will be significant limitations on the extent to which we can optimize the dissipation of this energy. When pumps are used, apart from fluid recompression and the associated fluid properties, there is no change in fluid composition. There are many specific mechanisms for providing pump power and the lift mechanism. e.g. Electrical powered centrifugal pumps, Hydraulic powered centrifugal/turbine, jet and reciprocating pumps and Sucker rod and screw pumps. In West Bengal Raniganj, coalfield is the most important coalfield. This coalfield is the easternmost of the Damodar Valley Coalfields. The coalfields lie mostly in the West Bengal and partly (western portion) in Bihar. The fluid production resulting from reservoir development will normally lead to a reduction in the reservoir pressure, increase in the fraction of water being produced together with a corresponding decrease in the produced gas fraction. When pumps are used, apart from fluid recompression and the associated fluid properties, there is no change in fluid composition. There are many specific mechanisms for providing pump power and the lift mechanism. Each artificial lift system has a preferred operating and economic envelope influenced by factors such as fluid gravity, G.O.R., production rate as well as development factors such as well type, location and availability of power. The objective of our project is to use identify the best pumping practices that can be implemented over the Raniganj field and thus optimize the production of Raniganj field.

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1. Introduction

Coal Bed Methane (CBM) is a form of natural gas (predominantly methane) extracted from coal seams. It is a gas which is created as part of the geological process of coal generation, and is varying quantities within all coal and is trapped within a coal seam by contained in formation water. CBM is chemically identical to other sources of gas, but is produced by non-conventional methods. Coalbed methane is exceptionally pure compared to conventional natural gas, containing only very small proportions of “wet” compounds (e.g., heavier hydrocarbons such as ethane and butane) and other gases (e.g., hydrogen sulfide and carbon dioxide). Coalbed methane gas is over 90 percent methane, and is suitable for introduction into a commercial pipeline with little or no treatment.

1.1 Methane Gas Generation in Coal

Methane gas is generated during the formation of coal through ‘coalification’ process of vegetable matter.

1. Biogenic methane is produced by anaerobic bacteria in the early stage of coalification.
2. Thermogenic methane is mainly during is mainly during coalification at temperatures of 120 – 150°C.

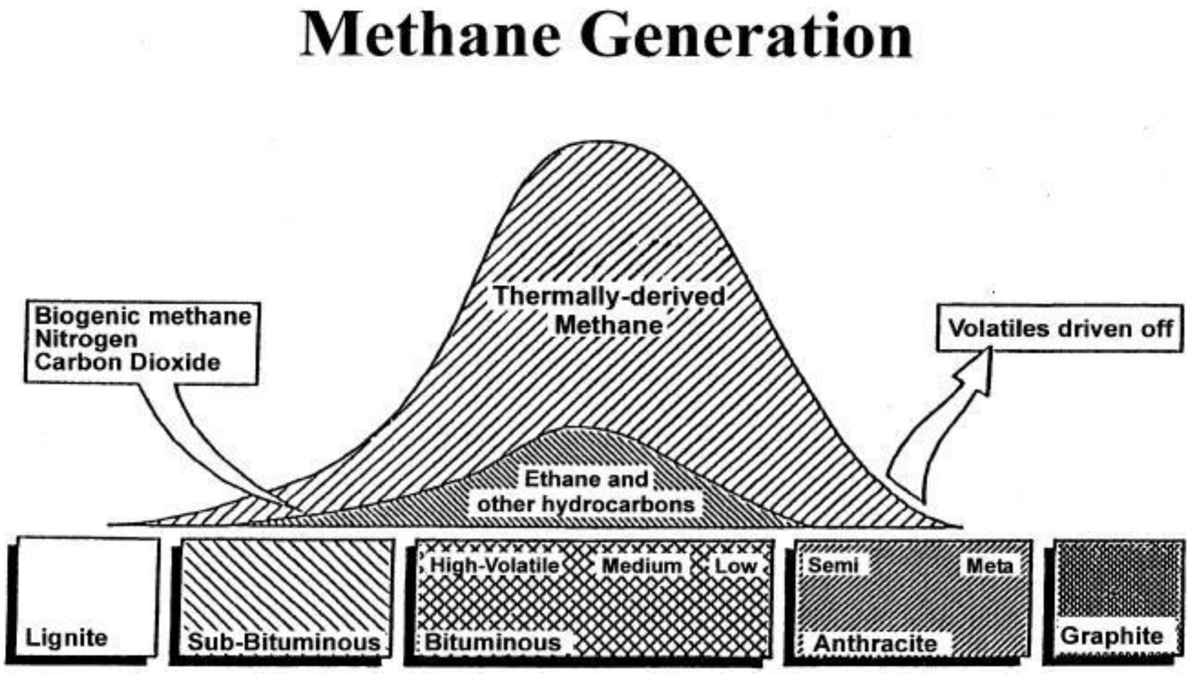


Figure 1

1.2 CBM vs. Conventional Gas Reservoir

CBM reservoirs are different from conventional gas reservoirs in three distinct characteristics:-

- Coal is both the reservoir and the source rock.
- Gas is stored by adsorption in the coal matrix instead of by compression in pore spaces as in conventional sandstone or carbonate reservoirs.
- The cleats are typically filled with water. If the gas content in the coal matrix is below equilibrium or the reservoir pressure is above a critical pressure, it will be necessary to produce water, known as dewatering, to reduce the pressure below the equilibrium pressure allowing the gas to desorb.

Conventional Gas	**Coal Bed Methane**
Darcy flow of gas to wellbore.	Diffusion through micropores by Fick's Law.
	Darcy flow through fractures.
Gas storage in macropores; real gas law.	Gas storage by adsorption on micropore surfaces.
Production schedule according to set decline curves.	Initial negative decline.
Gas content from logs.	Gas content from cores. Cannot get gas content from logs.
Gas to water ratio decreases with time.	Gas to water ratio increases with time in latter stages.
Inorganic reservoir rock.	Organic reservoir rock.
Hydraulic fracturing may be needed to enhance flow.	Hydraulic fracturing required in most of the basins except the eastern part of the Powder River basin where the permeability is very high. Permeability dependent on fractures.
Macropore size:[3] 1μ to 1 mm	Micropore size:[3] <5A° to 50A°
Reservoir and source rock independent.	Reservoir and source rock same.
Permeability not stress dependent.	Permeability highly stress dependent.

Well interference detrimental to production.	Well interference helps production. Must drill multiple wells to develop.

1.3 India’s Coal Bed methane Reserves

Coal Bed Methane could be a promising energy solution for India, which has large deposits of coal and limited oil & gas reserves. The total coal resource of India is about 248 BT of which the Indian Gondwana Basins contribute about 99 per cent. Further, the Damodar Valley Coalfields of Eastern India contribute 50 per cent of this resource.

As per Directorate General of Hydrocarbons (DGH) database, India has an estimated 92 Trillion Cubic Feet (tcf) of CBM gas reserves. India is world’s third largest producer of coal, however commercial production of CBM is still at a very nascent stage in the country. In India 99% of our coal production comes from the Gondwana coals which are found in three geological units:-

- Raniganj Formation – Upper Permian
- Barakar Formation - Lower Permian
- Karharbari Formation - Lower Permian

1.4 Raniganj Coalfield - In west Bengal Raniganj coalfield is the most important coalfield. This coalfield is the easternmost of the Damodar Valley Coalfields. The coalfields lie mostly in the West Bengal and partly (western portion) in Bihar. Next to Jharia coalfields, this is the most important coalfield in India. It is situated about 185 km north-west of Kolkata. The field is named after the town Raniganj which is situated in the south-eastern part of this field. The coalfield is surrounded by the Archean rocks on all sides except in the east. Coal bearing Gondwana strata lie beneath the alluvium cover. Coals of the Barakar Measures are low in moisture (1-3%), low in volatile matter (20-30%) whereas coals of Raniganj Measures are high in moisture (3-10%) and high in volatile matter (30-36%).

2. Coal Bed Methane Extraction

Methane has been traditionally extracted from coals to reduce mining hazards, as low explosive limits of methane in the air made it necessary to vent great volumes of the gas from gassy coal mines before working in the mines, but the gas was vented to the atmosphere with large fans in the mines. The environmental aspect of CBM emissions into the atmosphere from mines is an international problem, as can be surmised from the diversity of coal locations in the world. Emissions from coal mines are estimated to account for as much as 10% of methane emissions from all sources worldwide. Because of the complexity of coal reservoirs, formation evaluation techniques are extremely important for determining the commercial viability of coalbed-methane prospects. Methane from unmined coal seams is recovered through drainage systems constructed by drilling a series of vertical or horizontal wells directly into the seam. Water must first be drawn from the coal seam in order to reduce pressure and release the methane from its adsorbed state on the surface of the coal and the surrounding rock strata. Once dewatering has taken place and the pressure has been reduced, the released methane can escape more easily to the surface via the wells. The coal seams are often stimulated or "fractured" to make the CBM flow more freely.

2.1 Different phases of CBM Extraction-

Phase	Nature of Input/Activity
a) Drilling	Casing string design Drilling fluid Selection
b) Completion	Design/installation of completion string
c) Production	Monitoring well and completion performance
d) Workover/Recompletion	Diagnosis/recommendation/ installation of new or improved production systems
e) Abandonment	Identify candidates and procedures

3. Production Operations

Production is when the water and gas are produced. It is the process of bringing hydrocarbon (CH_4) to the surface. Methane gas will normally flow to the surface under natural flow when the discovery well is completed in a virgin reservoir. The fluid production resulting from reservoir development will normally lead to a reduction in the reservoir pressure, increase in the fraction of water being produced together with a corresponding decrease in the produced gas fraction.

To initiate gas production, water must be pumped out of the saturated coal zone. Dewatering reduces the cleat pressure allowing gas to desorb from the coal matrix and diffuse to the cleat. As a coal is dewatered, the cleat system progressively opens farther and farther away from the well.
Once the pressure in the cleat system is lowered by water production to the “critical desorption pressure,” gas will desorb from the matrix. Critical desorption pressure, as illustrated on is the pressure on the sorption isotherm that corresponds to the initial gas content. As the desorption process continues, a free methane gas saturation builds up within the cleat system. Once the gas saturation exceeds the critical gas saturation, the desorbed gas will flow along with water through the cleat system to the production well. As this process continues, gas flow increases from the expanding volume of dewatered coal. Water production decreases with time, which makes gas production from the well more economical.

Gas desorption from the matrix surface in turn causes molecular diffusion to occur within the coal matrix. The diffusion through the coal matrix is controlled by the concentration gradient and can be described by Fick’s Law:

$$Q_m = 2.697\sigma D\rho V(G - Gs)$$

q = Gas production (diffusion) rate, MCF/day
σ = matrix shape factor, dimensionless
D = matrix diffusivity constant, sec-1
V = Matrix volume, ft^3
ρ_c = Matrix Density, g/cm^3
G = Average matrix gas content, SCF/ton

As the desorption process continues, gas saturation within the cleat system increases and flow of methane becomes increasingly more dominant. Thus, water production declines rapidly until the gas rate reaches the peak value and water saturation approaches the irreducible water saturation.

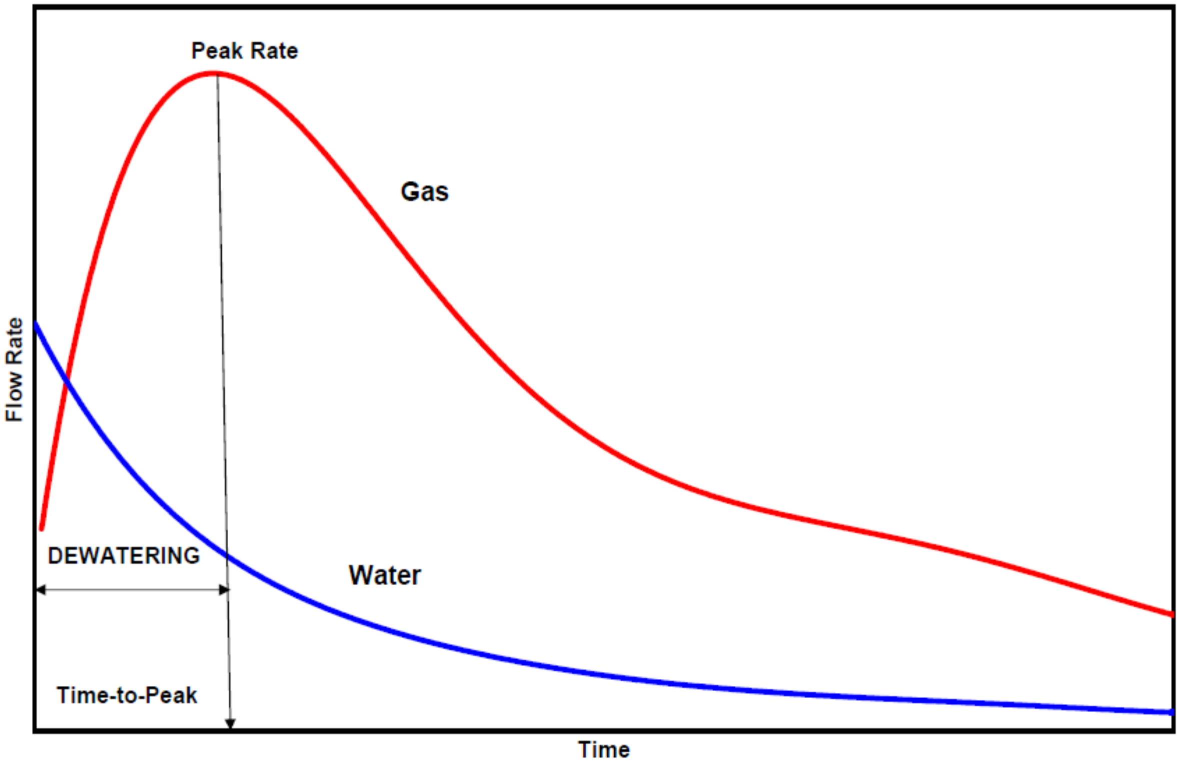


Figure2-Production History of CBM Well

3.1 Storage Capacity-

A sorption isotherm relates the gas storage capacity of a coal to pressure and depends on the rank, temperature, and the moisture content of the coal. The sorption isotherm can be used to predict the volume of gas that will be released from the coal as the reservoir pressure is reduced. The above equation assumes pure coal and for application in the field, the equation is modified to account for ash and moisture contents of the coal:

$G_s=(1-f_m-f_a)\ V_LP/(P_L+P)$

Where:
G = Gas storage capacity, SCF/ton
P = Pressure, psia
V_L = Langmuir volume constant, SCF/ton
P_L= Langmuir pressure constant, psia
f_a = Ash content, fraction
f_m = Moisture content, fraction

Gas storage Capacity of CBM wells from 3 different wells-

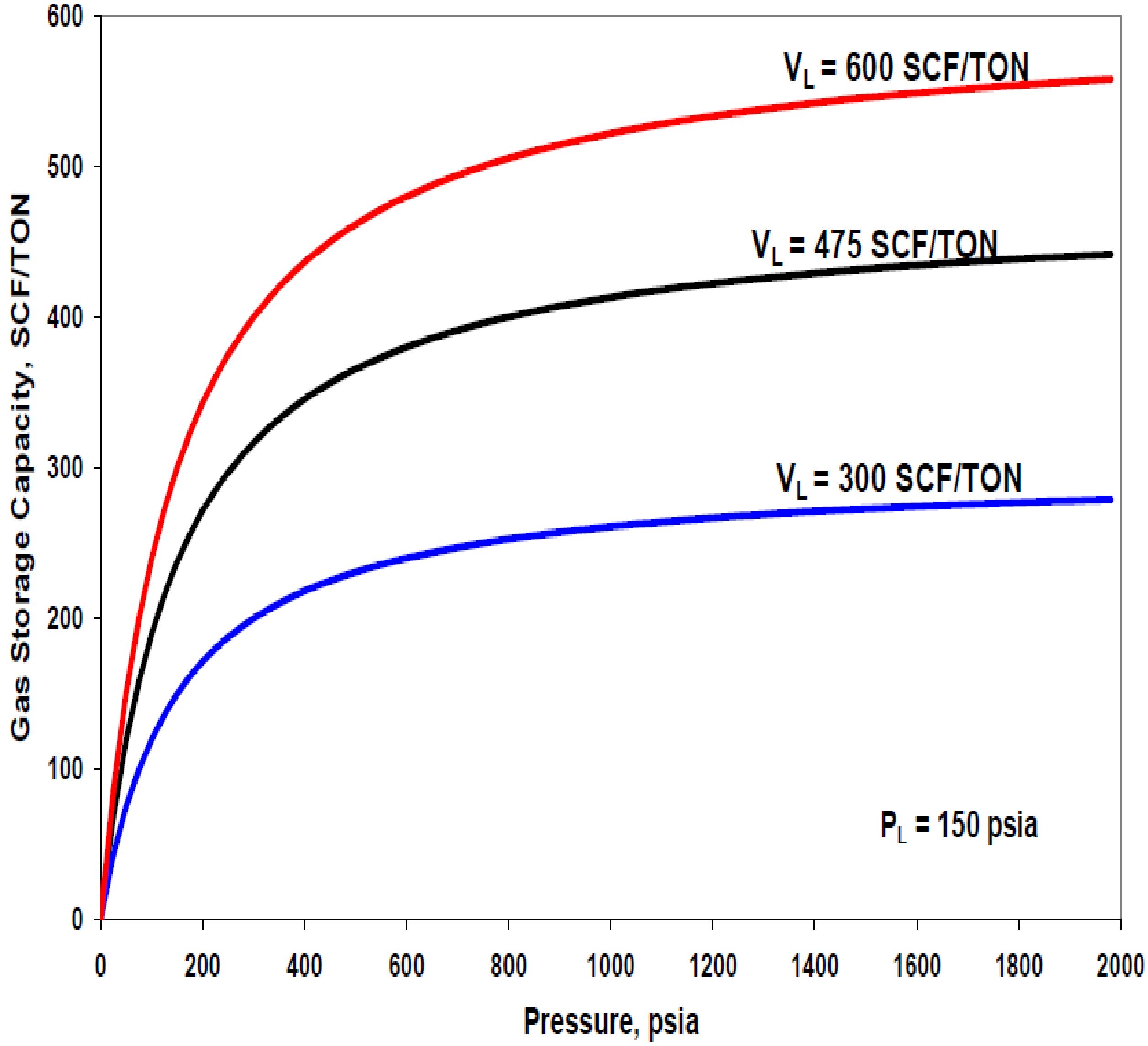


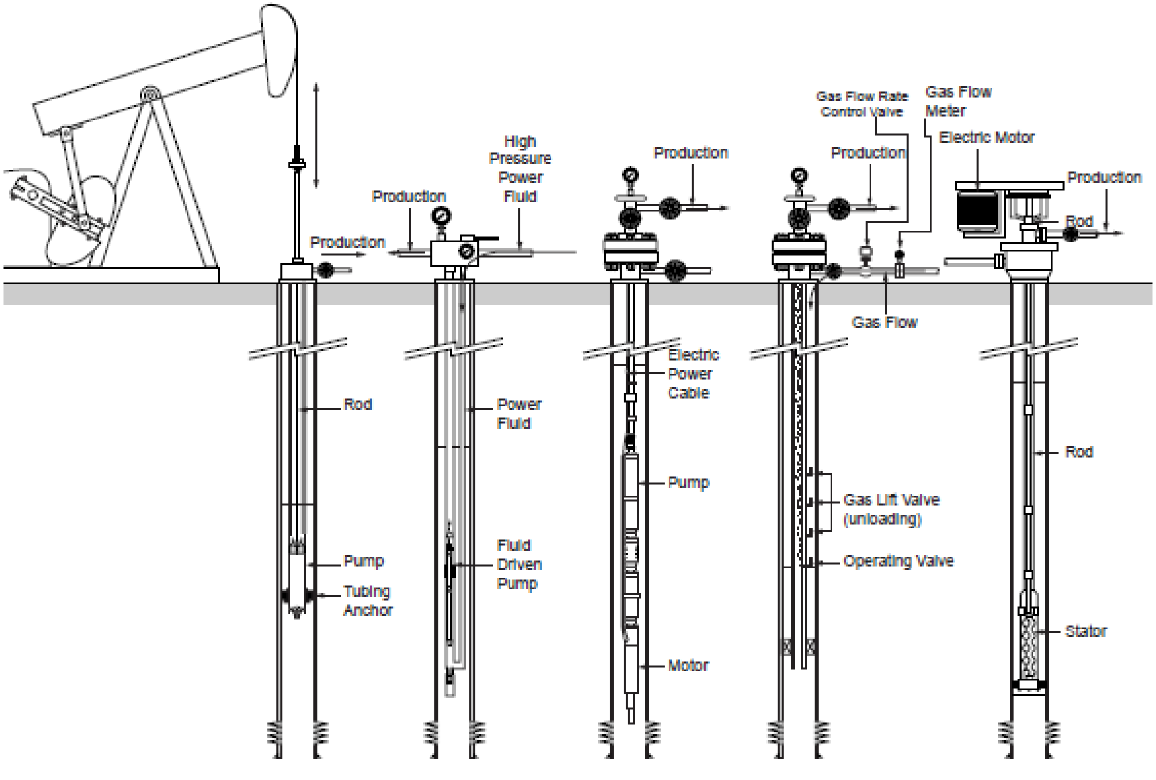
Figure 3 Gas Storage of 3 Different Wells

4. ARTIFICIAL LIFT

As stated above, wells will produce under natural flow conditions when reservoir pressure will support sustainable flow by meeting the entire pressure loss requirements between the reservoir and separator. When pumps are used, apart from fluid recompression and the associated fluid properties, there is no change in fluid composition. There are many specific mechanisms for providing pump power and the lift mechanism. e.g.

1. Electrical powered centrifugal pumps
2. Hydraulic powered centrifugal/turbine, jet and reciprocating pumps
3. Sucker rod and screw pumps

Each artificial lift system has a preferred operating and economic envelope influenced by factors such as fluid gravity, G.O.R., production rate as well as development factors such as well type, location and availability of power.



(i) Rod Pump (ii) Hydraulic Pump (iii) Submersible (iv) Gas lift (v) Progressing Cavity Pump (May also be driven by electric submersible motor)

Figure 4 Different Artificial Lift used for Production.

Raniganj Field Application Progressive Cavity Pump and Electrical Submersible Pump come into play for the CBM operations carried out by ESSAR. Below is a brief discussion of the features and process of the various artificial lift techniques available.

4.1 Sucker Rod Pump

System Description: Sucker-rod lift method is the oldest and most widely used type of artificial lift for most wells. The surface-pumping unit, which drives the underground pump, consists of a prime mover (usually an electric motor) and, normally, a beam fixed to a pivotal post. The post is called a Sampson post, and the beam is normally called a walking beam.

Process: This system allows the beam to rock back and forth, moving the downhole components up and down in the process. The entire surface system is run by a prime mover, V-belt drives, and a gearbox with a crank mechanism on it. When this type of system is used, it is usually called a beam-pump installation.

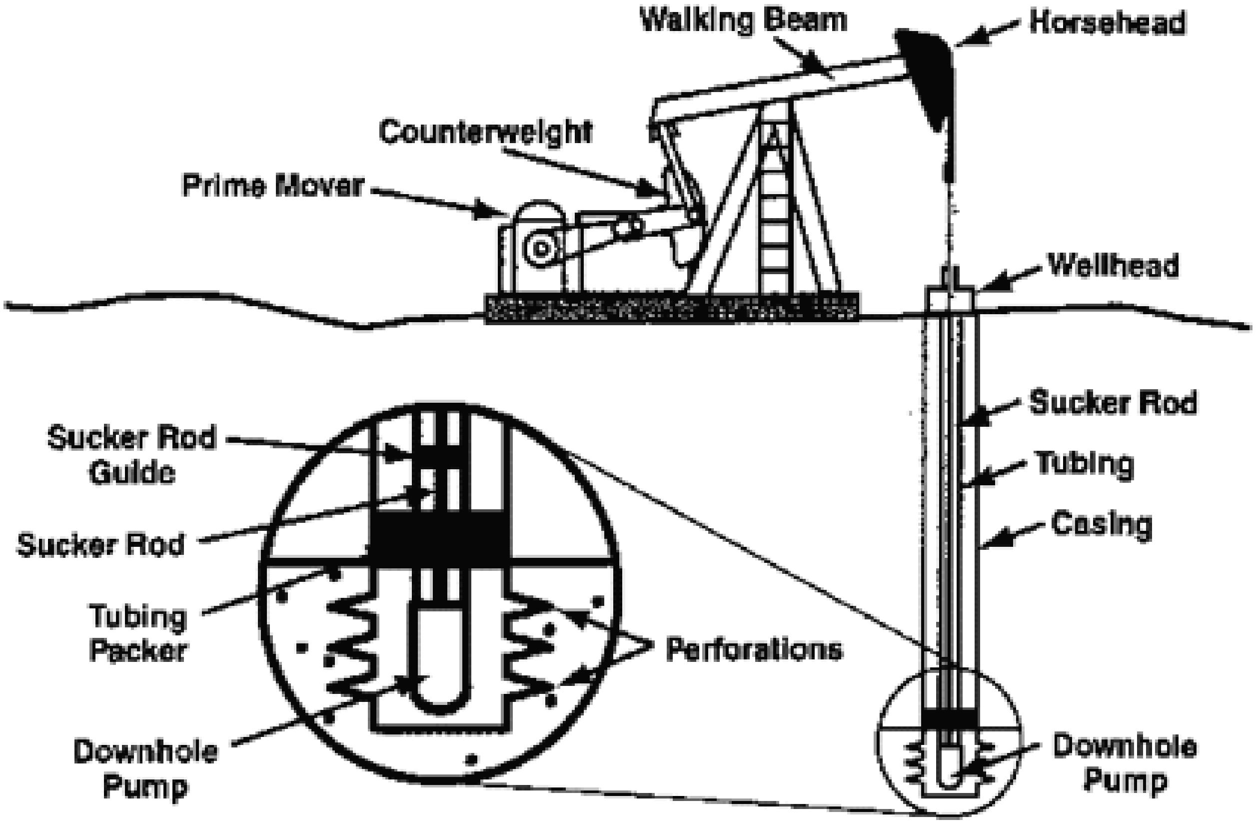


Figure 5

Underground pump are connected to the surface unit. The steel rods are normally screwed together in 25- or 30-ft lengths. The steel sucker rods typically fit inside the tubing and are stroked up and down by the surface-pumping unit. This activates the downhole, positive-displacement pump at volume of produced fluid is lifted through the sucker-rod tubing annulus and discharged at the surface the bottom of the well.

The "Upward" rod movement reduces the pressure within the pump barrel and the upward flow of fluid from below the pump lifts the standing valve’s ball off its seat. The pressure due to the fluid column above the plunger keeps the travelling valve ball on its seat.The pump capacity will often be greater than the well inflow capacity – the pump motor must be stopped at regular intervals when the fluid level is reduced to a specified, minimum safety level above the pump. This monitoring is often performed with an “Echometer”. API Recommended Practice 11L, published by the American Petroleum Institute, describes a field proven method for designing all elements of a Rod Pump.

4.2 Electric Submersible Pump (ESP)

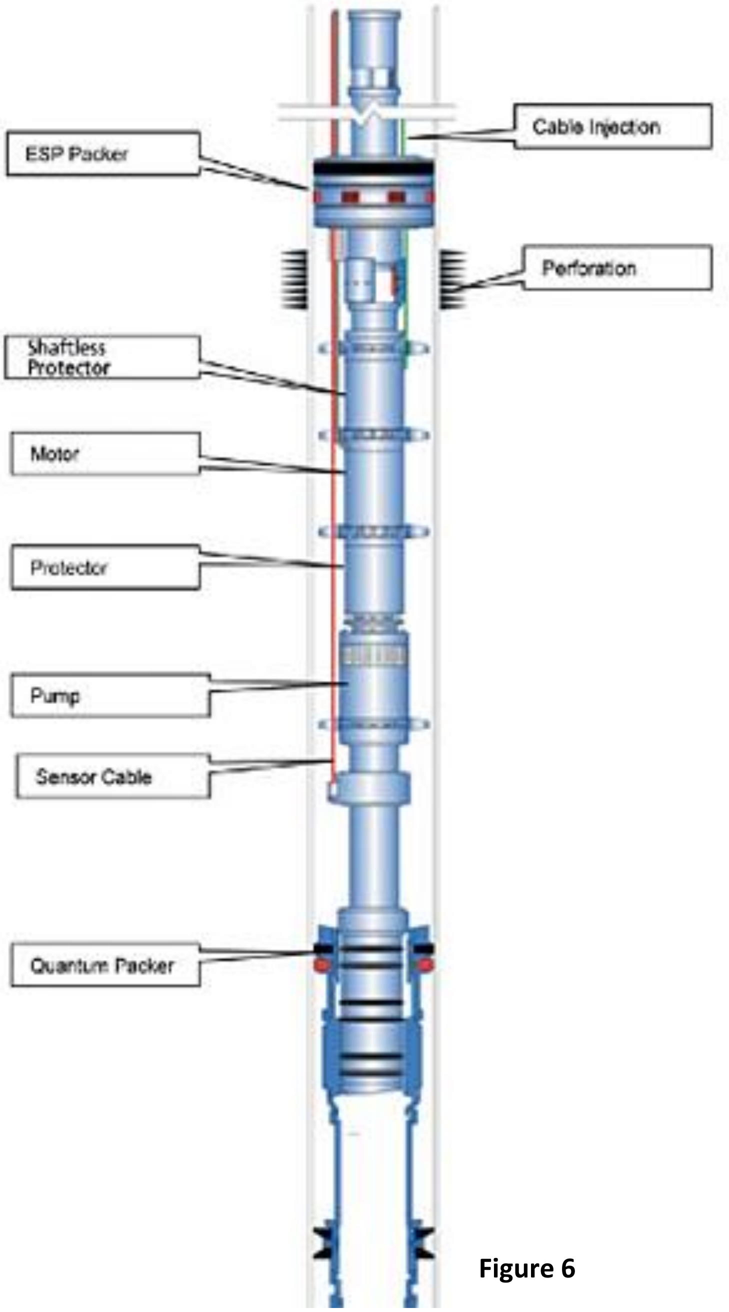


Figure 6

<u>System Description:</u> ESP system configuration is shown in Fig. It shows a tubing-hung unit with the downhole components comprising of:

- A multistage centrifugal pump with either an integral intake or separate, bolt-on intake.
- A seal-chamber section.
- A three-phase induction motor, with or without a sensor package.

<u>Process:</u>

- A VFD allows the speed of the electric motor to be altered e.g. starting the pump using the “nameplate” design frequency of 50Hz (Europe) or 60Hz (North America).
- The vent box separates the surface cable from the downhole cable. This ensures that any gas, which travels up the downhole cable, does not reach the electrical switchgear.
- The downhole cable penetrates the wellhead. It is banded to the tubing at regular intervals. Additional protection is supplied by cable protectors which are installed at critical points to prevent damage while the completion is being run into the hole.
- The pump unit consists of a stacked series of rotating centrifugal impellers running on a central drive shaft inside a stack of stationary diffusers, i.e. it is

essentially a series of small turbines. The pump intake may include a rotary gas separator if gas fractions higher than 20%.

- The Protector or Seal unit connects the drive shaft of the electric motor to the pump or gas separator shaft. The electric motor is powered by three phase alternating current supplied by the cable connected to the motor at the pothead. A downhole sensor package may be mounted underneath the motor.
- This technology has been extended to meet the challenges of:
    - Installing two separators in series.
    - Produced Sand.
    - Coning Suppression.
    - Managed Water Injection.

4.3 Progressive Cavity Pump

System Description**:** The surface and subsurface equipment for a typical electric drive system are shown below:

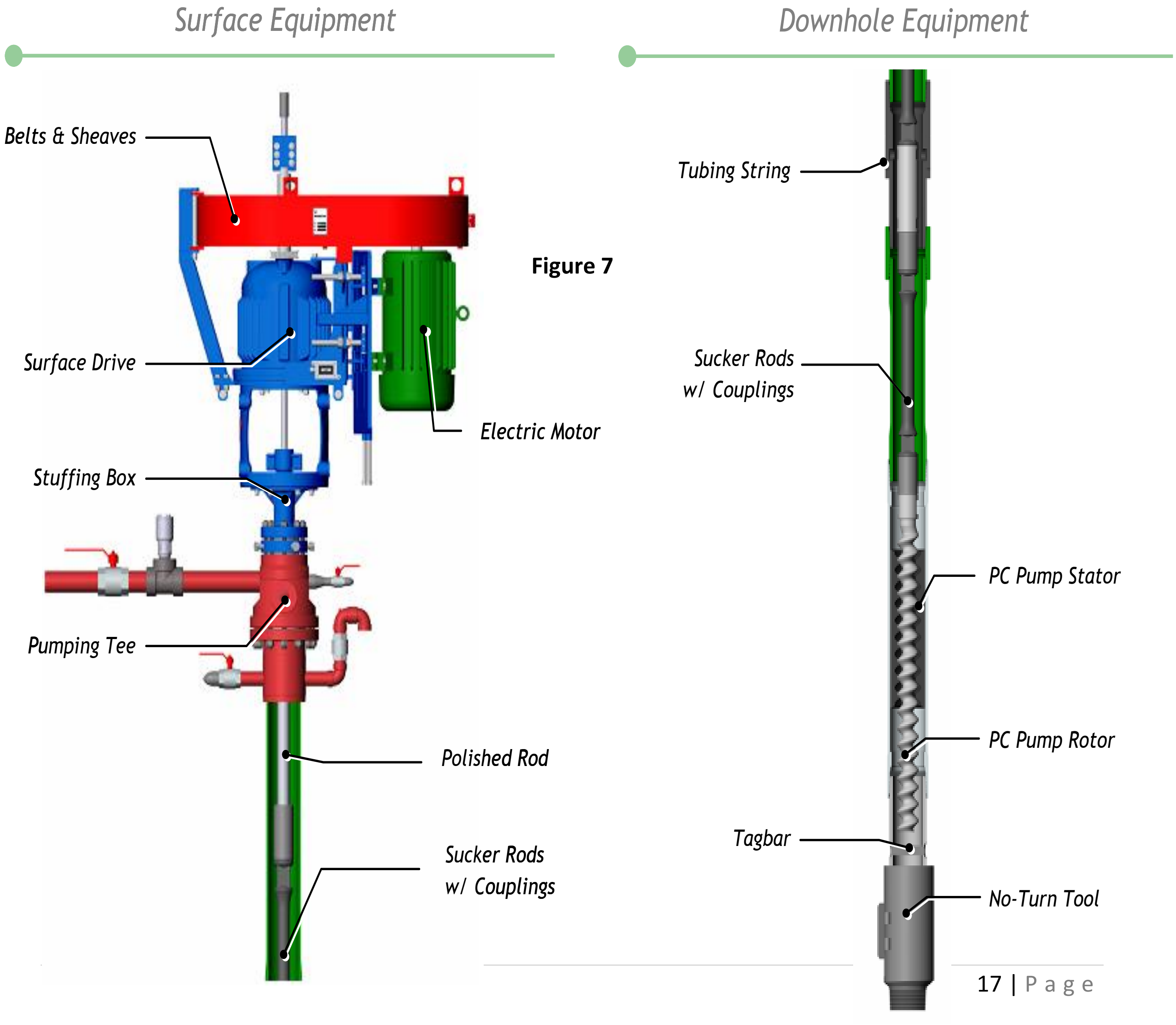


Figure 7

Process: Surface drives are typically electrically driven. Geared systems and inline electric or hydraulic systems are also available. All surface drive systems must have adequate backspin control and the ability to absorb the stored energy of the rod string torsion plus the full column of fluid. The rotor is run into the well on the end of the rod string which consists of either jointed sucker rod or continuous rod. The downhole assembly includes a tagbar to allow the rotor to be positively located relative to the stator. Large systems may require a no-turn device to prevent the torque in the pump from loosening the tubing connections.

Flow rate = k*Pitch of Stator*4*eccentricity*Stator minor diameter*N; Where k is a constant

New Technology: The resulting high torque and friction losses, as well as the tubing and rod failure discussed above, can be reduced by placing the motor downhole - this is known as a Progressing Cavity Electric Submersible Pump. Secondly, low cost replacement of the PCP unit can be achieved by making it wireline retrievable

4.5.1 PCP COMPONENTS:

4.5.1.1 Sub-Surface Components

- Tubing
  - Objective: To provide a conduit to the water to flow to the surface.
  - Selection Criteria: As wells are completed in different size casing depending on volume of water expected along with depth, pressure required to hydraulically fracture the coal seams and the amount of solids that the well will typically produce.
  - Raniganj Field: 2 7/8’ and 3 1/2’ (OD) tubings are used in 4 ½’/5 ½’ and 7’ casing respectively. All being External Upset End (EUE). This kind of end of tubing has two main features. Without changing the thread shape, the joint size increases through the upsetting process. In addition, it achieves sealing effect through the thread compound. There is a 0.076mm gap between addendum and crest.

- Sucker rod

  A sucker rod is a steel rod, typically between 25 and 30 feet (7 to 9 meters) in length, and threaded at both ends.

  - Objective: To transfer the rotary motion of the motor to the rotor as it is used to join together the surface and downhole components of a installed in a well.
  - Selection Criteria: Depending on volume of water expected along with depth and the amount of solids that the well will typically produce.
  - Raniganj Field: For PCP pump, 7/8” or 1” rod in 2 7/8” tubing and 1 1/8” rod in 3 ½” tubing are used in cross-sectional area will be less to bring more solids to surface because of higher velocity.

- Stator

  Stator is the outer part the PCP inside which rotor rotates and made cavities between stator and rotor. They are made from elastomers.

  - Objective: To pump the fluid in upward direction through the cavities inside with the help of rotor.
  - Selection Criteria: Stator selection is based on stator material, number of stages and geometry profile.
  - Raniganj Field: For PCP pump here, Medium Nitrile Elastomers are used as the stator's inner material.

- Rotor

  Rotor is the inner part the PCP. Generally they are made of high strength-steel and then coated with a wear resistant material to resist abrasion and reduce stator/rotor friction

- Objective: To create cavities between stator and rotor to pump the fluid in upward direction.
- Selection Criteria: Stator selection is based on stator material, number of stages and geometry profile.
- Raniganj Field: For PCP pump here, Medium (>40%) Nitrile (CNH2N) Elastomer is used as the stator's inner material.

- NTT (No-Turn Tool)

  The basic tool consists of a female keyed mandrel, a male keyed slip and a one piece cage. Its features include preventing the tubing and stator back off and requires low maintenance. It has superb flow characteristics in high sand and gas. It is cost effective and maximizes the pump life.

- Objective: To prevent the tubing from loosening up due to high torque.
- Selection Criteria: The selection criterion is based on the high torque that the tool can bear with the tubing material.
- Raniganj Field: For the CBM operations in Raniganj, NTTs with three spring are used accordingly keeping in mind the high torque problems in the pump from loosening of the tubing connections.

A NTT on site at Essar Raniganj

4.5.1.2 OTHER COMPONENTS

- Coupling

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both.

- Centralizer

A device fitted with a hinged collar and bow springs to keep the casing or liner in the center of the wellbore to help ensure efficient placement of a cement sheath around the casing string. If casing strings are cemented off-center, there is a high risk that a channel of drilling fluid or contaminated cement will be left where the casing contacts the formation, creating an imperfect seal.

- Polished rod

The uppermost joint in the string of sucker rods used is a pump artificial-lift system to adjust the required length of sucker rod. The polished rod enables an efficient hydraulic seal to be made around the reciprocating rod string.

- Stop bushing

Stop bushing is simply hollow coupling size equipment with a tag bar at the lower end of it. It stops the sucker rod to fall into the wellbore. Or it consist a lower inner diameter than sucker rod to restrict sucker rod's downward motion.

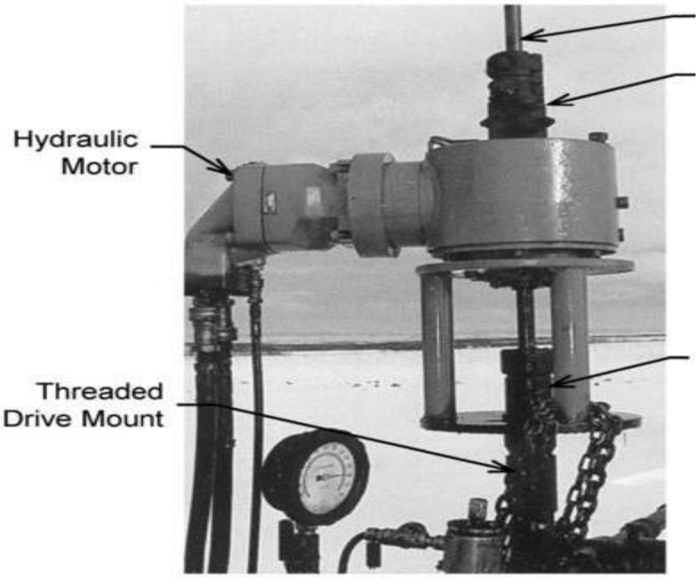
4.5.1.3 SURFACE COMPONENTS

- Drive head assembly

The wellhead drive unit consists of:

- A wellhead frame Thrust bearing, polished-rod braking system (in most cases),fixed gear or belt and sheave system(sometimes)

<u>Objective:</u> One important function of the drive head is to support the axial rodstring load. The thrust bearing, contained in the wellhead frame, supports this load while allowing the rod string to rotate with minimal friction.



(a) Open frame with integrated gearbox

Selection Criteria: Based on the axial load bearing and power transmission through the pulleys.
Raniganj Flied: Kudu Pumps and Netzsch Pumps of Horsepower ranging from 40hp to 100hp.In many cases, the wellhead frame threads directly onto the tubing head. However,here the use of flanged connections is applied over here. These systems facilitate proper alignment of the drive on the wellhead to help prevent stuffing box leakage and provide sufficient strength to carry the much heavier drive heads and motors used today.

- Flow Tee

Flow Tee is designed to allow maximum fluid flow through a branch connection. The drive heads typically mount onto composite pumping tees, which in turn mount onto the casing head. Note that the wellhead frame usually incorporates the stuffing box assembly.

- Well head

The primary purpose of a wellhead is to provide the suspension point and pressure seals for the casing strings that run from the bottom of the hole sections to the surface pressure control equipment. The surface pressure control is provided by a Drive head, which is installed on top of the wellhead, with isolation valves and chokes equipment to control the flow of well fluids during production.

5. OPERATIONAL FAILURES PUMPING & REMEDIAL METHODS

The production operation optimization includes process such as identification and resolution of problems that will occur with the production system. This area of work is critical to the ongoing viability of field developments and wells, and can be sub divided into a number of areas namely:-

Identification of problems and their source - this is normally conducted on the basis of surface information which indicates changes in production character istics such as rate and pressures. In addition down hole investigations using production logging techniques and transient pressure surveys (flow tests) can also help to identify the location of problems and the reasons for the changes.

Plan the required corrective action - this requires considerable attention to detail and will necessitate:-

- Identifying the equipment, manpower and other capabilities required.
- Identification and assessment of the unknowns/uncertainties
- Identification and evaluation of the key safety points and mile stones.
- The assessment of the probability of technical and economic success.
- To identify the required resources, skills and their supervision.
- The workover phase is the most dangerous in terms of well control and the potential for damage on existing production wells. Attention to detail and careful planning is essential.

5.1 Indications and Problems

5.1.1 Indications

- High torque
- Low torque
- No Flow

5.1.2 Problems

Surface Indications	**Reasons**	**Remedies**
High torque	Pump swelling	Replacement of pump
	Sand influx	Sand wash
Low torque	Tubing unscrewed	Fishing
	Sucker rod unscrewed	Fishing Tubing pull out
	Sucker rod failure	Tubing pull out, Replacement of sucker rod
No flow	Tubing leakage	Tubing Pull out Hydrotesting Replacement of damaged tubing
	Drop in water level	Lower the pump Replace the pump with lower capacity if water influx is low
	Pump failure	Pull out the string Replace the damaged pump

Table: Surface indication for Workover

5.2 Remedial Methods for Rotor-Stator Problem

Pump failures can be classified into different categories, each representing unique characteristics. Typical causes of failures can be determined by visually inspecting pump components and analyzing various symptoms of failure. Following table outlines common rotor and stator observations when a PC pump is removed from a well.

5.2.1 Rotor failure

A	Failure Type	Visual Signs	Possible Causes	Potential Solution
1.	Rotor surface checking	Checkered pattern	1.Heat 2.Lack of lubrication 3.Wear	1.Lowerig the pump 2.Operate at lower RPM 3.Install perforated tag sub
2.	Abrasion / Scoring	Score marks	1.Solids	1. Operate at lower RPM 2.Install extended slotted tag-sub
3.	Base metal wear	Worn surface coating	1.Sharp flat edges due to metal to metal contact 2.Smooth edges due to prolonged operation in abrasive environment	1.Re-evaluate space-out 2.Install larger displacement pump & lower the RPM
4.	Bent Rotor	Rotor is bent	1.Improper handling	1.Ensure proper pull-out & pull-in 2.Proper lifting & handling of rotor
5.	Broken rotor (Torsional)	Rough jagged surface throughout the cross section of rotor.	Due to high torsional stress caused by:	1. Install extended slotted tag-sub

			1.Solid entering the pump 2.Swelling of stator 3.Pump-off 4.Over-pressuring the pump 5.Operating it on the tag bar	2.perform compatibility test with stator 3. Operate it at lower RPM 4.Install larger pressure rated pump 5.Install high torque shutdown VFD
6.	Pitting	Small dimpling on the rotor.	Presence of a corrosive substances	1.Proper flushing after acid based work-over 2.Add corrosion inhibitor 3.Rotor with better corrosion resistance
7	Broken rotor (Fatigue)	Flat, smooth surface across the cross sectional area	1.A continuous torque and release of the pump 2.Long run life at higher RPM 3.Large space out and rotor is running in smaller ID	1.Install the smaller pump and operate it at Higher RPM 2.Use larger pump at low RPM 3.Re-evaluation of the space-out
			4.Landig in highly deviated section	4.Move the pump and use pup joint to land it in tangent section

8.	Worn tag bar	Tag bar will have a flattered pin & Worn rotor bottom	If the patterns are in 1.Clockwise direction (Due to improper space-out) 2.Counterclockwise direction Due to anti clockwise rotation of pump after shut in & Rotor break	1.Re-evaluate space-out 2.Check whether higher strength rods are needed

Table 9: Rotor failure

5.2.2Stator failure

B	Failure Type	Visual Signs	Possible Causes	Potential Solution
1.	Stators burnt elastomer	Elastomer is hardened on the contact surface of the stator & Smell like burnt rubber	Excessive heat due to 1.Gas 2.Swelling of elastomer 3.Pump off	1.Install pump or tail joints below the perforation 2.Perform compatibility test with wellbore fluid on elastomer 3.Operate it at lower RPM
2.	Blisters	Blisters on the surface of stator when it is brought to the surface	1.Gas enters the elastomer under high pressure 2.When pump is shut down in low fluid level	1.Lower the pump 2.Increase trip time

3.	Missing elastomer (Large pieces)	Large pieces are missing from elastomer	1.Exceeded over pressure rating 2.Large solids 3.Pump off	1.Install pump with higher pressure rating 2.Install slotted screen 3.Operate it at lower RPM
4.	Missing elastomer (Small pieces)	Missing pieces of elastomer throughout the stator	1.Solids 2.Pump off	1. Install slotted screen 2. Operate it at lower RPM
5.	Swollen elastomer	Smaller ID & High torque	1.Arometais such as Benzene, Toluene & Xylene and Other incompatible chemicals injected in the wellbore 2.Gas entering the elastomer & CO_2.	1. Perform compatibility test with wellbore fluid on elastomer 2.Lower the pump or Install gas separator

Examples of damaged rotors

Figures 1 to 3 show examples of different types of rotor damage. (Photographs provided courtesy of CFER Technologies.)

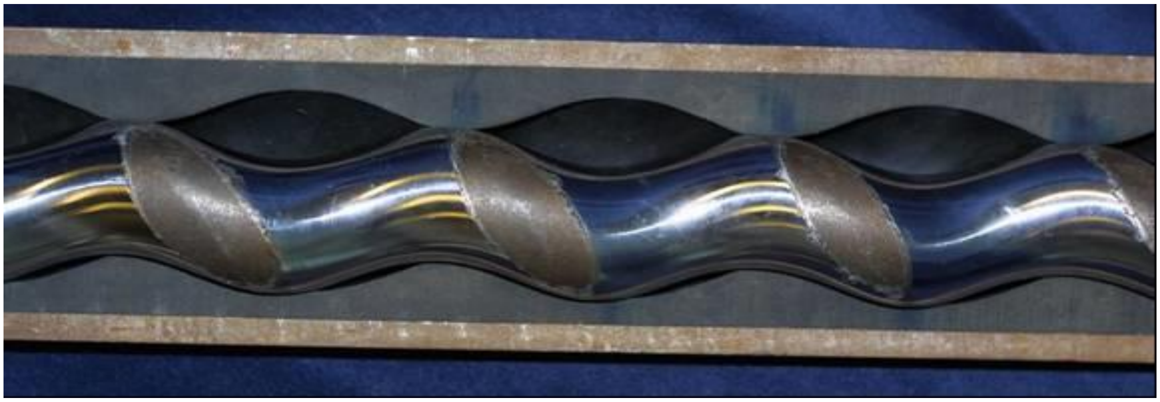


Figure 8 — Worn rotor

Figure 9 — Rotor cracked from excessive heat

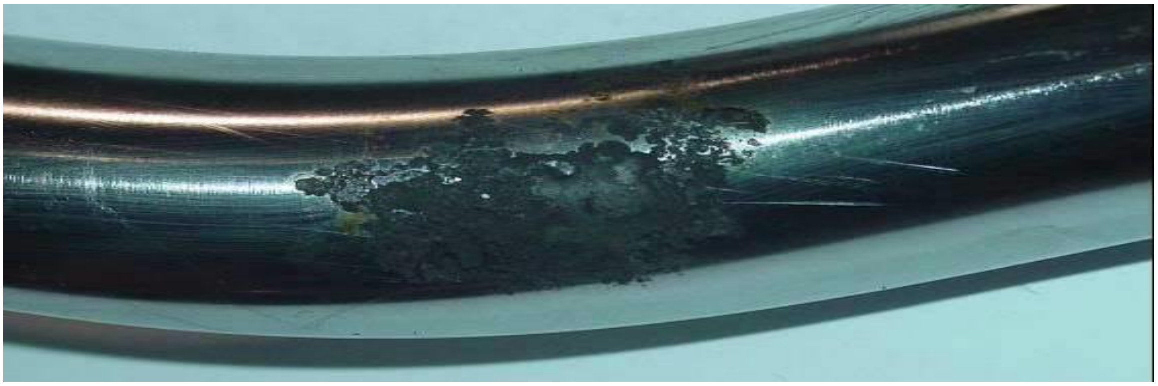


Figure 10 — Pitted rotor

Examples of damaged stators

Figures 4 to 11 show examples of different types of stator damage.

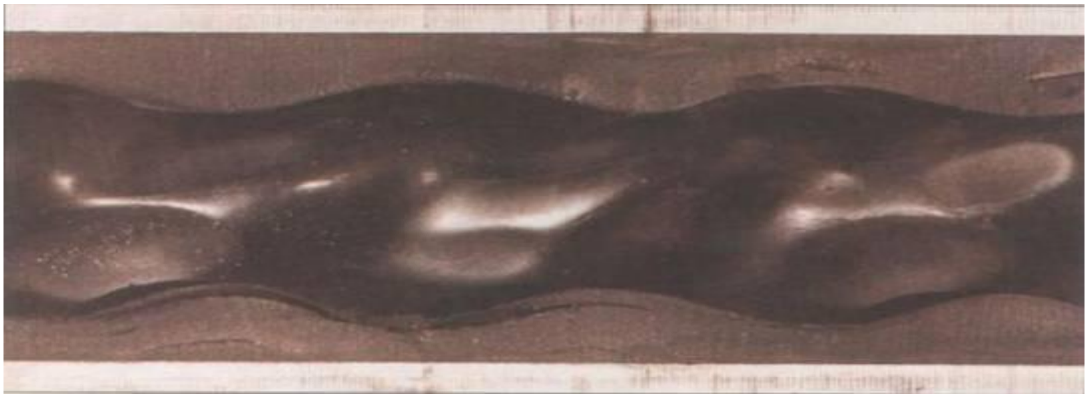


Figure 11 — Blistered stator, possibly from decomprerssion of absorbed gasses

Figure 1 — Burned/overheated stator

Figure 12 — Eroded/pressure washed stator

Figure 13 — De-bonded stator

Figure 14— Torn/chunked stator

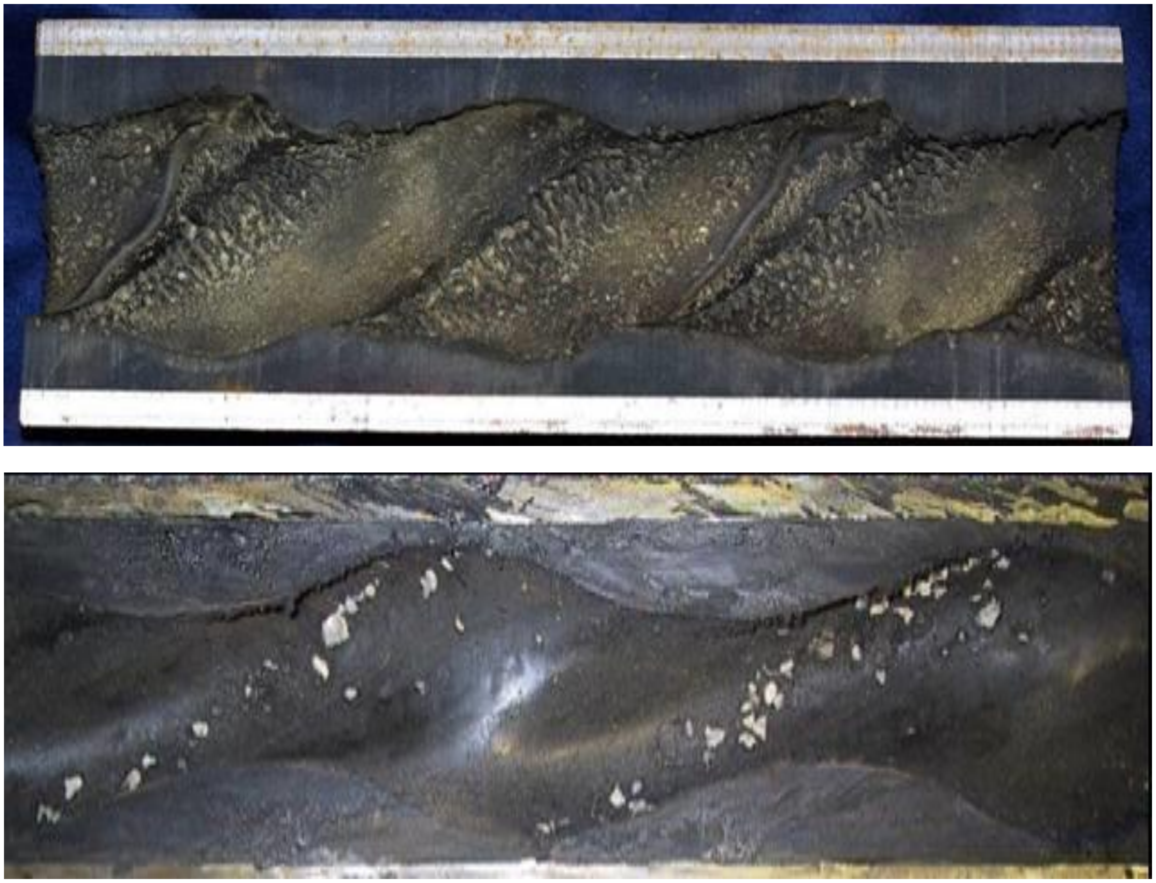


Figure 15 — Stators contaminated with foreign material (two examples)

5.3 Workover Operations

5.3.1 Flushing

Flushing technique to be performed when

- If sand fouled a pump, the workover crew had to pull all the tubing to reach the pump and then replace it. Chances were it would plug again in a few days or even hours.
- Sometimes the wellbore itself would become partially filled with sand and a bailer, run on a sand line was used to bite into the sand and remove it one bailer full at a time - a long laborious process.

5.3.2 Spaceout

- NTT Setting depth:

  NTT should be placed sufficient below from the lowest perforation. Typical distance is 250 – 300 feet.

- Spacing Calculation:

When the maximum load is achieved the rod string is no longer supported by the stop pin, i.e., there will be no more actual contact between the rotor and the bottom limit device. The string is then fully stretched, a condition that also includes the elastic extension due to its own weight. Parameters required for calculation include Actual differential pressure (Δp [bar]), length of rod string (L_0 [m]), spacing factor from table (K [-]),distance b/w stop pin and rotor during operation (d [cm]), static fluid level (L_{static} [m]), fluid temperature (T_{fluid} [^{o}C]), average air temperature inside the empty tubing (T_{air}[^{o}C]).

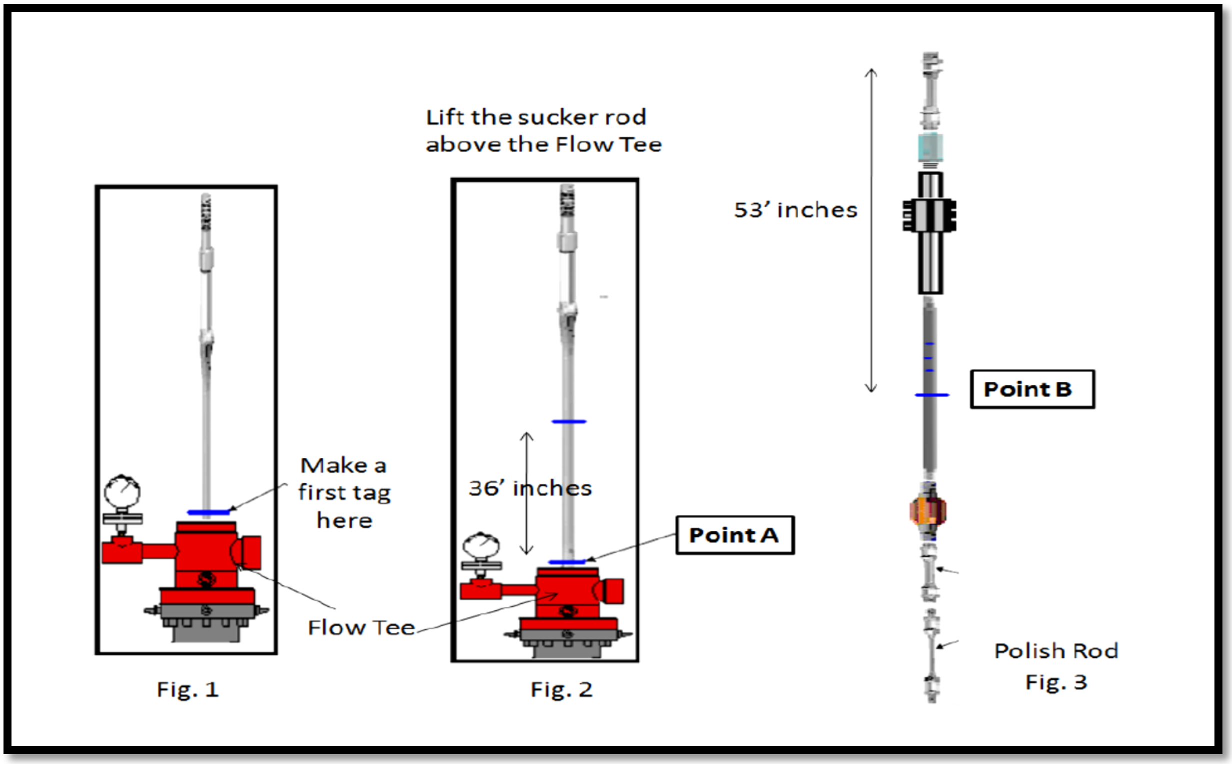
$$Y = \frac{\Delta P.L.k}{1000} + d + L_{static.}12.10^{-6} .(T_{fluid-}T_{air}).100$$

Where,

Δp	[kgf/cm^2 or bar]	actual differential of pressure
L_o	[m]	length of rod string
k	[-]	spacing factor from table
d	[cm]	recommended distance between stop pin and rotor during operation
L_{static}	[m]	static fluid level
T_{fluid}	[^{o}C]	fluid temperature
T,	[^{0}C]	average air temperature inside the empty tubing

d = 30 em for a pump pressure capacity up to 120 bar

d =50 em for a pump pressure capacity more than 120 bar



5.3.3 Sand Wash

Movement of sand and accumulation of debris can have a considerable impact on fluid flow. Down hole in a well, influx of sand can impair or stop the flow of water from a reservoir.

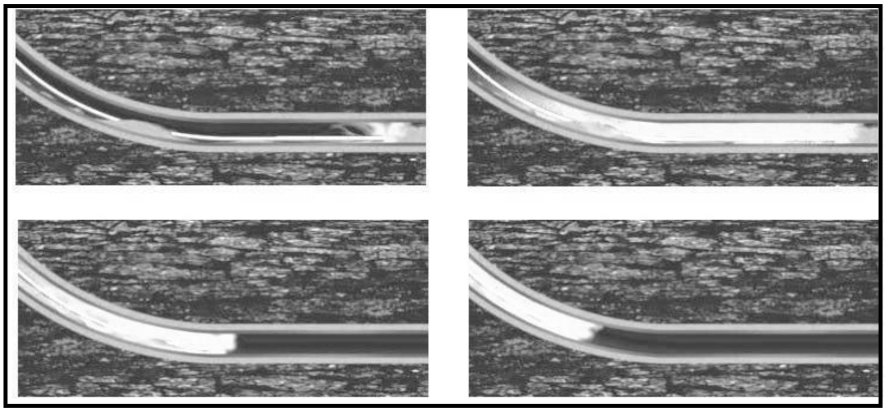


Figure 16: Sand Wash

For this here wellbore cleanout uses a jetting tool conveyed downhole by using tubing only. While pumping cleanout fluid down the tubing, the tool is lowered, or washed, into the sand. The cleaning fluid is made by mixing polymer with water. The jetting tool, or wash nozzle, is generally designed to create fluid turbulence that helps mobilize and suspend solid particles. As the jetting tool moves upward toward a newly formed bed, turbulence generated by the jetting action also helps to mobilize the fill, transporting it up hole until solids again settle.

5.3.4 Sand Bailing

The Bailer is designed to be used to bail sand and debris from horizontal well bores where difficulty is experienced circulating the sand out in the conventional Manner. The Bailer is run to depth and fired by over-pressuring the coiled tubing at which time the sand or debris is sucked into the atmospheric chamber. A flapper valve retains the sand and fingers on the bottom sub also act as a junk basket, to retain any larger debris. A 3" diameter by 30' long Bailer will bail approximately one cubic foot of sand per run.The Bailer is normally run in conjunction with a Sequencing Tool, to allow circulation whilst running into the well and over pressuring to fire the bailer when desired.

5.3.5 Scrapping

Scrapers (or Go Gauge) are used to clean the tubing's inside wall, rollers restore the inner diameter of tubing to their normal inside diameter and patches form a permanent sealed connection between two strings of tubing or casing. Scrapping is a simple operation in which scrapping tool is run inside a well bore using workover Rig with the help of tubing.

6. PCP DESIGN ANALYSIS

6.1 Company Name: C-FER Technologies Ltd.
Software Used: PC-Pump^{R}

6.1.1 Features:

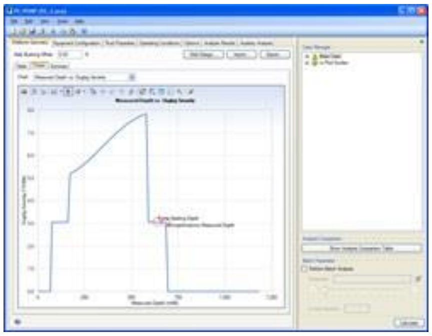
- Enhanced system configuration module includes equipment specification, perforation depth, and well survey.
- Enhanced analysis module includes specifications for operating conditions and fluid properties.
- Quick conversion to/from SI and Imperial units

6.1.2 Benefits:

- Select optimum configuration for new well from complete, up-to-date vendor database
- Minimize downtime while problem-solving a non-productive well
- An intuitive interface, instant access to standard and vendor component libraries
- Sophisticated hydraulic and mechanical modeling routines

6.1.3 Design Tools

XX contains a System Configuration module that allows users to enter wellbore geometry information, select casing and tubing sizes, build a rod string from various rod manufacturers and types, and finally select a pump to evaluate downhole. Alternatively, a downhole drive system can be specified and analyzed. In Analysis Inputs, you specify the fluid properties and operating conditions appropriate for the well you are analyzing, and then you click on the calculate button.
XX has many user-friendly features that minimize design time, such as the ability to run equipment or batch comparisons. In addition, XX has default settings that can be specified by the user for easy facilitation of multiple well designs.



- Wellbore Geometry:

The wellbore geometry window enables the user to enter an existing wellbore profile or create one using the well design mode. Possible wellbore input methods include importing a text file or copying information from an excel file.

- System Configuration

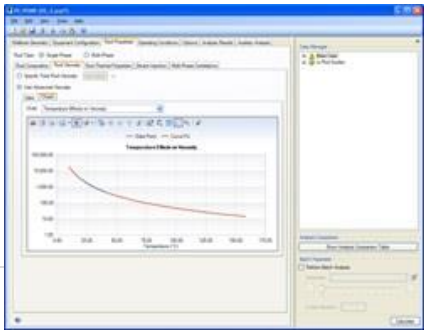
PC-PUMP® contains a System Configuration module that allows users to enter wellbore geometry information, select casing and tubing sizes, build a rod string from various rod manufacturers and types, and finally select a pump to evaluate downhole. Alternatively, a downhole drive system can be specified and analyzed.

- Pump Selection

The pump selection window allows the user to select one or more pumps for analysis from an extensive database containing almost 2000 pump models. Features of the pump selection window include:

- Tubular Selection

The tubular selection window allows for the selection of casing, tubing, tail joints and diluent injection. For downhole drive systems a shroud can be selected in place of a tail joint. PC-PUMP® has the ability to notify the user when the selected pump



and tubing will not fit in the selected casing. Tapered tubing and casing strings can also be entered.

- Rod String Selection

The rod string selection window enables the user to build almost any type of rod string using continuous, standard or hollow rods. Couplings and rod guides can be added, where the number of rod guides per rod can be specified or selected by the program program based on a maximum tubing/rod contact force. A powerful aspect of the rod string window is the ability for the user to build a rod string with different characteristics at different depths.

- Surface Drive Equipment Selection

In surface drive mode, the selection of drive equipment is optional. The surface equipment consists of a drivehead, belts, hydraulics and a prime mover. Driveheads, hydraulic pumps and hydraulic motors are selected from a database of vendor equipment.

- Downhole Drive Equipment Selection

In downhole drive mode, the drive equipment must be specified, as it can have a significant impact on the flow between the perforations and the pump intake. Downhole drive equipment consists of three parts: the motor, the “drive assembly”, which XX defines to be all the equipment between the motor and the pump

- Fluid Properties

The fluid can be specified to be single-phase (no gas) or multi-phase (solution gas and/or free gas is present). Fluid properties for single-phase fluid can be entered by specifying the actual density, or by specifying the fluid composition—allowing the program to calculate the density. Fluid properties for multi-phase fluid takes into consideration the location of the pump intake (or tail joint or shroud intake if applicable) with respect to the perforations and determines the amount of free gas present in the pump.

- Operating Conditions

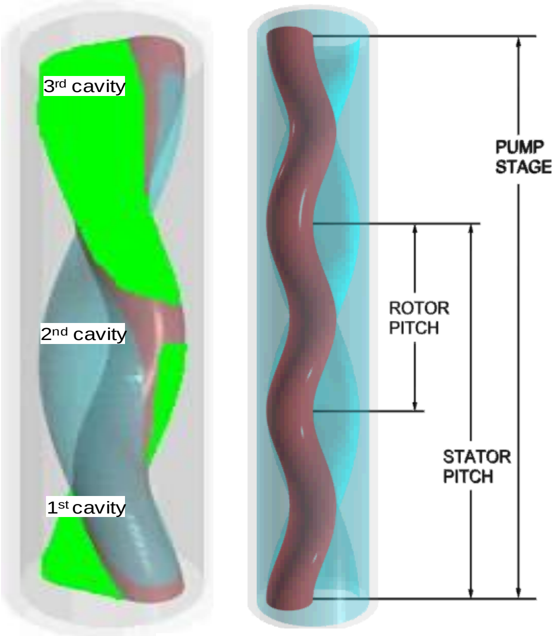
The operating conditions panel allows the user to specify basic downhole conditions and how the system will be run. The panel includes a series of flow rate parameters (fluid rate and pump speed), downhole pressure parameters (fluid level, submergence, bottomhole pressure and motor frequency (downhole drive mode only)) and IPR (Inflow Performance Relationships) data.

6.2 Design of PCP:

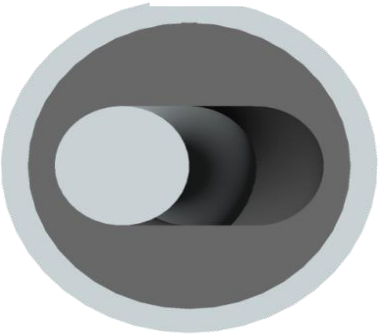
6.2.1 Operating Principles:

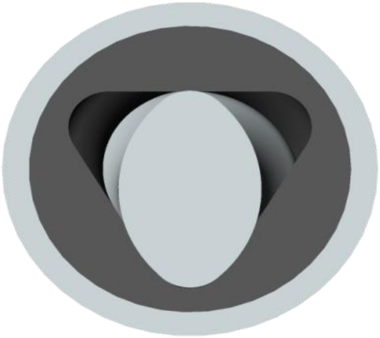
PC pumps consist of a rotor turning inside of a stator whereby the rotor is the only moving component. The rotor is helical and typically has a round cross section (single lobe). The stator cavity is also helical, but the stator pitch is twice the pitch of the rotor. The stator cavity cross-sectional shape has one more lobe than the rotor. For a single lobe rotor, the stator cavity cross-section is like a rectangle with rounded ends (2 lobes) similar to a race track. The resulting assembly creates sealed cavities between the rotor and stator which “progress” from the pump inlet to the outlet as the rotor turns (a *progressing* cavity pump). The cavities are sealed so the pump is a positive displacement device. Therefore a PC pump will hold a column of fluid when the pump rotation stops.

Single Lobe

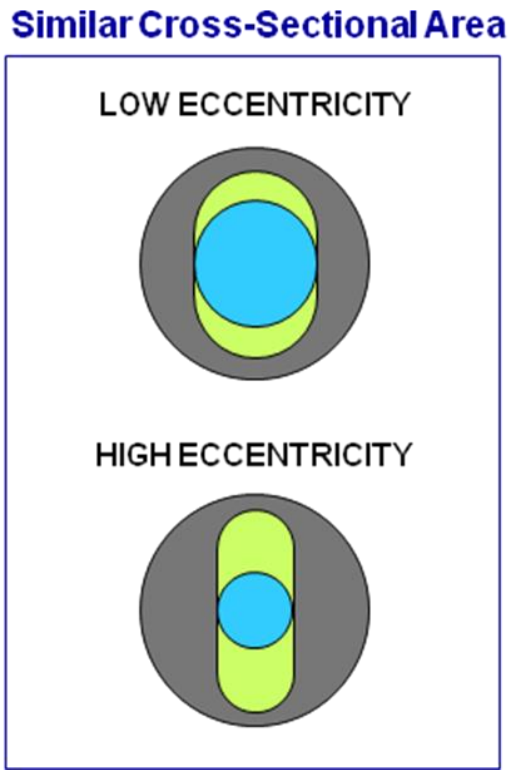


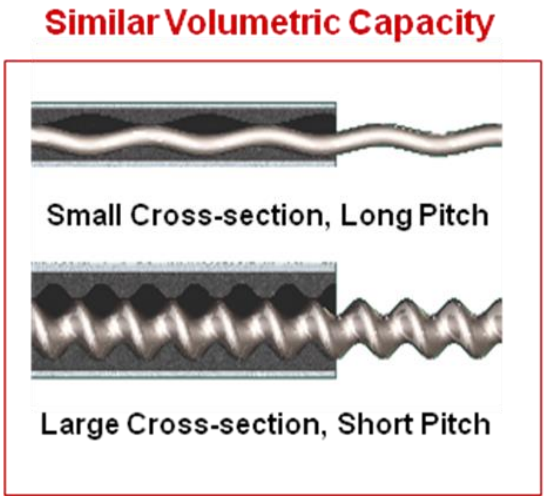
Multi-lobe





The lift capacity (depth rating) of the pump is dependent on the number of stages and the fit of the rotor to the stator. The volume capacity (production rate) of the pump is dependent upon the cavity size and the pump rate of rotation. The cavity size is determined by the rotor eccentricity and pitch. Long pitches and high eccentricity result in high displacement (high production volume) per rotor revolution. Short pitch pumps reduce the fluid velocity through the pump which reduces abrasive wear on the pump from fluids that contain particulate matter. Relatively long pitches relative to eccentricity are used for less viscous liquids such as water, while relatively short pitches relative to eccentricity are used for more viscous liquids such as heavy oil.





6.2.2 <u>Operating Limits:</u>

The PC pump rotary motion and positive displacement combined with direct mechanical drive from the surface result in the highest system efficiency of any lift system. The volumetric efficiency of the pump is directly related to the stator-to-rotor interference fit. Tighter fits allow less slippage and result in higher volumetric efficiency. Looser fits provide increased cooling and lubrication resulting in longer life for the pump. Therefore, efficiency is often a trade-off for operating life. The elastomer in the stator deforms to accommodate particulate matter pressed against the stator ID by the rotor lobes. The particles are then released back into the flow stream after the rotor lobe passes by. Because of high efficiency and tolerance to particulate matter, PC pump systems are ideal for use in many CBM/CSG wells. In deep CBM/CSG wells (typically > 6000’ TVD) and where local PC pump service expertise is limited rod pump systems tend to be more competitive. In shallow CBM/CSG wells (less than 1500’ TVD) lower cost small ESP systems can be competitive. PC pumps have no valves or centrifugal stages so they will not gas lock although they will have reduced efficiency in the presence of gas. Excessive GLR through the pump for extended periods of time can damage the elastomer due to elastomer hysteresis heating in the absence of liquid cooling. Typical operating speeds are between 150 and 400 rpm. Speeds slower than 150 rpm can result in stick-slip behavior due to system fluid properties and friction elements (rod friction within the tubing, rotor/stator interference fit). Speeds over 500 rpm can result in excessive rod whirl which can damage the rotor and tubing. Rotors are sized for a specific interference fit with the stator elastomer in order to allow a designed amount of slippage (fluid leakage) between stages to provide pump lubrication and cooling. Most systems are designed for volumetric efficiencies of 60% to 85%. Depending on the application conditions higher efficiencies may compromise pump run life, and lower efficiencies will increase operating costs.

7. DESIGN RECOMMENDATIONS FOR PC PUMP:

Pump failures can be minimized by close attention to avoiding pump-off conditions and by minimizing the amount of gas through the pump. Landing the pump below the gas entry interval, the use of subsurface gauges and VFDs (variable frequency drives) with pump-off logic all help extend pump operating life. Tubing and rod damage can be minimized by using continuous rod systems to eliminate the couplings and the corresponding concentrated side contact forces. Continuous rod will have 75% less side load pressure than conventional sucker rod couplings in PC pump applications because the side load is spread along the length of the rod. If conventional sucker rod is used, tubing rotators and repositioning of the rod string can extend the life of tubing.

7.1Design for Free Gas

Free gas occupies space in the pump cavity. This reduces liquid displacement and reduces pump lubrication and cooling. In gas wells attempts should be made to reduce the amount of free gas that enters the PCP. The following practices should be considered when free gas is present:

- Land the PCP below the perforations.
- If the pump is landed above the perforations a tail-joint assembly should extend below the pump to effectively place the intake below the perforations.
- Use a downhole gas separator.
- Use a charge “tandem” PC pump configuration in which a higher volume capacity lower lift pump compresses well fluids prior to the intake of the primary lift pump.
- Tandem pumps must be sized to allow the rotor of the lower pump to pass through the stator of the upper pump during run-in and retrieval.

7.2 Design for highly deviated wells

Continuous sucker rod is recommended for any PC pump system installed in deviated wells. The continuous rod will greatly reduce side loads and tubing wear without the reliability issues associated with sucker rod guides. Biased intake separators are available to reduce gas ingestion in deviated wells. The separators draw in liquids from the low side of the tubing while allowing gas to pass along the high side of the tubing.

7.3 Design for Particulate Matter

High concentrations of particulate matter can be produced with PC pump systems if attention is given to not allow the particulate matter to settle in the tubing or rat-hole. Production tubing should be sized so that produced fluid velocities are adequate to lift particulate matter to the surface. Smaller tubing will increase fluid velocities. The following chart illustrates the critical velocities required to lift a coal particle to surface inside 2.875” tubing with 0.875” sucker rods. Based on the chart a production rate of ≅ 109 bbls/day would be required to lift a US Standard Sieve Number 20 particle to surface.

7.4 Design for Water and Thermal Elastomer Swell

The amount of fluid and thermal elastomer swell is unique to the elastomer compound and fluid conditions. At elevated temperatures >60°C the amount of fluid swell is significant with some elastomers. Therefore it is common for the manufacturer to perform a fluid compatibility test using the produced fluid under simulated operating conditions. The fluid compatibility testing accomplishes two purposes.

- Identifies the best elastomer for the application.
- Provides the ability to model and select rotor dimensions that will provide an optimized and balanced rotor/stator interference fit across the stator cavity profile.
- Incorrect rotor/stator fit can result in poor performance and run life.

7.5 Life Expectancy

Life expectancy in CBM/CSG wells has averaged around 18 months globally and typically ranges from 12 to 36 months. Although solids and coal fines can be detrimental to any pump, PC pump system failures in CBM/CSG have more often been related to rod-tubing wear and continuous gas production through the pump. The rod-tubing wear is related to the well geometry and the resulting water-wet side loads between the sucker rod couplings and the tubing ID. In some areas high concentration of CO_2 in the produced water can cause Explosive Decompression (ED) of the stator elastomer.

For Example: In Canada and similar areas with significant PC pump manufacturing infrastructure it is common to re-use rotors as the stators wear and are replaced. Typically, three stators will be replaced for each rotor replaced. In locations where PC pump manufacturing infrastructure is less developed the rotor hard coating thickness may be reduced in order to minimize costs since the rotors will not be reused. In these applications the rotors are designed to last as long as the stators.

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