A

DISSERTATION REPORT

ON

OPTIMIZATION OF AIR DRILLING PARAMETERS & WELL COMPLETION STRATEGIES FOR MAXIMIZING PRODUCTIVITY OF CBM FIELDS IN SOHAGPUR BLOCK.

(2nd February 2015 – 10th April 2015)

AT

RELIANCE INDUSTIES LIMITED (E&P)
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CHRISTOPHER DSOUZA

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U.P.E.S. DEHRADUN.

EXECUTIVE SUMMARY

The E& P division of Reliance industries Limited were awarded the Sohagpur East Block & Sohagpur West block through a competitive bidding process in the first CBM round in 2001. They have 100% participating interest in these blocks.

RIL is embarking on full-fledged development of Sohagpur CBM blocks (West & East). The development of these blocks envisage requirement of over 1000 wells to be drilled and completed in a period of around 10 years. The development is planned in phased manner. For first phase, 229 wells are planned in Sohagpur West. The target completion date of the 229 wells is 30th June 2015. All these wells will be hooked up to surface production facility, ready for dewatering and gas production from 1st July 2015.

For this block, air drilled vertical wells represent the optimum approach & for dewatering the seams, PCP is preferred. During my stay at Reliance, I observed that reliance is facing heavy rig time losses both during drilling & completion period. Finding the reasons for this nonproductive time is very essential as it will help the company to rectify their operational errors & save costs.

This report discusses the various on field operations carried out by Reliance in the Sohagpur block. Air drilling & its applicability in Sohagpur is described in detail. The report also focusses on the well completion strategies implemented by Reliance to produce CBM with special emphasis on dewatering techniques. The scope of this report includes selection criteria for artificial lifts to be used here based on economic & technical parameters. The report includes detailed description on Progressive cavity pumps.

The principle objectives of this field project includes doing a Non-productive time (NPT) analysis for drilling operations, recognising the reasons for it & recommending alternate ways to mitigate it. Other objectives include preparing an optimized well completion plan suggesting various ways to reduce Rig Time losses with introduction of new and innovative technologies.

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1.1. GEOLOGICAL SET-UP

Sohagpur CBM Blocks are part of the South Rewa Basin which forms the central part of the Gondwana Supergroup. Sohagpur Gondwana basin is east-west elongated occurring at the southern part of South Rewa Gondwana master basin. A complete sequence of Gondwana rocks from Upper Carboniferous Talchir Formation to Lower Cretaceous Lameta Formation occurs in this Coalfield. Structurally it is a half graben. A major east-west normal fault, namely Bamhani Chilpa fault traverses the basin. The CBM block forms the down thrown segment of this fault. The CBM block is situated in the northern downthrown segment of this major fault along which Raniganj and Barakar Formations are juxtaposed. A vast tract of coal bearing Barakar Formation is exposed to the south of Bamhani Chilpa Fault.

The Barakar sediments are bounded by the outcropping Talchir along southern and eastern fringes of the coalfield. Successive younger sediments of Barren Measures outcrop towards south near Burhar, Raniganj outcrops in a large part of CBM block, followed by Pali and Parsora further north, while the younger Lameta beds are found outside the CBM block towards southwest. The Gondwanas are intruded by Upper Cretaceous Trap derived doleritic intrusive, which at times has devolatilised the coals.

1.2. GEOLOGICAL INFORMATION - GENERAL GEOLOGY & STRATIGRAPHY

The Sohagpur Coalfield is a part of the large sediment filled, 'Gondwana' age, trough located in the drainage basin along the Son River. Structurally it is a half graben. A geological map and general stratigraphic section is shown in Figure . The prominent structural feature of the Sohagpur coal field is the system of ENE-WSW to east-west trending sub parallel faults. In the Sohagpur coalfield, the Barakar Formation is the main coal bearing unit. Eight to ten coal seams have been developed in the upper part of the Barakar Formation. There are five to seven regional coal seams that occur at depths of 400 - 800m within the Sohagpur blocks. Although the lower part of the Barakar formation contains coal beds in the Sohagpur coalfield, they are generally locally distributed and relatively thin. In addition, multiple coal seams with carbonacous shale interbeds are present in Raniganj formation at shallower depths of 50 - 350m. Dolerite dykes are quite common both in eastern and western parts of the field. This information has been collected from reports provided by RIL.

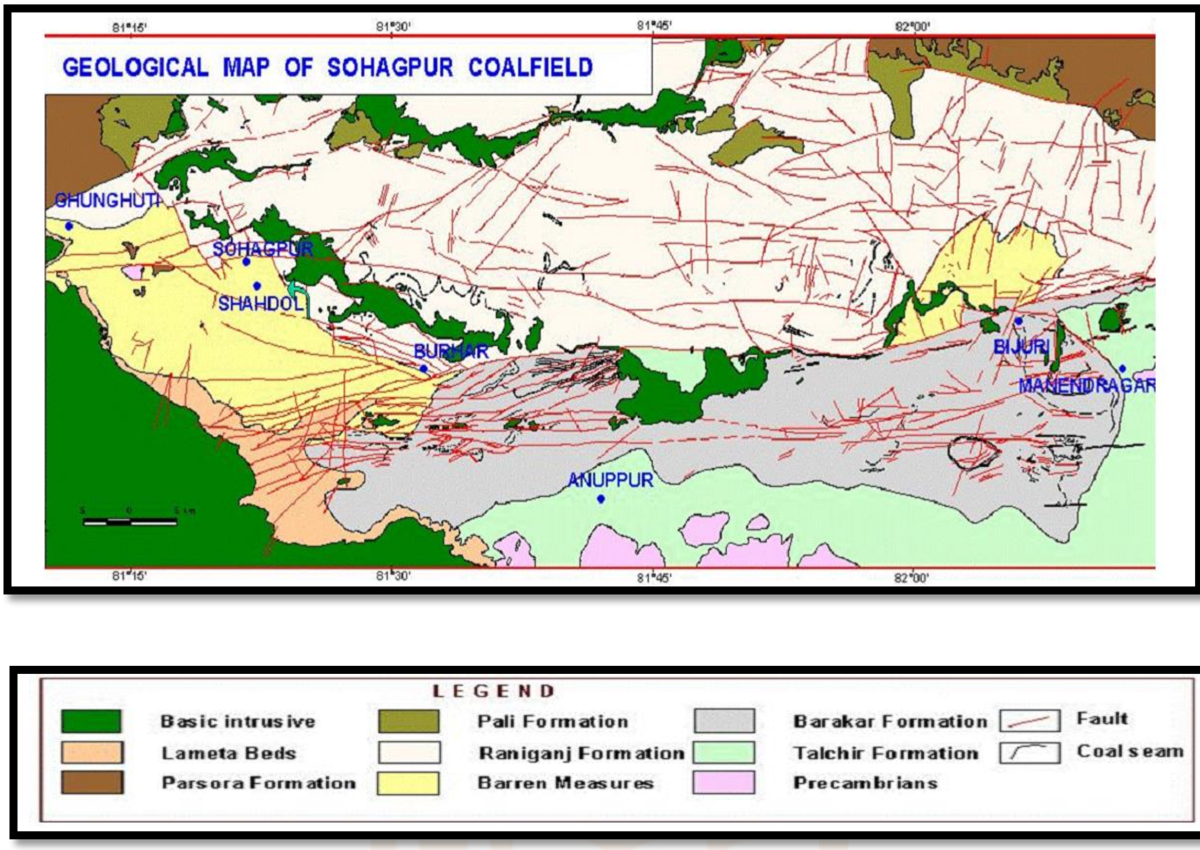


Figure 1– Geological Map of Sohagpur basin

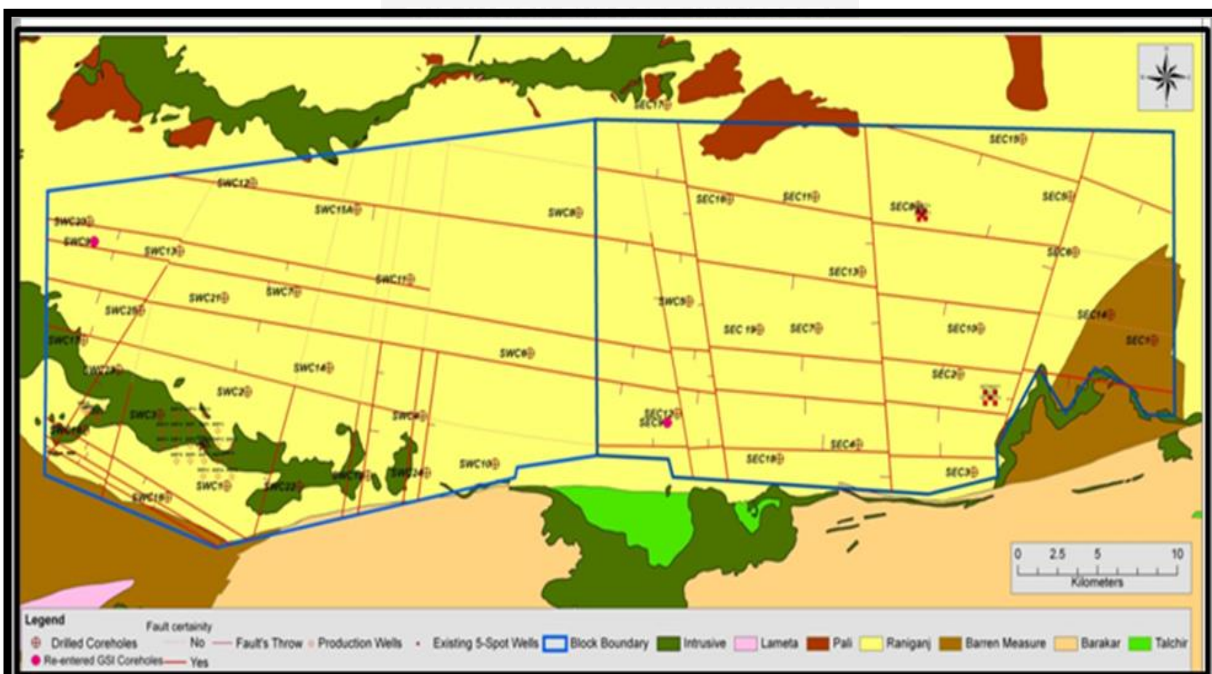


Figure 2 – Geological map of Sohagpur East and West blocks

The Sohagpur Block is divided into two licence blocks as shown in Figure , the thickness, gas contents and coal properties as determined from the RIL data set, are listed below

	SOHAGPUR WEST	SOHAGPUR EAST
1. Coal Thickness	5 - 33 m	6 - 32 m
2. In-situ Gas Content	0.3 - 6.1 m^3/t	1.2 - 12.9 m^3/t

Table 1– Coal thickness and gas contents for Sohagpur East and West.

Basin	Sohagpur
Coal Formation	Barakar
Depth Range (m)	400-800
Coal Rank	Low to High Volatile Bituminous Coals
Sulphur (%)	Nil
Ash (%)	8 to 30
Coal Age	Early Permian
Φ (%)	0.2 to 3
K (mD)	0.3 to 367
No. of Seams	2 Major and 6 to 7 Minor
Seam Thickness (m)	4 to 12 & 0.5 to 2
Vitrinite Reflectance	0.4 to 1.2
Fracture Gradient(psi/ft)	0.8-1.1
Gas Storage (SCF/Ton)	200 to 280
Density (g/cc)	1.6-2.2
Reserves (TCF)	3.65
Acreage(Km^2)	995

Table 2 – Summary of coal properties for Sohagpur Basin

The generalized stratigraphic and lithological section in Sohagpur CBM blocks.

Formation	Lithological Description	Thickness(m)
Recent	Soil – Loose with occasional boulders and pebbles of sand and kankar.	0 –15
Intrusive	Dolerite – greenish black, very hard and compact	50 – 140
Raniganj	Dominantly fine grained micaceous sandstone interbedded with medium to coarse grained sandstone, argillaceous to calcareous matrix with gray shale, carbonaceous shale and coal.	50 – 525
Barren Measures	Dominantly medium to coarse sandstone, hard with bands of chloritic shale	90
	Grey to greenish grey shale/clay, fine to coarse sandstone often chloritic, hard and compact.	120
	Coarse to fine sandstone with interbands of green chloritic shale.	20
Barakar	Coarse grained arkosic sandstone, feldspathic matrix with coal, shale and carbonaceous shale.	200
	Fine to medium grained sandstone with thin coal, carbonaceous shale and gray shale	100

The depth range of the various formations is typically as under:

		Depth Range(Mts.)	
BLOCK	Formation	NORTHERN PART	SOUTHERN PART
SOHAGPUR WEST BLOCK	Raniganj	0-400	0-150
	Barren Measures	400-650	150-350
	Dolerite	700-850	0-100
	Barakar	650-1000	350-600

Based on the reservoir evaluation performed by RIL, gas-in-place (GIP) values were taken into consideration and the Sohagpur block areas were divided by RIL into 3 major Sectors as defined below.

- Sector-I : Area with GIP values >100+ MMCM/ Km^2
- Sector-II: Area with GIP values 100-50 MMCM/ Km^2
- Sector-III: Area with GIP values <50 MMCM/Km^2

The Sectors were further divided into 32 Sub-sectors based on the following parameters:

- GIP values
- Permeability
- Saturation
- Geological boundaries

Of these 3 sectors, Sectors-I and II containing bulk of resource and favourable production characteristics have been targeted for development. Accordingly, the CBM production potential is assessed for the Sectors I and II for the current development phase.

The sectors are further divided into number of Sub-sectors based on reservoir parameters to study the variability of production. Total no of sub-sectors in Sohagpur West are 13, namely I-A1, I-A2, I-B, IC, I-D, I-E, I-F, I-G, I-H, I-I, II-A, II-B, II-C.

2. RELIANCE PROGRAM SUMMARY

The E& P division of Reliance industries Limited were awarded the SohagpurEast Block & Sohagpur West block through a competitive bidding process in the first CBM round in 2001. They have 100% participating interest in these blocks.

RIL is the Operator of the two contiguous CBM Blocks in Sohagpur viz. SP (West) - CBM-2001/1 and SP (East) - CBM/2001/, comprising an area of 500 Sq. Kms and 495 Sq. Kms respectively. They are located in Shahdol and Anuppur districts of Madhya Pradesh state in Central India.

Company has carried out extensive exploration and assessment work in the area. Sohagpur CBM Blocks are located in the Sohagpur Basin which is a part of Gondwanas. The age of these formations is Permian (very old) and therefore the strata are hard and compact. Igneous intrusion (dolerite) is also encountered in most of the block areas which is extremely hard rock in the form of low angle sills with thickness varying from 40 - 120m at different depths.

The coal bearing formation is "Barakar" formation and contains 5 major and 2-3 local coal seams at depths from 250 to 900 meters. The coal seams have a total thickness of 10 to 25 meters. The coal seams are near hydrostatic pressure (~ 0.433 psi/ft).

RIL have completed an extensive exploration & appraisal of the licence blocks by drilling over 40 exploration core holes and 36 (26-West + 10-East) production test wells. These wells have been connected to three local Gas Gathering Stations (GGS); one GGS is located in Sohagpur-West and other two GGS's are located in Sohagpur-East area.

RIL is embarking on full-fledged development of Sohagpur CBM blocks (West & East). The development of these blocks envisage requirement of over 1000 wells to be drilled and completed in a period of around 10 years. The development is planned in phased manner. For first phase, 229 wells are planned in Sohagpur West. The target completion date of the 229 wells is 30th June 2015. All these wells will be hooked up to surface production facility, ready for dewatering and gas production from 1st July 2015.

A number of approaches to drilling and completion were identified for development of the Sohagpur block. This assessment indicates that air drilled vertical wells represent the optimum approach in most cases. In a small number of sub-sectors deviated and horizontal drilling and completion will yield better results however, in practice, the use of these techniques in only a small number of sub-sectors within a larger programme may not be justified.

The artificial lift methods for dewatering Sohagpur CBM wells have been examined. Progressive cavity pumps (PCP) are the preferred primary method of artificial lift for dewatering these wells in the early stages of most sectors. Electrical submersible pumps (ESP) may be required for deviated or horizontal wells. In later stages of development, as water production declines to below 2 cubic meters per day, sucker rod pumps (SRP) may be the most suitable method of dewatering.

For fracture stimulation of the coal the recommended technique for zonal isolation in the Sohagpur wells is 'Ball & Baffles', as the average number of zones in most of the sub-sectors is 5 or less. 'Ball & Baffles' are economical as they require the services of a rig for a shorter duration when compared to the perforation and plug technique. The use of coiled tubing as opposed to wire line depends on the number of zones being targeted. As the average number of zones is less than five, wire line is recommended.

Perforation techniques are described and assessed for use in Sohagpur and recommendations for the perforation of coal seams are provided. For stimulation of coal seams in Sohagpur a hybrid fracturing fluid is recommended. The term "hybrid" in this case refers to a water pad followed by cross-linked fluid sand stages. The potential benefits of this technique in coal includes minimizing damage caused by the gel and maximizing regained permeability as well as containing height growth and lowering cost. The hybrid fluid system will distribute the proppant more efficiently than the current linear gel with less damage to the formation.

The wells will be completed in following manner

- Drill 17 ½" hole and lower and cement 14" false conductor up to 18 m.
- Drill surface hole (12 ¼" or 10 5/8") lower and cement surface casing (9 5/8" or 8 5/8") up to 200 m.
- Drill production hole (8 ½" or 7 7/8") and lower and cement production casing (5 ½" or 7") up to TD.
- Perforate the desired coal seams and Hydro-fracture the same.
- Complete the well with PCP with 2-7/8" EUE tubing and 1" sucker rods with slim hole coupling.

PROJECT OBJECTIVES

The Company intends to develop this field based on the following objectives:

- ✓ Follow and implement a drilling and completion programme which will meet the business purposes of maximizing productivity and in a cost effective method.
- ✓ To complete the wells in minimum possible time.
- ✓ Selected design should ensure optimum installed and operating and maintenance costs over the field life estimated to be about 25 years.
- ✓ Where ever possible, ensure standardization of drilling and completion material and consumable so as to optimize operations and inventory of material.
- ✓ Simplicity of design and fitness for purpose.
- ✓ Benchmarking with major CBM developments / projects across the world.
- ✓ All Health, Safety and Environmental standards are to be adhered to.
- ✓ Ensure compliance with all applicable Indian and International Codes, Standards, Rules and Regulations Acts and Guidelines and follow best industry practices

Coming back to Air Drilling, as a base case, the wells will be drilled using DTH hammer & bit. Air package consisting of two air compressors and one booster with a capacity of approximately 2100 CFM & 1200 psi pressure rating has been provisioned with the Rig. Provision has also been kept for mud pump and mud tanks to enable conventional mud drilling for contingencies. In the following sections Air drilling, DTH Hammer & trouble shooting, problems associated with it & ways to optimize the air drilling parameters are described in detail.

3. AIR DRILLING TECHNIQUES

3.1. INTRODUCTION

Underbalanced Drilling (UBD) is a technique in which oil, gas or geothermal wells are drilled using pressures lower than the reservoir pressure. The result is an increase in rate of penetration (ROP), reduced formation damage and reduced drilling costs. Air drilling provides an efficient system in terms of operations costs and environmental safety benefits.

"Air Drilling" refers to the use of air in the circulating system via compressors and booster systems. The purpose for using an air drilling method is to drill low-pressure formations. During the last 20 years, air drilling techniques have been applied worldwide, successfully drilling for energy.

The five general classifications of air drilling techniques are as follows:

1. "Dust" Drilling
2. "Mist" Drilling
3. "Foam" Drilling
4. "Aerated Fluid" Drilling
5. "Nitrogen" Drilling

Advantages

Air drilling techniques offer the following advantages, when compared to the use of conventional mud systems.

- ✓ Faster Rates of Penetration. (Especially in harder formations)
- ✓ Improved Bit performance. (More footage per bit)
- ✓ Detection of low-pressure zones.
- ✓ Effective pressure control through loss circulation zones.
- ✓ Lower mud material costs.
- ✓ Fast return of uncontaminated cuttings for geological evaluation.
- ✓ Minimized formation damage.
- ✓ Improvements in Deviation Control. (Due to less weight on bit).

- ✓ Operating conditions are cleaner.
- ✓ Overall costs for drilling operations are lower.

Disadvantages

- ✓ Formation pressure control is minimal and, therefore, drilling is limited to geological regions where reservoir pore pressures are low.
- ✓ Drilling is limited to geological regions where the rock formations are mature and competent because there is little or no fluid pressure to support the borehole wall and prevent sloughing.
- ✓ There is limited ability to cope with significant volumes of water entering the annulus from water producing formations.
- ✓ The bit gauge can be appreciably reduced during drilling (with exception when using Diamond Enhanced Inserts- D.E.I.)
- ✓ The drill pipe can experience rather high wear due to sand blasting characteristics of annular stream flow.
- ✓ There is little or no drill string cushion effect, which results from fluid in the borehole during drill string handling mishaps.
- ✓ There is danger of downhole fire.

This increase in R.O.P. may be 2-5 times the drilling rate of a conventional mud drilled hole. This can reduce the number of days required to complete a well, and reduce drilling costs.

Rate of Penetration – (R.O.P.)

The downhole circulating density of an air drilling system is low, compared to a typical mud system. The decreased circulating fluid pressure exerted on the wellbore increases the relief of the vertical and axial stresses residual in the formations. This results in a “reverse pressure” gradient that increases the drill ability of the rock. As the down hole circulating fluid pressure is lowered below the formation pressure, the rock tends to “explode” at the bit tooth. This result in faster penetration rates provided there is sufficient circulating fluid volume to clear the hole of cuttings.

Bit Performance

An air drilling system provides sufficient fluid turbulence to ensure proper cleaning of the cutting structure. Abrasive cuttings are carried away from the bit and into the annulus, faster than a conventional mud system. This lessens the regrinding of drilled cuttings, increasing the removal efficiency of the solids control equipment, and improving bit performance. (R.O.P.) Elevated formation temperatures are common when drilling a geothermal well. One of the main factors affecting the performance ofa bit is bearing life. As high formation temperatures are encountered, bearing life can be decreased. An air drilling system supplies the bit with a cool stream of air that flows around the bearings, reducing the bearing temperature and increasing bit performance.

Decreasing the bearing temperature and reducing the regrinding of drilled cuttings, increases the footage that can be drilled for a given bit. This can result in fewer bits required to complete a well, reducing well costs.

Drilling through Loss Zones

Once “loss” or production zones are encountered, drilling may continue through and beyond these low-pressure formations. The operator may increase production from each well, by drilling deeper and encountering new production zones.

The existing air circulating system may or may not have to be changed to maintain full circulation. A properly engineered air drilling system will permit a rapid conversion from one technique to another, without any excessive delay.

Minimize Formation Damage

The use of air drilling techniques can minimize formation damage and enhance production from low-pressure wells, when compared to a conventional mud drilled well. If the circulating fluid pressure is less than the formation pressure, there is little chance that circulating fluids and cuttings will invade and damage producing zones.

Some geothermal operators have indicated that wells completed with conventional drilling fluid systems have less geothermal production, when compared to wells dried with air drilling systems in the same area. These operators feel that low bottom hole circulating pressures decrease invasion and “Baking off in the high temperature fractures of drilling fluid and cuttings.

3.2. DUST DRILLING

Compressed air is injected into the stand pipe and circulated through the drill string in much the same way as conventional mud. The “Dust” technique is used when drilling dry formations, or where any water influx is slight enough to be absorbed by the air stream. The name “Dust” was chosen because cuttings return to the surface as a cloud of dust.

The drilling fluid is used to cool the drill string and bit. The temperature of the air injected into the hole should be slightly higher than the temperature at ambient conditions. As the air travels down the drill string the air is heated to the temperature of the surrounding formation.

When the air passes through the jet nozzles, the air expands and the velocity increases to supersonic flow. This expansion occurs because of the large pressure drop between the bottom hole and the above bit pressures. This causes the temperature to decrease and cool the bit and the bit bearings. As the air travels up the annulus, the air is then reheated to the temperature of the surrounding formation.

If lubrication is desired of the drill string and bit, a lubricant must be added to the air stream. There are several products that perform this function. The application of a lubricant decreases torque and increases bit life. If soap is used, there will be an increase in the carrying capacity of the circulating fluid.

“Dust” drilling is the ultimate progression from a high to a low density drilling fluid. Bottom hole pressures slightly exceed the value of the air column pressure head plus the weight of the entrained cuttings. This allows for maximum relief of the vertical and axial stresses residual in the formations. This procedure offers the fastest drilling rates and best economy.

Hole Cleaning

The lifting power of an air drilling system is proportional to the circulating density, and to the square of the velocity. The density, and thus the suspension properties, of an air stream is much lower than a conventional mud system. Therefore, the annular velocity is the primary factor in transporting the cuttings to the surface. Air volumes that generate annular velocities of 3,000 ft/min. are normally adequate to “Dust” drill. However, when penetration rates exceed 60-ft/hr. or when cuttings are large or wet, higher annular velocities may be required to effectively clean the hole.

3.3. MIST DRILLING

This technique is used where the amount ofwater-influx is high enough to prevent “Dust” drilling, but not enough to cause hole-cleaning problems. The name “Mist” was chosen because a pretreated drilling fluid is injected with the air, and the combination returns to the surface as a mist. A small quantity of water containing a foaming agent (soap) is injected into the “air” stream at the surface, with the water mist being carried in the air in what is a continuous air system.

This technique offers increased drilling rates and economy over that of a conventional mud drilled hole. The lower bottom hole circulating pressure exerted on the well bore allows for greater relief of the vertical and axial stresses residual in the formations. Like dry air drilling, this system relies on the annular velocity of the air for cuttings transport out of the hole. Air mist drilling is used when the amount of water influx is high enough to preclude air dust drilling, but not so high as to cause hole cleaning problems.

Essentially, the equipment for a successful “dust” and “mist” drilling applications is the same. The principle difference being an increase in the air volume requirements 30%, and the injection of a pretreated drilling mud.

Hole Cleaning

Switching to a “mist” drilling technique requires an increase of at least 30% in the air volume. The additional volume is needed to overcome higher frictional losses caused by wet cuttings adhering to the drillstring and hole, higher slip velocities of larger wet cuttings, and transportation of the heavier wet air column. The mud is injected with the air stream to disperse the cuttings and inhibit them from adhering to the drill string and hole.

Although injection pressure of 100 to 200 p.s.i.g. are normally enough for “dust” drilling, pressures exceeding 350 p.s.i.g. can be encountered while “mist” drilling. Pressures of 1250 p.s.i.g. may be requires when large amounts of fluids are present in the annulus. The rate of fluid intrusion will dictate the amount of air and fluid that must be injected to efficiently clean the hole. Formation fluid entries of up to 150 bbl/hr (100gpm) have been successfully “mist” drilled.

The addition of a foaming agent reduces the interfacial tension of the water and cuttings in the hole and allows small water/cutting droplets to be dispersed as a fine mist in the returning air stream. This allows the cuttings and water to be removed from the hole without formation of mud rings and bit balling.

Proper amounts of water and soap must beadded to achieve a nominally continuous flow of foam and cuttings and adequate separation of the cuttings. Obtaining the proper combination of water and soap is a trial and error process. Good starting points are:

- ✓ 1.5 – 2.0 bph water/per inch of hole diameter (8.75" bit = 14 – 18 bph /water)
- ✓ 2 – 3 GPH soap – fresh water
- ✓ 2 – 4 GPH soap – Brine Water

The above totals are based on experience with the air hammer and may need to be adjusted according to hole conditions and bit selection. The requirements are a function of the type and volume of influx water. Many produced brines are effective defoamers, requiring use of additional soap. Produced oil requires a special type of soap.

To determine the proper amount of water and soap to be injected, several "rules of thumb" are helpful:

- ✓ Air volumes for mist must increase by 30% as compared to dust drilling.
- ✓ Pressures generally run at 300 - 600 psi for mist.
- ✓ Insufficient air/soap leads to hole surging.

In the Above sections, only Dust & mist type air drilling techniques are discussed as only these two techniques are being used at Reliance's Sohagpur block. In the proceeding section, we will discuss why mostly vertical wells are drilled at reliance and why they selected air drilling for their operations.

3.4. AIR DRILLING RIG EQUIPMENT

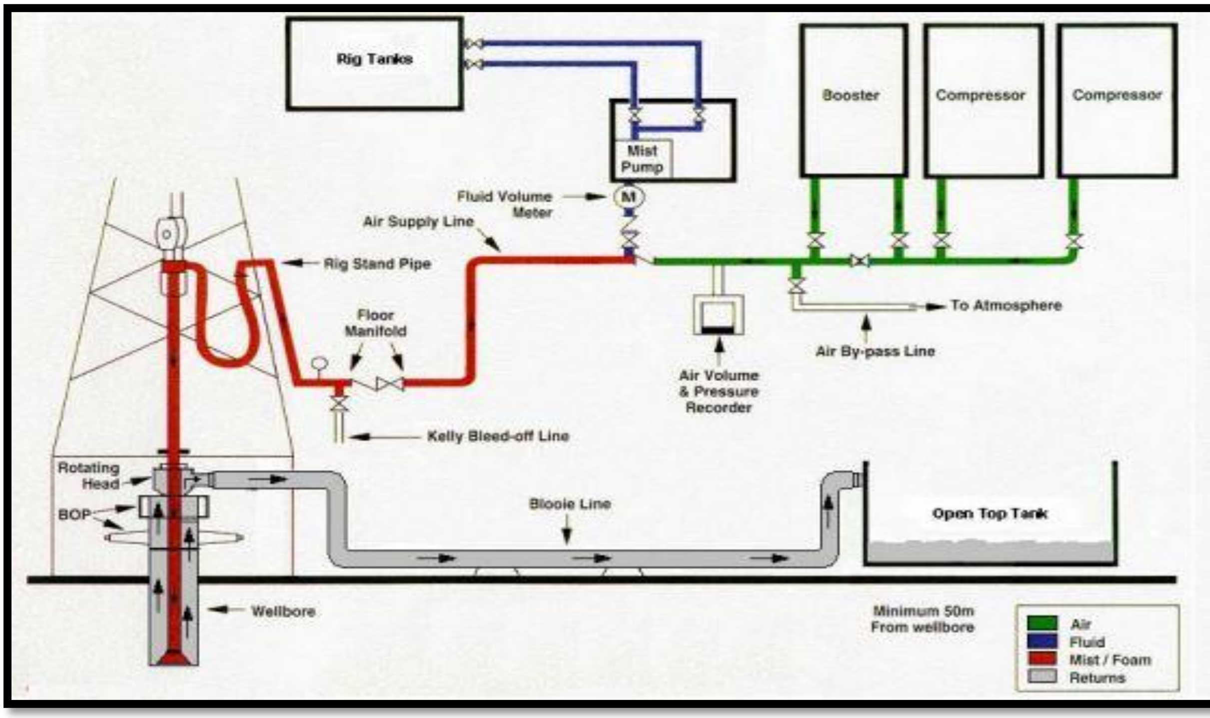


Figure 3: Air Drilling Schematic

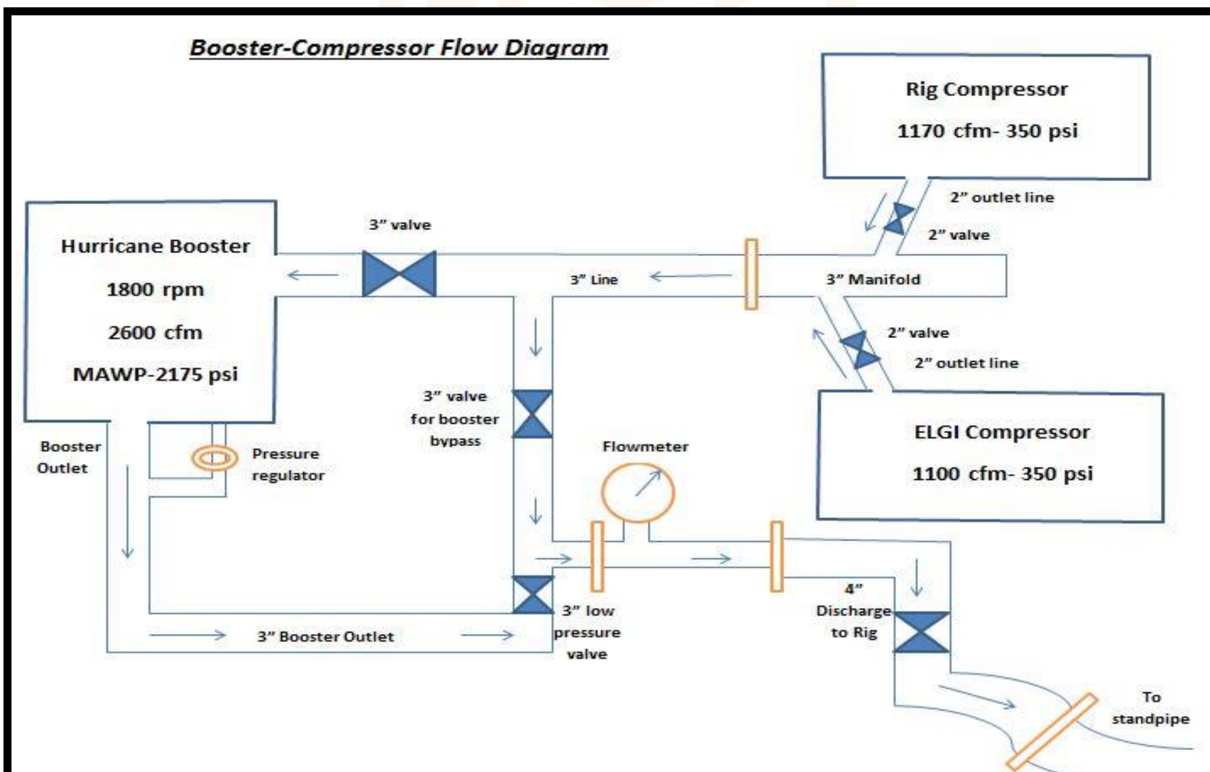


Figure 4: Booster-Compressor Flow Diagram

Air Compressors

There is two basic types of compressor equipment used in air drilling, the screw and piston type air compressors. During air drilling operations the compressor uses local atmospheric air. The compressor unit intakes a specific volumetric rate of atmospheric air, compresses the volume to the required pressure level (or it pressure capability limit) and injects this air into the standpipe manifolds. A booster may be required to increase the pressure of the airflow from the compressors. The piston type compressor is the general type used for air drilling operations. This type of compressor has the important characteristics of responding to pressure variations without appreciably altering the volumetric flow rate from the machine. Increased pressure requirements are met with increased power to produce a higher pressure at the exit.

In air drilling the volumetric flow rate is very important to hole cleaning and the field equipment must have the capability of producing a relative constant volumetric flow rate under a variety of pressure conditions. There have been many disputes in the past regarding the manner in which the volumetric output of a compressor unit is reported.

The equipment available to provide required air are compressors and boosters. The compressors take ambient air at a specific rate, compress it to required pressure or to the limit of the unit, and deliver the compressed air to the standpipe and downhole. Most compressors for oil field use produce in the range of 500 to 1,200 SCFM (standard cubic feet per minute) at a maximum pressure of approximately 300 psi. They are one, two or three stage. Compressor requirements are determined once the downhole air and gas requirements are determined, as detailed elsewhere. Compressor output ratings are generally given at standard atmospheric and temperature conditions, and must be corrected for actual ambient conditions.

Boosters

Boosters are positive displacement compressors that take the exit volume of the compressors and compress it to a higher pressure. Boosters generally can increase pressure from 100 psi to as much as 5,000 psi. The capacity and pressure rating of the booster is a function of the inlet pressure. As the inlet pressure increases, the volume through the booster increases and the outlet pressure will increase without excessive heat.

3.5. DETERMINE BAILING VELOCITY AND SCFM REQUIREMENTS

Let's determine the recommended bailing velocity of a 7 7/8" hole dusting with 4 ½" drill pipe at 6000' when drilling sand. (Sand weight is 165 lbs/ft^3)

First we use a simplified formula to get an estimate:

$V = 528\ D^{0.5}\ C^{0.5}$ (U.S. Units)

Where:

V = Bailing Velocity in Feet per minute

D = Rock Density in pounds per cubic feet

C = Diameter of Rock cuttings in inches

We assume a large chip size of ½", so that we are assured of cleaning small ones from hole.

$V = 528\ ^{0.5}\ C\ ^{0.5}$

$V = 528\ (165)^{0.5}\ (0.5)^{0.5}$

V = 4795 FT/MIN (1000' Depth.) = 6119 ft/min (6000' Depth)

A good usable rule of thumb is to add 5% compounded per 1000' to compensate for depth and compressibility changes.

Now that we have the recommended bailing velocity the following formula will be used to determine the CFM required.

$$\mathbf{CFM = \frac{V\,(D^2_H - DDP^2)}{183.3}}$$

Where:

V = Bailing Velocity In ft/min

D_H = Diameter Hole in Inches

DDP = Diameter Drill Pipe in Inches

183.3 = Constant Conversion Factor (U.S. Units)

CFM = Standard Cubic Feet per Minute

$$\mathbf{CFM} = \frac{V\,(D^2_H - DDP^2)}{183.3} = \frac{6119\,(7.875^2 - 4.5^2)}{183.3} = \frac{6119(62.01 - 20.25)}{183.3} = 1394\ \text{cfm}$$

Recommended Air Requirements for Dust Drilling SCFM

Hole Size	Drill Pipe	Depth/Feet 1000	2000	4000	6000	8000	10000	12000
		SCFM						
16"–17 ½"	4 ½	7481	7854	8658	9544	10520	11599	12786
14 ¾ - 15	4 ½	5356	5624	6201	6837	7537	8310	9162
12 ¼"	4 ½	3395	3565	3929	4332	4775	5264	5803
11"	4 ½	2635	2766	3049	3362	3706	4086	4504
9 ⅞	4 ½	2021	2121	2339	2578	2842	3133	3454
8 ½-8 ¾	4 ½	1473	1546	1704	1879	2071	2283	2517
7 ⅞	4 ½	1092	1147	1264	1393	1536	1693	1867
6 ¾	3 ½	871	914	1008	1111	1225	1351	1489

*** Recommended additional 30% for mist drilling and directional wells.**

Figure 5: Recommended Air Requirements for Dust Drilling (SCFM)

AIR VOLUME

- ✓ Minimum A.V. of 3000 ft/min. (Angel's curves)
- ✓ Optimum A.V. of 5000+ ft/min. (Field experience)
- ✓ 30% additional air volume suggested for misting and/or directional applications

Air Volume suggested for drilling and cleaning these straight air circulation holes is suggested to be enough to deliver an annular velocity of 5000 feet/min. It is also suggested that an additional 30% air volume should be used when misting or drilling a directional hole.

Air Volume (SCFM) Correction Factor For Altitude And Ambient Temperature

	ALTITUDE IN FEET					
Temperature °F	0	1000	2000	3000	4000	5000
-40	.805	.835	.866	.898	.932	.968
-30	.824	.855	.886	.920	.954	.991
-20	.844	.875	.907	.941	.976	1.014
-10	.863	.895	.928	.962	.999	1.037
0	.882	.915	.948	.984	1.021	1.060
10	.901	.935	.969	1.005	1.043	1.083
20	.920	.954	.990	1.026	1.065	1.106
30	.939	.974	1.010	1.048	1.087	1.129
40	.959	.994	1.031	1.069	1.110	1.152
50	.978	1.014	1.051	1.091	1.132	1.175
60	.997	1.034	1.072	1.112	1.154	1.198
70	1.016	1.054	1.093	1.133	1.176	1.221
80	1.035	1.074	1.113	1.155	1.198	1.244
90	1.055	10.94	1.0134	1.176	1.221	1.267
100	1.074	1.114	1.154	1.198	1.243	1.290
110	1.093	1.133	1.175	1.219	1.265	1.313
120	1.112	1.153	1.196	1.240	1.287	1.336

Figure 6: Air Volume Correction Factor

WOB & RPM

- WOB should be minimized but must maintain a "closed" hammer
- Typically 500 lbs. or less per inch of bit diameter is found to be sufficient.
- RPM should depend upon formation, hole size and frequency of the hammer
- RPM with high frequency hammer in soft formation would utilize higher RPM (i.e. 40 – 60 RPM for 7 7/8''-8 ½'' hole size)
- RPM for hard abrasive formations should be as low as possible. (i.e. 10 – 20 RPM)

The short rapid blow of the down hole air hammer provides for good penetration rates while drilling straight holes. When increasing the blows per minute, (BPM), an accompanying increase in the rpm may be required. When drilling in softer formations, the rpm's may have to be increased.

4. DRILLING & COMPLETION APPROACH AT RELIANCE.

The Basis of design for Sohagpur East and West concluded that a number of approaches to drilling and completion were feasible although vertical wells, drilled with air and with fracture stimulation were the optimum approach in most cases.

Virtually all of the wells here have been drilled using air/mist drilling methods. Use of drilling fluids (mud) to drill the wells is not a desirable option due to potential formation damage to the coal and due to logistical issues at the well sites

The wells in Sohagpur have generally been drilled using Air or Foam from surface through the reservoir to TD. The main advantage in utilizing an underbalanced air (dust) drilling system is the increased penetration rate that is two to five times greater than that incurred in a conventional mud drilled hole. The typical ROP observed for air drilling in Sohagpur is 15.6 meters per hour based on analysis of wells drilled in West Sohagpur block through July, 2011. There should also be reduced skin damage to low pressure pay zones resulting in lowered completion costs.

However, sloughing formations like those experienced in some areas of Sohagpur are poor candidates for air (dust) drilling as sloughing formations require some hydrostatic pressure for stability. Also some of the hole problems encountered during operations such as logging may be due to insufficient hole cleaning.

In assessing the suitability of the various techniques identified in the Basis of design, first a risk assessment was carried out, covering the full drilling and completion approach and identified mitigation measures where possible. These are listed in the below table

Sr.No.	Type	Description	Mitigation
1	Pad Drilling	Pad Drilling is not feasible in West Block due to the limited depth of the coal seams which results in less than 80 acre well spacing.	Detailed NPV study needs to be done to decide the optimum spacing for West Block
2	Stuck Pipe	Stuck pipe is known risk in some of the sub sectors for the RIL CBM block, which occurs mainly due to the hole caving/collapse of chocolate shale formation.	Use of mud for drilling in the sub sectors prone for stuck pipe.
3	Air Drilling	Hole caving or collapse during drilling production hole & drill string stuck up.	Use of foam sweeps as effective medium for hole cleaning along with air.

4	Foam Drilling	Effective use of hammer and reduced ROP, cost associated with foam.	NPT caused due to hole caving/collapse and wiper trips will balance increased cost of operation.
5	Liquid Mud	Reduction in production due to reservoir damage, reduced ROP and solid handling equipment cost. Larger surface footprint for mud handling equipment.	Hydraulic fracturing will reduce the reservoir damage to some extent, but will not completely recover the damage.
6	Horizontal Wells	Effective hole cleaning of horizontal section. Hole sloughing or collapse.	Use of mud or foam as drilling fluid.
7	Cementing Operation	Cement fall back and invasion in cleats and natural fractures. Poor cement Job	Low density cement slurry.
8	Logging Operation	Tool Held Up	Improve hole cleaning methods. Wiper Trip
9	Surface section	Loose surface formation (max up to 6-8 m)	Drill 14-3/4” hole with air hammer and set 11-3/4” conductor and cement to surface.
10	Coiled Tubing Drilling	The technique utilizes a mud motor to drive the bit. Drilling in harder rocks, particularly the dolerites found in the Sohagpur basin would be difficult.	A further study would be required but without the necessary equipment infrastructure this would be difficult.

Table 3– Risk Assessment of different drilling and completion techniques

The majority of wells in Sohagpur East and West are considered suitable for vertical air drilling utilizing a down-the-hole hammer with the potential for clean-out using foam to achieve better returns to surface. We cannot achieve the required 160 acre spacing in these sub sectors, primarily due to the juxtaposition of dolerite sills, using deviated or horizontal drilling techniques hence vertical wells are recommended.

A critical factor in identifying the suitability of deviated wells is achieving suitable well-spacing of up to 160 acres and the position of dolerite sills relative to the coal seams. This was found to exist in 2 sub sectors. In a particular sub sector, where the coal permeability is greater than 3 mD and seam thickness greater than 3m, horizontal wells were the most suitable technique.

4.1. FEASIBILITY OF PAD DRILLING IN SOHAGPUR

Pad drilling can benefit the operator in the following ways:

- Placing several wells on one site reduces the company's impact on developable land. This is especially important in populated areas. Placing multiple wells on the same pad can dramatically minimize surface disturbance.
- This process further reduces surface disturbance by eliminating the need for additional lease roads. This, in turn, decreases the company's road construction costs.
- Multi-well pads are far more efficient, because once a well is drilled; the rig moves only 20 feet or so to drill the next one. This reduces transportation cost and truck traffic.
- In rural areas, the Company can be more flexible about where to place its wells. This gives the Operator more input on both the placement of the wells and the construction of the road leading to those wells.
- Within an incorporated area, a multi-well pad reduces the uncertainty involved with the permit process. Most cities and towns require a permit for each new well. If four wells are to be placed on the same pad, the chances are greater that each of those four permits will be approved.
- An operator often can reduce the number of storage tanks and liquid separators by consolidating the operations of several wells onto one pad. This further decreases the Company's surface disturbance while reducing operating expenses.

For RIL Sohagpur CBM block, the application of the Pad Drilling is limited due to two main reasons:

1. The coal seams are not deep enough to achieve the desired well spacing.
2. The dolerite intrusion which is present above the coal seams is difficult to drill directionally.

When planning the wells for at least 80 acre spacing then the top most coal seam, normally Seam V, needs to be at least 750 m TVD for the deviated slant well and 786 m TVD for the "S" Profile well.

The constraints for designing a directional well in Sohagpur are as follows:

- The dogleg angle is limited to about 2.5 degree/100ft due to the shallow kick off depth.
- A 40 degree inclination is recommended with an absolute maximum of 45 degrees. Higher inclinations are not recommended in wells which may be prone to hole caving or collapse. Also, if the hole angle is greater than 45 degrees, then cutting beds are more likely to develop.
- A hole angle of more than 45 degrees through the coal seam may have an adverse impact on the fracture stimulation.

For deviated wells, we will hold the 40 degree inclination until the coal seam V. Seam V should be 750 m TVD or deeper to achieve 80 acre spacing for 3 wells per pad. Similarly for "S"-shaped wells we will build to 40 degrees inclination and then drop this angle to 25 degree with 3 deg./100ft dog leg into seam V. For this well design seam V must be 786 m or below to achieve 80 acre spacing. Therefore pad drilling may not be practical in the West Block sectors as the dolerite intrusion is present in the directional section.

4.2. GENERAL COAL DRILLING PRACTICES

Suggested drilling practices for Sohagpur East and West are listed below:

1. Correlate the anticipated depths and calculate the coal seam thickness based on hole angle and true vertical thickness of the seam.
2. In directional CBM Wells, plan slides in the sand /shales. Rotate drill the coals.
3. Coals are affected by surges.
   - Do not set the pipe on the slips with the pumps on.
   - Start mud pumps up slowly.
   - Ream down slowly.
4. Check torque, drag, and pump pressure before starting to drill again. If parameters are not normal, do not drill. Continue working the pipe and circulating until parameters are normal.

5. Do not pump sweeps unless hole conditions indicate a problem. POOH without pumps on and if conditions don't improve then a sweep could be considered. If a sweep is required, then the following is recommended:

    - Use tandem sweeps. Do not pump sweeps while drilling.
    - The first sweep to be low volume low-vis followed immediately by larger, weighted, higher vis. No other fluid should be pumped in between them. The low-vis volume should be large enough to stay intact (20 bbl).
    - Increase rotary speed when sweep clears the bit and the bit should be off bottom.

6. Avoid back reaming except for during coal drilling operations.
7. If hole conditions other than cuttings build-up indicate back reaming is necessary, the hole will have to be circulated clean after the operation.
8. Wiper trips to clean the hole are not recommended and are unnecessary.
9. If torque and drag are excessive and haven't returned to normal after executing the hole cleaning procedures, then a wiper trip may be warranted.
10. Reduced exposure time - bit/equipment trips only when essential, on operational call.
11. Prior to a trip, clean hole at maximum flowrate and pipe RPM.
12. POOH without pumps or rotation.
13. If it pulls tight, RIH few stands and circulate at max flowrate and RPM for 30 minutes.
14. Again POOH without pumps or rotation. If the tight spot has disappeared or moved up the hole, then it was probably cuttings. It is at the same spot it will have to be backreamed.
15. If back reaming is required, it will be necessary to circulate clean again
16. If the drill string is tending to jam (pack off), back off the weight and rotate to break up large pieces. This will allow them circulate past the BHA.
17. Drill with a low WOB and high RPM, rather than high WOB. Control the drilling rate to prevent overloading of the annulus if the coal is tending to break out.

5. NON PRODUCTIVE TIME (NPT) ANALYSIS DURING DRILLING & RECOMMENDATIONS:

One major assignment I was given in reliance was to do the nonproductive time analysis for their wells. Knowing the nonproductive time helps the company understand the time & cost they are losing due to various reasons & can focus on specific areas where by implementing optimized drilling practices, such NPT can be reduced and lot of capital can be saved.

Although Reliance has a huge database showing NPT from each well over the years and the reasons for it but I was told to do the analysis for the wells drilled by a particular drilling service provider from May 2014 up to February 2015 as it was indicated that during this time NPT was very high. I reviewed the well data of 20 wells and came up with the following observations & recommendations.

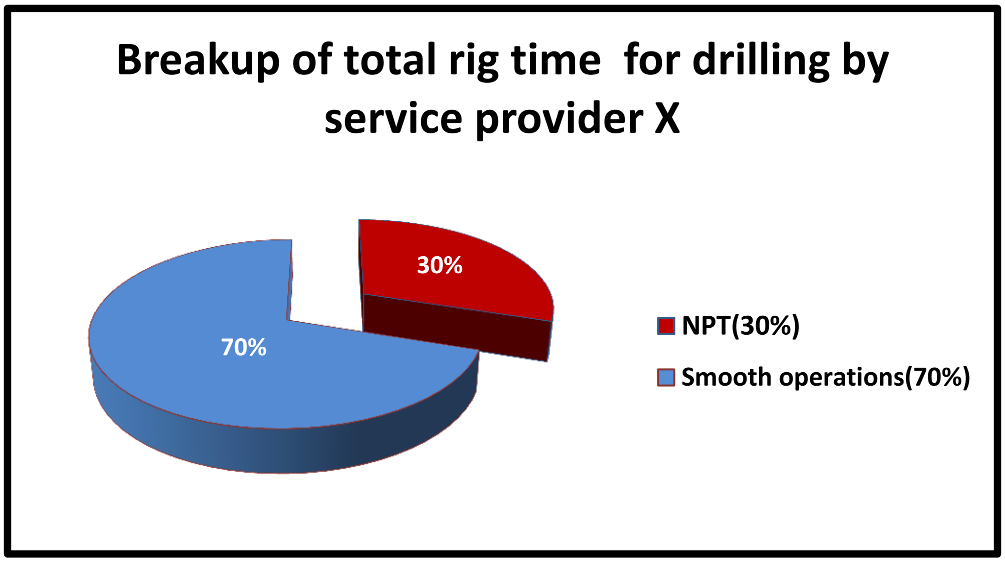


Figure 7: Breakup of Total rig time

As seen in the above pie chart, an astonishing 30% (around 1450 hrs) of the total rig time during these 8 months accounted for Non Productive time. Now this is a serious problem as owing to this NPT, reliance was incurring heavy losses that accounted to roughly over Rs 2 Crore which is a humongous sum of money. A more detailed breakup of the NPT is given in the following pie chart

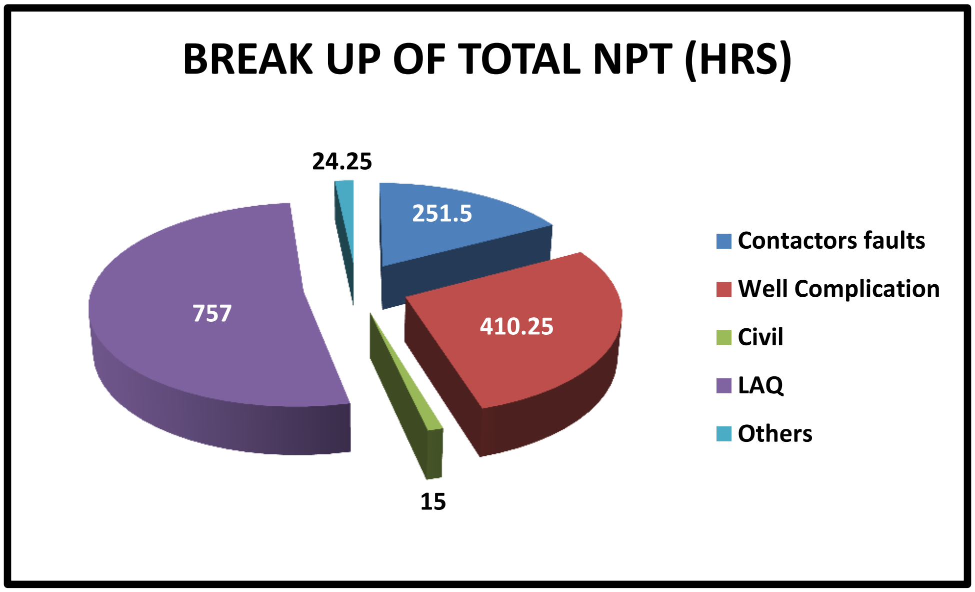


Figure 8: Breakup of total NPT

5.1. OBSERVATIONS & RECOMMENDATIONS:

- More than half of total NPT was accounted to Land acquisition issues. As observed at many exploration sites in India, more than the technological issues, political and social problems are the major contributers of NPT & Shahdol –Madhya Pradesh is no different. The NPT due to Land Acquisition included:
    - Villagers stopped vehicles on approach road near a well
    - Villagers of stopped the water tankers deployed for dewatering the waste pits & damaged the fencing and poles.
    - Villagers entered inside drill site and stopped the work, pelted stones, refused to leave site(Major problem).
    - Villagers coming to the site in huge mobs and stopping operations, demanding compensation for using their land.
- As the LAQ problem is such a huge issue here, preventive measures must be taken by reliance by chalking some kind of deal with the villagers like employing them as labours or making proper roadways for their villages, opening up schools, engage more in CSR activities, Compensating people with proper money for using their land and making sure that the money reaches them & there is proper paper work for it. It's a fact that reliance

have realized that in order to carry out operations smoothly in shahdol, they do need local support, so Reliance must do their bit in gaining the trust of the people there so that they won't cause problems in their operations.

- The NPT due to well complications is huge and has to be reduced by optimized drilling practices. 80% of the NPT in well complications was due to pipe stuck. There is a typical pattern of pipe stuck observed here following by a general on field practice. Pipe stuck happens here usually due to heavy cave –ins. In such a case, if there is tight pull & cuttings cannot be lifted by the medium of air or foam then the circulating medium is switched to mud (Bentonite system) & further drilling is continued by mud drilling using TCR bit. Many a times even if the complete well is drilled using air drilling then in such cases, 90% of the times when logging tool is lowered gets stuck due to cave ins & the tool has to be removed & the whole well has to be reamed with mud.

- Instead of switching always to mud drilling once heavy cave ins happen or when pipe gets stuck , the reason for cave ins must be identified and minimized so that the pipe sticking problem reduces hence saving costs. Cave-ins happens due to swelling & breaking of shale. Shale swells when it comes in contact with water. There is a seam of shale in sohagpur which is named chocolate shale (named after colour) which shows maximum swelling tendency.

- Cave-ins can be minimized by:
    - Using dust (Air) drilling for as long as possible instead of switching to mist (Air+ Water+ chemicals) drilling right at the start.
    - Use booster pump only when necessary as if booster pump is started after drilling down after each pipe to clean and lift the cuttings, the pressure from the booster pumps will enlarge the hole at that point which will not only result in uneven hole size but also produce large pieces of cuttings which falls on the assembly while drilling further& lead to pipe stuck.
    - All air drilling parameters must be set optimally like the RPM, CFM etc for smooth operations & cutting size, quantity must be continuously monitored near the waste pit as it will give a fair indication of the cuttings being lifted.

- Instead of switching to bentonite system of mud drilling, KCL-PHPA system must be tried as KCL is considered as a better shale inhibitor. Although polymer mud is way expensive than bentonite mud, it must be tried as polymer mud gives better results. The argument for using KCL-PHPA mud is valid as in the bentonite system, barite, the weighting agent which helps to form the filter cake is told to be used in less quantity or none by the geologists as it has detrimental effects on the coal seam. In such a situation, bentonite mud system becomes less effective hence replacing it with polymer mud is a better option.

6. WELL COMPLETION

Techniques for completing coalbed methane wells have evolved from completion experience with conventional oil and gas wells. Though some conventional techniques can be applied directly, others have been modified to accommodate the unique characteristics of coal reservoirs.

The primary goal in completing coal bed methane well is to establish communication between the wellbore and the target formation. Effective formation access is essential to successfully stimulate and produce the well.

6.1. COMPLETING IN CASED HOLE

To maximize production from shallow, thin coal seams, most operators today complete multiple coal horizons through casing. Using cased hole completion methods will help avoid the problems of open hole completions and will help:

- ✓ Maintain hole stability
- ✓ The packer could become stuck in the open hole.
- ✓ Allow selective completion of multiple coal seams
- ✓ Maintain control over the well during stimulation operations
- ✓ Reduce coal fines production
- ✓ Allow the use of resettable packers rather than inflatable packers

The cased hole completion method is especially effective for completing multiple zones in a single well. Though cased hole completions provide several important benefits, they also can have some drawbacks that may reduce their effectiveness:

- ✓ Cement invasion caused by fracturing the coal during cementing operations can cause formation damage.
- ✓ Blockage of access points (perforations or slots) because of coal abrasion during stimulation or because of coal movement behind the casing during production.

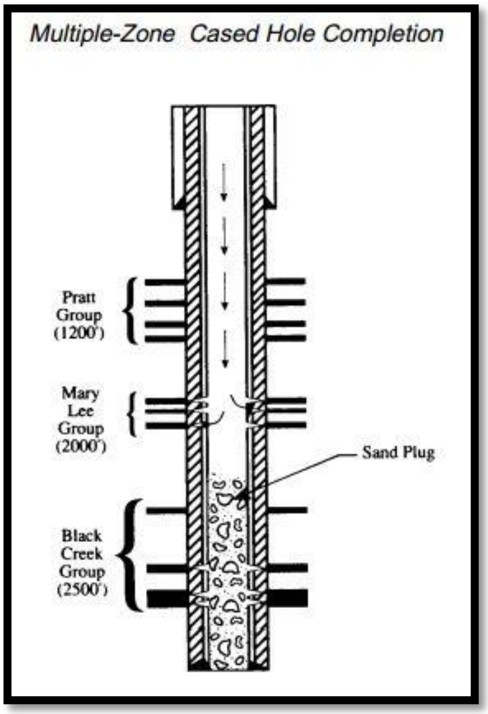


Figure 9: Cased hole Completion

For the above benefits offered by cased hole completions & by reviewing the performance of cased hole completions in the analogous CBM basins worldwide, it was hence decided to use cased hole completions followed by wireline perforation & hydraulic fracturing in Sohagpur block to complete the wells.

6.2. CBM ZONAL ISOLATION TECHNIQUES

1. Coiled Tubing Completions

Hydraulic Fracturing assisted with Coiled Tubing (CT) has been applied recently in CBM completions. In areas where the target is to treat a significant number of multiple seams, CT is an efficient tool. CT creates the perforations, and allows you to perform the Hydrofracture (HF) treatment without having to pull out of hole (POOH), which saves on valuable time and increases the speed of the operation significantly. Having CT in hole allows you to immediately to down and cleanout the wellbore.

Hydrajet Perforation Annulus Path (HPAP) Fracturing

The HPAP technique uses the CT to deliver a high velocity fluid to the formation or casing wall through jets at up to 700ft/sec . Hydra jetting is the process of impinging abrasive fluid at a high velocity for a specified period of time, which generates enough erosion to cut through the casing, cement, and near-wellbore formation damage to make an adequate perforation in the formation. Note that no separate perforation stage is required in this technique.

Relevance to Sohagpur

The argument to employ CT is evenly balanced, as the number of potential jobs in the Sohagpur sub sectors average not more than 4 to 5. For this number of jobs, employing CT will take more time for ILM, which impacts the advantage CT brings in doing more jobs at a quicker pace

2. **Ball and Baffles**

Ball and baffles zonal isolation is a recommended completion technique when treating a smaller number of coal seams. The baffles are run in casing string collars. Baffles successively are run in from the bottom to the top of Casing. Perforations will have to be performed between stages. The balls and baffles need to be drilled out post-fracturing work over. As mentioned its drawback is the limited number of zones it can be applied to. While ball and baffle technique is a fast staging method, it can still leave debris at bottom of hole from baffles and balls being knocked/drilled out. It can also limit gun sizes and if seams are very close on measurements, could end up with a baffle covered in screen-out cases. To mitigate this problem it may be necessary to drill out to TD after completion with a mill to get back to casing ID and bottom of hole.

Relevance to Sohagpur

This technique is the best suited method to zonal isolation for the Sohagpur field, as the average zone in most of the sub sectors is 4. It is economical as it does not require the services of a rig for a longer duration as required for the perforation and plug technique. Hence the Zonal isolation in Sohagpur is done by ball & baffle.

3. **Perforate and Plug**

In this technique the zones are isolated using different types of plugs and perforated using wireline. The technique allows for larger number of zones to be stimulated. One of the issues is that a wireline unit will required on location leading to extra cost. Perforation balls can be used for if multiple seams are to be performed in the same job.

EZ Drill Bridge Plug

These bridge plugs are built from cast iron, brass and rubber to provide unsurpassed drillability.

Relevance to Sohagpur

This technique is not recommended in Sohagpur due to the low number of treatment jobs. It will increase the cost of the operation as it will require either a slick line or rig for setting the plugs, the plugs will also have to be drilled out to get a well on production.

6.3. SELECTING PRODUCTION TUBING

Selecting the proper tubing string helps ensure the well is capable of producing the water rates necessary to effectively de-water the reservoir and maximize gas production. When selecting a tubing string, consider the guidelines below:

- ✓ Select tubing size based on the estimated maximum water rate to be produced, the type and size of pump you will use and the formation pressures expected.
- ✓ When ordering the tubing string, order enough tubing so you can set the pump below the lowermost coal seam.
- ✓ The inside diameter of the tubing must provide a produced fluid velocity to minimise the total pressure loss as defined by the tubing performance relationship.
- ✓ The tensile strength of the string of made up tubing must be high enough to allow suspension of all the joints to the production zone without tensile failure occurring of any of the joints above.
- ✓ The completion string must be able to withstand high internal pressures as a result of fluid flow entry into the tubing.
- ✓ The completion string must be able to withstand high external differential pressures between the annulus and the tubing.
- ✓ The tubing must be resistant to chemical corrosion which may arise because of fluid contact in the wellbore, and might ultimately accelerate string failure by one of the loads and stresses

Considering the Cost factor, downhole pump to be used & based on the results from analogous CBM basins, 2-7/8" Tubing is used as production tubing in the Sohagpur Block

7. ARTIFICIAL LIFT SELECTION FOR SOHAGPUR BLOCK:

7.1. Factors taken into for dewatering Sohagpur field.

- ✓ Relatively high water production during initial dewatering phase
- ✓ History of pump failures due to proppant flow back
- ✓ Life cycle costs of pump systems
- ✓ Well depths and rates vary by sector
- ✓ Type of wellbore trajectory (vertical vs. deviated vs. horizontal)
- ✓ Surface facilities not yet designed

The primary methods of artificial lift considered for dewatering CBM wells in Sohagpur were the following:

- ✓ Electrical Submersible Pumps (ESP)
- ✓ Progressive Cavity Pumps (PSP)
- ✓ Sucker Rod Pumps

The ESP was considered for the following reasons:

- ✓ Produces high water volumes
- ✓ High reliability under given conditions
- ✓ Known entity with 20 plus years of successful CBM experience.

The PCP was considered for the following reasons:

- ✓ Solids production capability
- ✓ Local supply and service
- ✓ Specifically developed elastomers for CBM operations with double Chrome rotors
- ✓ Can be optimized for long run life

The sucker rod pump system was considered for the following reasons:

- ✓ Good low volume option
- ✓ Worldwide recognition and familiarity.

Other methods of artificial lift that have been used for CBM include gas lift, plunger lift, and hydraulic jet pumps .These methods were not considered as suitable options due to the quantities of water to produce and the low bottom hole pressure requirements.

7.2. PUMP SETTING DEPTH IN THE WELLBORE

A best practice to optimize pump production in a vertical well is to place the intake of the producing pump below the last producing coal. Experience by Global experts indicates the pump should be placed a minimum of 75 ft (23 m) below the bottom coal seam with a preference of 100 ft (30.5 m). There should be an additional 50 ft (15.2 m) of rat hole below the pump intake.

Placing the pump always below the coal seams is not desirable. There are three major issues that need to be addressed before deciding the pump setting depth whether it should be placed above the perforations, between the perforations or below the perforations. They are:

- ✓ Top of water column
- ✓ Sand Production
- ✓ Gas Production.

Knowing the **Top of the water column** is ideal so that the pump may not run off dry. The depth of water column is found by a device called echometer. Usually the top of water column is well above the top of perforation so dewatering in this case can be done efficiently irrespective of the depth at which the pump is placed.

If there **is high sand production** then placing the pump at the bottom of the seam is not advisable. Taking an example of PCP, if lowered below the bottom seam in such a case, the abrasive HF sand will enter the pump & can settle between the cavities, abrade the elastomer, increase the torque leading to various problems like sucker rods snapping. So in case of high sand production, it is advisable of place the pump above or in between the perforations.

If there **is high gas production** then placing the pump above the top of seam is not advisable. Taking an example of PCP, if lowered to the top of the seams in such a case, the gas will enter the pump depending on whether it gets an easy passage through. If gas enters the pump, it may lead to swelling of the elastomer in the stator which will increase the interference fit between the stator and rotor eventually leading to high torque and a bundle of problems along with it.

If there **is high gas and sand production**, there is a conundrum as to where to place the pump. In such cases, the pump is set between the seams depending from which seam there is either high gas/sand production. If there is a normal gas and sand production, the pump is set in between the seam depending on whose production is higher & that which is more damaging to the pump. Generally sand is considered more dangerous as it has a quick effect on the torque of the pump if it enters the pump as compared to gas entering the pump.

In Normal cases, here at Sohagpur, when completing the Well initially, the pump is lowered to a depth about 40 metres above the top perforation unless there is high gas or sand production right from the start.

7.3. <u>ESP VS PCP FOR SOHAGPUR BLOCK</u>

The argument between ESP vs PCP on whose better can just go on. Unfortunately there hasn't been a study conducted on the performance, efficiency, no of running days of ESP and PCP for CBM wells. Both the pumps suit well to the conditions of the sohagpur block. So which pump must be selected?

Estimated pump run life cycle is based upon each lift systems' characteristic. The ESP operates best at higher volumes where tubing velocities can be maintained high enough to carry any solids the well makes to surface. A PCP operates best at slower speeds and lower flow rates and is capable of digesting clays and other floating materials that the CBM typically start producing later in the wells life. As new technology is developed over the coming years, artificial lift methods should be evaluated based on conditions being experienced in the field.

Based on a study of pump performance projections showing run times of ESP & PCP by Marathon Oil Company, these run times which calculated in the study were correlated to the estimated production rates for a typical Sector 1 well (Of Reliance's Sohagpur Block). The fact that PCP run time does not decline a rapidly as that of the ESP is indicative of the fact that PSP's can handle a larger concentration of solids. However, the ESP is a better performer at the higher production rates.Obtaining long run pump operation life depends upon the following:

- ✓ Flowback of fracturing proppant is strictly controlled or eliminated
- ✓ Pumps remain running 24 hrs per day without down time
- ✓ ESP's are properly shrouded and screened for solids
- ✓ ESP's are operated with adequate fluid to prevent pump off
- ✓ PCP's operate at as slow RPM as possible not to exceed 300 RM for optimum life
- ✓ PCP's are never dead headed or run dry
- ✓ Pump manufacturer's operational recommendations

Industry experience and anecdotal evidence indicate that PCP's operated under the conditions described above in fluid ranges of 50 to 1500 bpd can expect an average run life of 2 - 3 years. Similarly, ESP's operated in fluid ranges at or above 150 bpd and above can expect an average run life of 2 -3 years.

The points going in favour of PCP instead of ESP for Sohagpur block are as follows.

- ✓ Minimum Power requirement is instrumental reducing the cost of the well. In a study conducted by Reliance, although the initial requirement of power for PCP is higher but in the long run ESP requires more power adding to the cost.
- ✓ In the PCP vs ESP life cycle cost estimate (NPV analysis)for a well of 700 m, 51/2" casing, period of 10 years at a discount rate of 8%, the cost estimate for PCP was much lower as compared to ESP.
- ✓ PCP has better solid control as compared to ESP
- ✓ Handling ESP requires trained professionals & and for any minor loose connections for which the pump may not work, it has to be removed out.
- ✓ Studies suggest that PCP is more reliable. But that one, we can leave to the operators as irrespective of the pump, what matters is how you handle the pump & that will decide its reliability.

- ✓ PCP has a way better turn down ratio as compared to ESP. With an ESP your turndown ratio is so poor that a 10-15% error can push the pump into a region where it will not work and must be replaced. A PCP sized for about the middle of its operating range can generally handle ±1,000%. So there are more chances of the motor getting burnt up due to dry run in ECP. Moreover due to excessive heating of motor in ESP, there is formation of scales.

- ✓ Abrasive HF Sand will affect ESP more than PCP as with ESP more speed is involved which provides momentum to the sand particles leading to damage or cutting of pipes and hence shortening the life of the pump.

For all the above reasons, PCP is selected over ESP in Sohagpur.

8. PROGRESSIVE CAVITY PUMP

Progressing cavity pumps are relatively new to the oil and gas industry. They have been used extensively for coal bed methane wells in a number of areas of the Black Warrior Basin. In contrast to the beam pump, which is driven by a reciprocating rod, the progressing cavity pump is driven by a rotating rod.

Progressing cavity pumps can operate at a wide range of speeds and lift varying amounts of fluids. In addition, progressing cavity pumps usually cost less to install, occupy less space on the surface, and are less visually prominent (a consideration in urban areas) than beam pumps.

8.1. SYSTEM DESCRIPTION

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

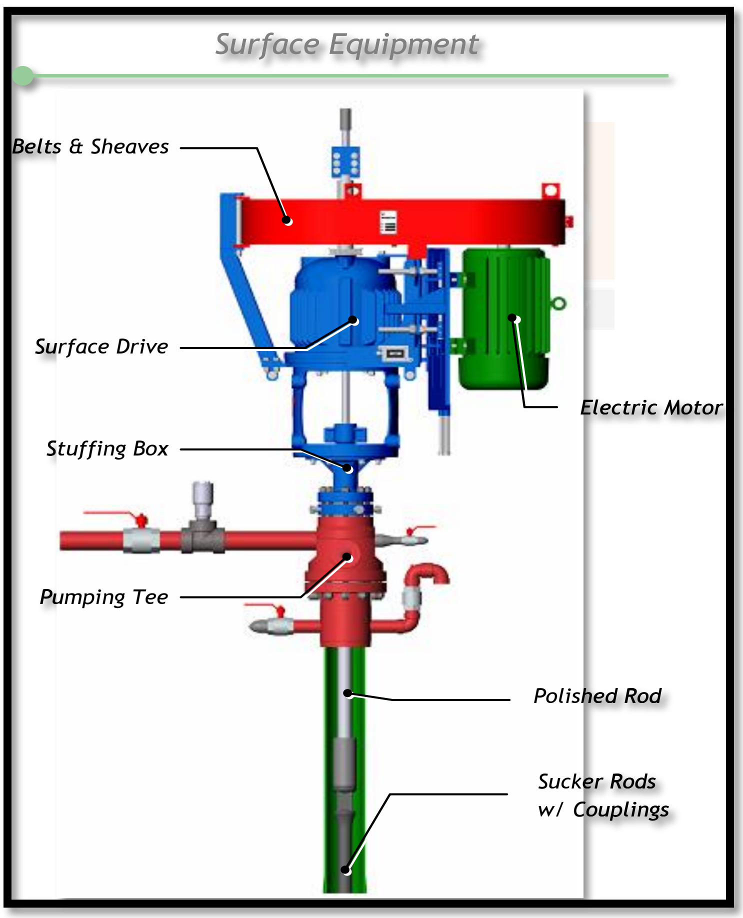


Figure 10: Surface Equipment

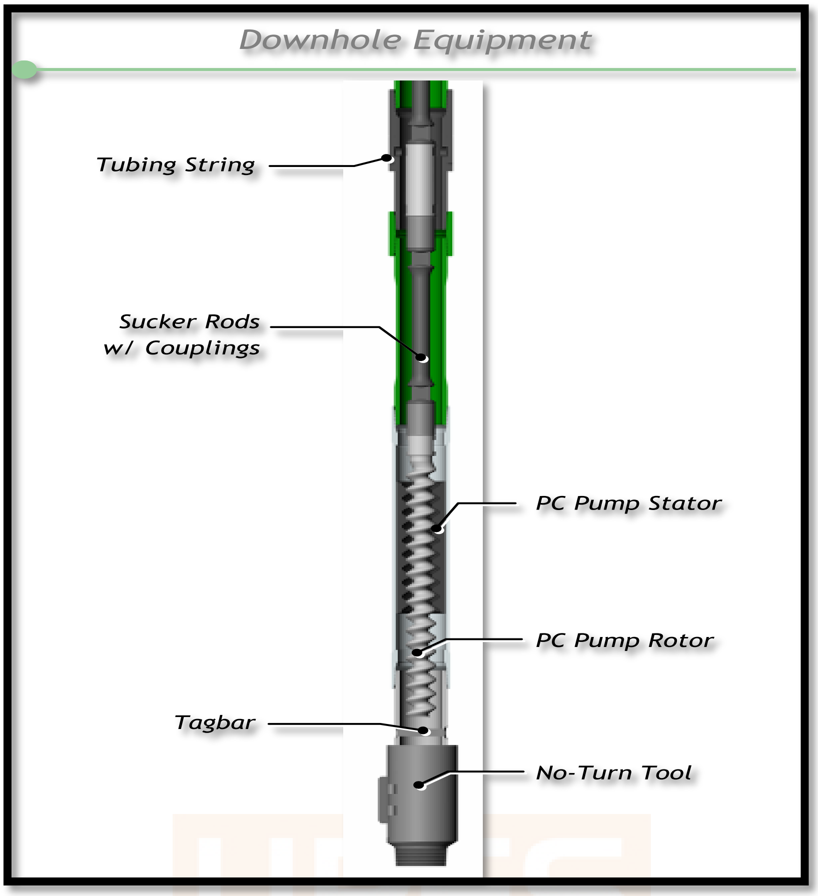


Figure 11: Downhole Equipment

(Illustrations courtesy of Weatherford International)

Surface drives are typically electrically driven. Gas engine driven generators can be used to supply electricity where line power is not available. Hydraulic transmissions consisting of an engine driven pump driving a hydraulic motor on the surface drive are also common.

Most surface drives have belt and sheave reductions to provide additional speed adjustment. Geared systems and inline electric or hydraulic systems are also available. <u>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</u>.

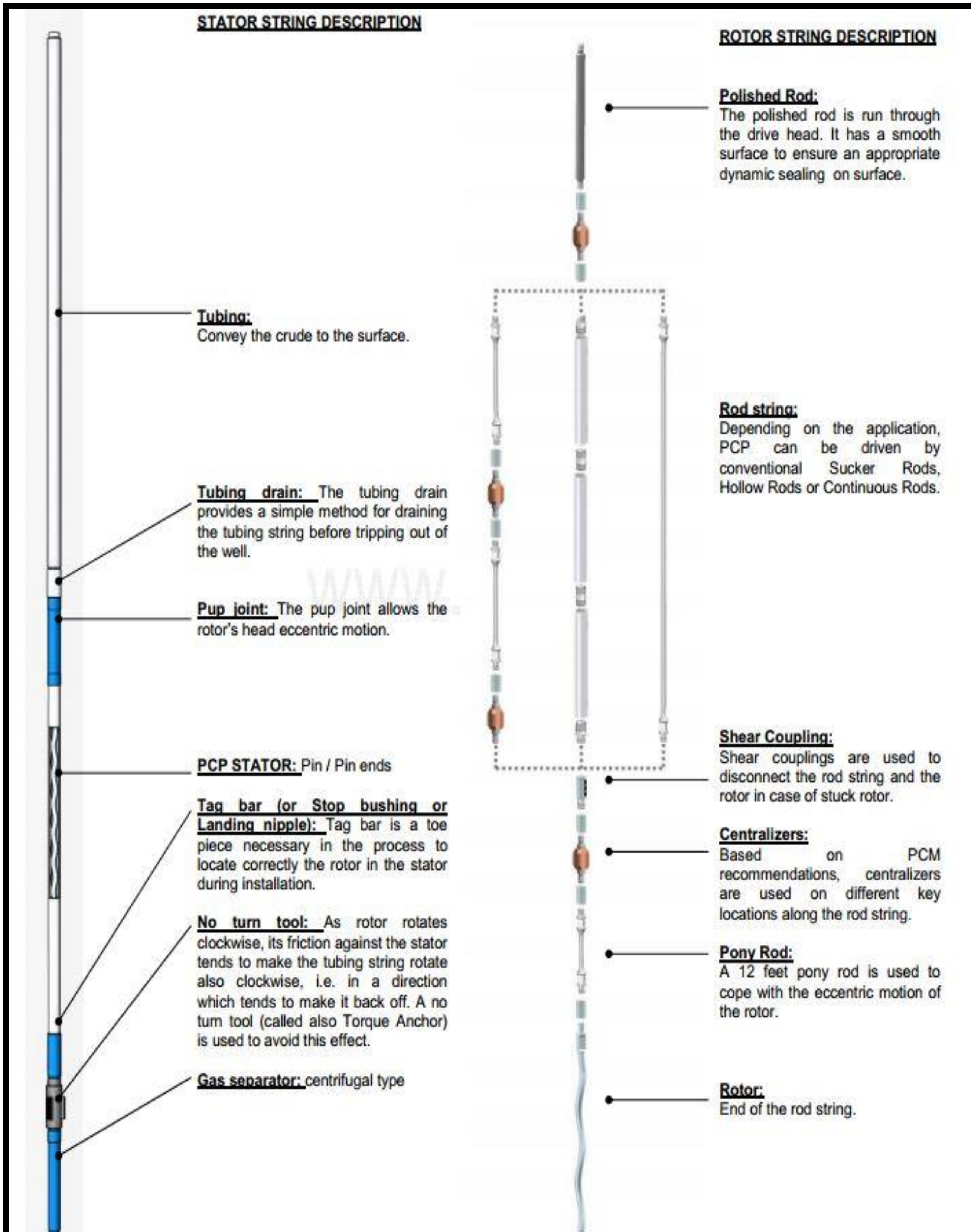


Figure 12: Stator & Rotor String Description

The stuffing box includes a seal to keep pressurized well fluids from escaping. Stuffing boxes for PC pump systems are specifically designed to seal against rotating polished rods. Stuffing boxes designed for reciprocating rod applications should not be used for PC pump systems unless they are qualified by the manufacturer for use with rotating rods or PC pump systems.

Below the stuffing box the pumping tee provides a flow connection to the production tubing. Special "composite" pumping tees for PC pump systems clamp on the polished rod to support the rod string and seal against the polished rod to isolate well fluids. This allows the stuffing box and surface drive to be serviced or removed safely without pulling the rod string. The stators for conventional PC pumps are run as part of the production tubing string. 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. Installation procedures include running the rotor to the tagbar and then spacing back to align the rotor into the stator. The rotor space-out is unique to the pump geometry, well operating conditions, and rod string configuration.

Tubing insertable systems are available in which the stator and rotor are run as one assembly with the rod string inside of the tubing. This simplifies running and retrieval, so insertable pumps are usually preferred over conventional pumps. The use of insertable pumps is limited by the tubing size.

Large systems may require a no-turn device to prevent the torque in the pump from loosening the tubing connections. Smaller systems with properly torqued tubing typically do not require no-turn devices although no-turn devices are often included as a precaution.

In general, selecting a progressing cavity pump system involves:

- ✓ Determining the pumping depth, flowline pressure and the desired well production rate
- ✓ Evaluating the API gravity and pumping characteristics of the formation fluid
- ✓ Checking pump speed guidelines against formation fluid abrasiveness
- ✓ Evaluating pump compatibility with any chemical additives to be used
- ✓ Determining the appropriate pump size and operating speed
- ✓ Determining the proper sucker rod size

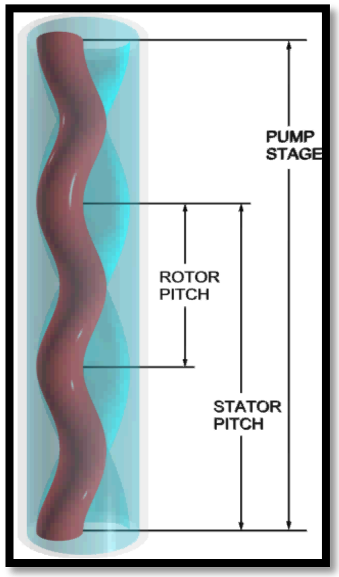
- ✓ Selecting the proper surface drive head
- ✓ Selecting the appropriate prime mover and drive system

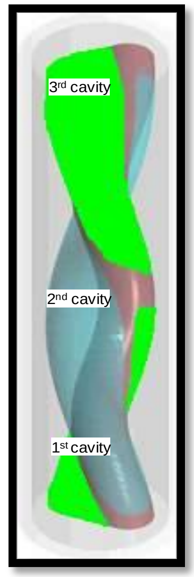
8.2. OPERATING PRINCIPLE

It is based on the principle of positive displacement, a cavity when exposed to the fluid gets filled and this trapped fluid is displaced positively from inlet end to the discharge end. Pumping is due to the sealed cavities, like a piston pump, and so has similar operational characteristics, such as being able to pump at extremely low rates, even to high pressure, revealing the effect to be purely positive displacement

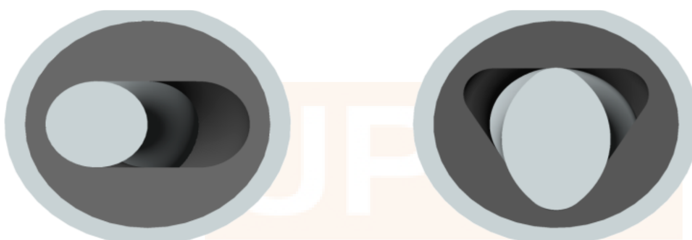
PC pumps consist of a rotor turning inside of a stator whereby the rotor is the only moving component. The rotor is helical and typically has a round cross section (single lobe). The stator cavity is double helical, but the stator pitch is twice the pitch of the rotor. The stator cavity cross-sectional 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.

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.

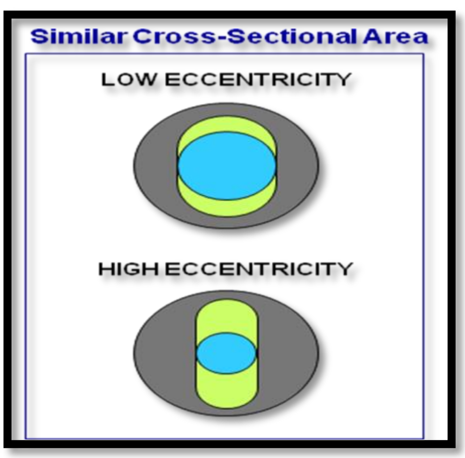


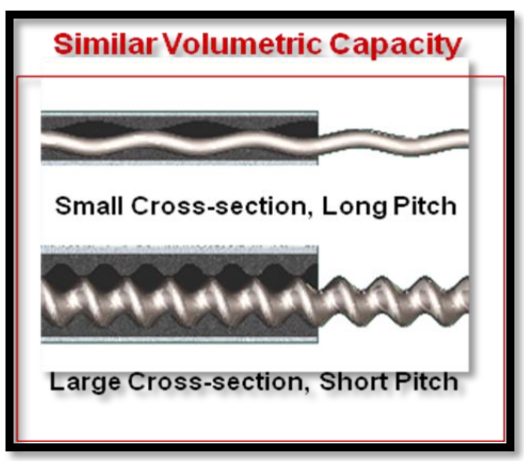


Single Lobe **Multi-lobe**



(Figures courtesy of Weatherford International)





8.3. <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.

PC pump systems are relatively tolerant of sand and particulate matter compared to most common lift technologies. 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.

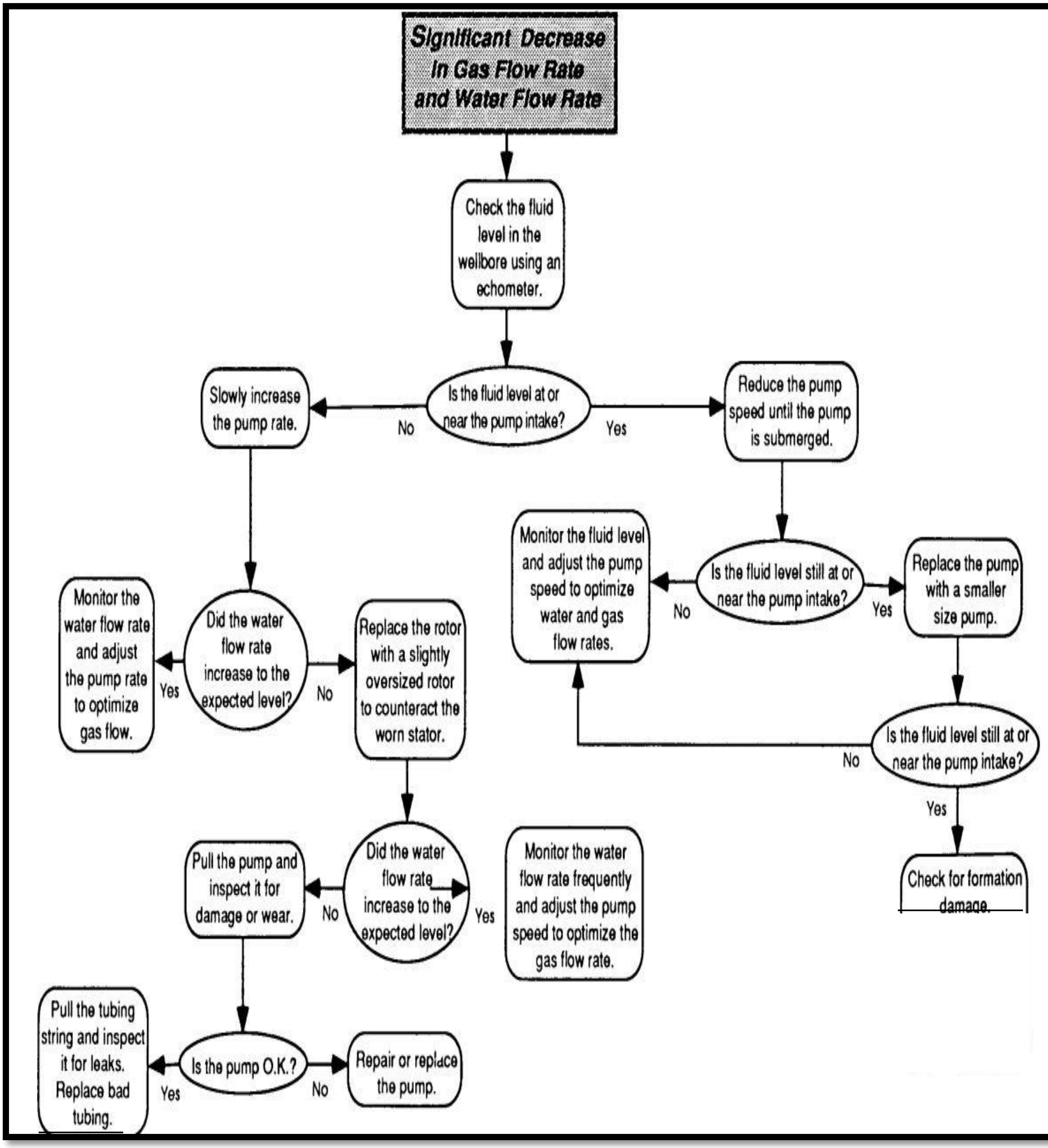
	Typical Range	Maximum
Operating depth TVD	1,000 to 4,500 ft	8,600 ft
Operating volume	5 to 2,500 BPD	5,000 BPD
Operating temperature	75° to 185°F	Over 300°F
Corrosion handling	Good to 185° F	Fair > 185° F
Gas tolerance	Limited for CO_2 and aromatic BETEX gasses	
Gas handling	Will not gas lock, high GLR reduces efficiency	
Solids handling	Excellent	

Table 4: Operating limits of PCP

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.

9. TROUBLESHOOTING THE PC PUMP



Problem observed	Possible cause	Reason	Activity	Preventive method to be followed
torque fluctuation	sand influx	High dewatering rate	Measure sand	Decrease RPM but not below 100.
	gas influx through tubing	Pump above perforations	Check for intermittent flow	use of gas anchor
			Measure gas form tubing	use tail pipe
	contact of sucker rod and tubing	Poor rod guide placement		proper rod stretch and Proper Placement of guides to be done
	problem in Engine		Check voltage	Reduce load by reducing RPM of pump.
high torque during startup	stator choked with sand	backflow of sand	Flush the well	
	elastomer swelling	water impact at higher temperature		change stator
High torque when running	sand influx	High dewatering rate	Measure sand	Reduce rpm but not below 100
	High differential head		Measure and water level	Reduce pump rpm but not below 100.
low torque and no water on surface	sucker rod snapped	high torque/pump choked with sand	Check for flow at surface and torque value also check for backflow of rotor when stopped.	limit torque capacity of motor from VFD
		rod thread washed out		do not exceed the makeup torque max value (770 n-m)
	sucker rod unscrew	reverse rotation of pump		breaking system should be effective
		loose make up		sucker rod should be make up at specified torque
	tubing puncture near the pump	wear due to contact of sucker rod and tubing	Tubing integrity test	proper rod stretch to be ensure
	tubing unscrew	Loose connection		tubing should be make up at specified torque
		NTT failure(due to history of torque fluctuations)		NTT Dye condition should be checked before installing
normal torque but no flow at surface	tubing puncture near the surface	wear due to contact of sucker rod and tubing	Tubing integrity test	proper rod stretch to be ensure
	pump failure	elastomer wear		change stator
		blistering due to gas		
intermittent flow	elastomer damaged	Gas influx causes blistering	Measure gas form tubing	change stator
	gas influx through tubing	Pump above perforations	Measure gas form tubing	use tail pipe
				use of gas anchor
Annulus pressure dropped	Tubing puncture	wear due to contact of sucker rod and tubing	Tubing integrity test	Proper Placement of guides to be done
	Pump failure	Damaged seal lines		Change the stator

10. OBSERVATIONS & RECOMMENDATIONS FOR AN OPTIMIZED COMPLETION PLAN

Following are some of the points discussed regarding the completion practices incorporated by reliance & how they can be optimized to save costs & time.

- **During Milling, TCR bit can be used directly instead of using the FMT (Flat mill tool) first and then the TCR bit.**
    - Usually the milling is done using FMT to mill through the 3 balls & baffles. Milling by FMT is faster as compared to TCR bit. But there are parts of the baffle plate that FMT cannot mill efficiently. So before running the scrapper, a trip using a TCR bit is used to mill the remaining portion of the baffle plate. So using the combination of FMT+TCR is time consuming wherein the trip-out time of FMT & trip in time of TCR adds to the extra time. Instead If we use Just the TCR bit to mill the ball & baffle, it will take more time to mill as compared to FMT but lesser time as compared to FMT+TCR.

Following is the comparison of (FMT+TCR) vs TCR. Effective milling times are compared for wells with analogous depths & position of Ball-Baffle.

Sr. No	Activity	Ball& Baffle Position	Ball O.D. inches	Baffle I.D. inches	FMT+TCR Combination Avg milling time(hrs)	TCR Avg Milling time
1.	R/I assembly upto top of first ball	-	--		2.3 hrs	2.3hrs
2.	Milling first ball & baffle	450 m	4	3.87	8.5hrs	12hrs
3.	Milling second ball & baffle	475m	3.75	3.5	7 hrs	9.7 hrs
4.	Milling third ball & baffle	500m	3.25	3.06	5.7hrs	7.8 hrs

5.	Trip out of FMT	-	-	-	3.5 hrs	-
6.	R/I with TCR assembly	-	-	-	2.3 hrs	-
7.	Milling of remaining portion of baffle(All 3) by TCR	-	-	-	2.5+1.5+1=5 hrs	-
8.	Total time taken	-	-	-	34.3 hrs	29.8 hrs

Table 5 – FMT+TCR vs TCR

From the above table, we can see that using just TCR bit can save us over 4 hrs of time, which is a lot considering the fact how costly the operations are.

Instead, latest milling tool from Baker Hughes like the Metal Muncher can also be used as it is highly effective & will save a lot of time. But then the economics of using a new tool is up to the company. The above comparative analysis was done as both the ways to mill were already being used on field. So I suggest that as Milling with TCR will be more time effective, it must be applies to all the wells.

- **Another way to save time while milling would include fishing out the first ball instead of milling it**.
    - A locally fabricated overshot tool is available with the service company, which can be used to fish out the top ball (4 inches). This will indeed save a lot of time as compared to milling it.
    - For fishing out the top ball, total time required is (considering the previous case, Running in with assembly= 2.3 hrs + Pull out with fish= 3.15 hrs, which gives a total of) 5.45 hrs.
    - Compared to milling, which requires 8.5 hrs on average, we can save around 3.05 hrs by fishing the top ball.
- **Another way to reduce milling time would be by increasing the weight on bit.**
    - A general practice on field here is to add 7 to 8 drill collars in Bottom hole assembly while milling of ball & baffle.

  - Adding more drill collars to the assembly would indeed reduce the milling time. But the question is how many more or maximum number of drill collars can be added to achieve an optimized drilling time. This can be done only by increasing the number of collars by 1 for every field & milling time must be noted.
  - However there is an operational constraint on the field that the hook load of the workover rig is 30 tons. i.e. by adding a max of 8 drill collars for a depth of 450m would mean that 3/4th of the hook load capacity is already reached. Therefore currently adding more than 8 DC is not possible. However in future, if a new workover rig is to be commissioned here, it must be made sure that the hook load is higher e.g. 50 tons.

- **Number of workovers to a single well can be minimized**. One way of doing it would be to directly install new & final pumps for completion. In the wells reviewed by me, following observations were made:
  1. Instead of installing a new pump, an old pump is installed
  2. First work over is done after a month of dewatering to retrieve the old pump and lower a kill string.
  3. After being shut for 1-3 years, final work over is done in the form of installing new pump for dewatering as final completion.
  - The reason for this current practice must be identified as so many work over operations on a single well site is not only time consuming, but a costly affair.
  - Following may be the probable reasons for such multiple workovers:
    1. **<u>Operational Constraint</u>**: Depending on the management decisions & financials, it is possible that the team must have been told to use limited number of pumps for the whole field & use it on rotational basis.
    2. **<u>Non availability of New Pumps</u>**: There could be a case wherein due to supply & logistics problems existing, the company may be compelled to use limited number of pumps.
    3. **<u>Performance Issue</u>**: If the reason for using old pumps is that, the team is unsure of the performance of the well that there may be high quantity of sand or gas that may damage the new pumps then such an issue can be rectified. Being unsure of the Well behavior can be the case, when completing & monitoring the first 20-30 wells in that area. But after completing over 100 wells, a general trend of the performance of wells

can be chalked down and further help can be taken from the studies carried out during the exploration phase.

- **Reasons for sand column being over 100 metres must be identified**:
  - In the reviewed wells, it has been observed that sand columns as high as 80 m, 100m or even 180m in one case have been tagged. Sand column of 30 metres on average is observed over every ball and baffle. Such sand columns not only engage extra time for sand cleaning but also damage the pump or tubing making it difficult to carry out an optimized operation.
  - Firstly it is instrumental to analyze whether the sand in the well bore is the formation sand or the injected proppant. There has been a conclusive proof that the sand in the well bore is actually the injected proppant.
  - Secondly we have to analyze the reasons for proppant flowback in the wellbore in such a high amount. The probable reasons for this may be
    1. **Inefficient Hydraulic Fracturing job**: it is possible that many times the HF job may have led to an early screenout leading to such high flowback, the gel strength may not be high enough to place the proppant inside the formation & gel break must have happened in the wellbore itself giving a high sand column, also during pumping the fluids instead of gradually ramping the slurry stages, sudden change in stages is practiced here. So it would be prudent & timely step to consider re designing the frac job done here to properly analyse the characteristics & in situ stresses of the coal seams by taking into consideration the post frac job reports & many such parameters helping to find the reason for high proppant flow back or early screenouts. Also the frac jobs must be evaluated by methods like micro-seismic technique or tiltmeter.
    2. **Setting the right RPM during initial dewatering**: Many a times, not setting an optimized RPM may lead to higher rate of dewatering which may result in the proppant flowing back to the wellbore along with formation water. So it is important to set the RPM to an optimized minimum depending on the flow rate of water required to flow back but within the limits such that the proppant may not flow back.

- **Consider adding tail pipes below the NTT (No turn tool) such that the PID (pump intake depth) is below the bottom most producing coal seam.**
    - Currently, the on field practice for lowering the new kudu 76k900 pumps(Final completion pumps) is that the pump is lowered to about 40 metres above the top of perforation(top seam) & consequently pump is lowered below the seams depending on the water level in the wellbore i.e. there will be multiple workovers on the same well for lowering the pump. More workovers means more time and more costs. One of the disadvantages of such a practice (no tail pipe) is that the gas will enter the pump, swell the elastomer, due to this the frictional torque will increase leading to pump failure. Even though such cases have been reported in the past, Reliance did not prefer the tail pipes. It is important to know the thought process behind such a step. Only logical conclusion to such a step would be that they are very sure that gas if entering the pump enters at a very slow rate in small quantities & that it doesn't cause elastomer swelling to a great extent. But that would be a very optimistic assumption if considered.
    - Although previously i.e. initial completion with 300TP pumps, tail pipes were added. That means no added workovers, once the pump is lowered. But this practice was recently discontinued. A reasonable explanation for doing so would be that the proppant column built over a time is so high that would clog the tail pipe completely. Hence rate of dewatering would reduce & also the pump would be stuck leading to snapping of tubing or sucker rods at the weakest joints leading to extra costs. I feel instead of discontinuing adding tail pipes and spending more on multiple workovers for lowering pumps, the real reason or the root cause must be identified. In this case, it is quite evident that the root cause is the rising proppant column which the company has conveniently ignored. As previously discussed, causes for high proppant column must be identified & the problem must be rectified for an optimized well completion & production.
- **What is the ideal pump setting depth?**
    - Well there can never be an ideal pump setting depth due to many reasons like gas or sand production or reservoir heterogeneity. But in absence of such problems the most favourable pump setting depth would be below the bottom most producing seam.

CONCLUSION:

Working & learning for two months on field in Reliance's Sohapur block was indeed a fruitful experience. I learned the various nuances of field life at the same time got in depth knowledge on field operations including Air Drilling, Completion operations, PCP working, workover operations from field professionals. I got to know the various well problems associated with air drilling & hoe to mitigate them. Working closely with the service company helped me gain valuable technical insights on performing field operations. At the Same time, spending time in an operator company like Reliance helped me understand the management aspect of running operations in a field.

As I was a trainee in reliance, I got the opportunity to interact & discuss field problems with their multidisciplinary team involving geologists, mud engineers, production engineers etc.

My project was to recognize the reasons for nonproductive time leading to heavy rig time losses both during drilling & completion Operations. In the report I have made a conscious effort to recognize the major causes of nonproductive time & have recommended some preventive measures & alternate solutions to save time & costs. Through the optimized completion plan, I have suggested some time saving methods of carrying out operations & have tried to make the overall well completion Strategies here at reliance cost effective.

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