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Middle East Artificial Lift Forum

ESP Analysis and Optimization by Operational Trends

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Abstract

Artificial Lifting Technology plays crucial role in PDO Oil Operations. Company's total production is attributed to these innovative techniques. ESP's presently contribute 38 % of total Artificial Lift Installations.

PDO is exercising ESP Operating data trend analysis through its network system. It enables real time monitoring, control, and design of ESP's thereby optimizing, Safety and environment protection, Operating Cost, Production Rates, Capital Cost, Preventable Failures, Personal Effectiveness and Minimizes Losses.

The data network provides several data values which are trended over time through various plots as, ESP Electrical Data (Current, Voltage, Frequency etc.) & ESP Operating data as (Water Cut, Gross Production Rate, Net Production Rate, Tubing Pressure, Down hole Pressure and Tubing Temperature). The data trend plots are used to show Well level and System level variable vs. Time.
The prime parameters deducted for Well analysis are Gradient Traverse plots utilized for monitoring well & inflow performance, which changes with the time, whereas, all remaining relevant variables stay constant (as well completion, Fluid Properties data and Pump System). Any abnormal down hole behavior can be detected and route cause of well system upset is rectified. The production Optimization is attained by ensuring that the well system continues to run in desirable/optimal operating conditions.

This paper discusses the well design, well inflow and outflow behavior analyzed simultaneously (the intersection point of both of these curves precisely defines the well operating point). The comprehensive usage of these data sets help in understanding the pump operating behavior. The diagnosis based on all such concepts enables right / real time decision to sustain ESP at optimum range, leading to enhancing ESP run life. The continued practice of this concept has resulted in +2000 m3/d gains in production, enhancing ESP Run Life by 6% and saving $ 0.5 million, in one year, in one of its concession areas.

Introduction

PDO ESP network system (operated by custom built Shell software, "Field Ware") enables real-time monitoring, control, optimization and design of electrical submersible pumps. This is achieved by installing commodity transmitters at the wellhead and sometime down hole. Transmitter signals are routed back to the computer and processed to quickly flag pump problems and to monitor pump performance (Fig-1)

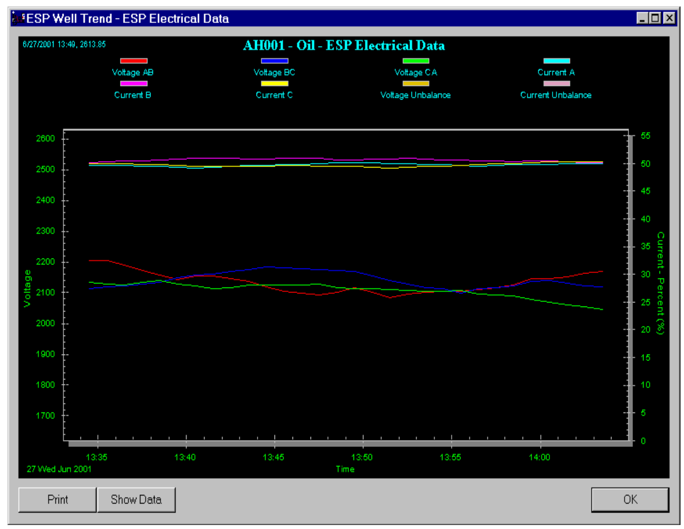


Fig-1

The System simultaneously enables the real-time detection of low and off production and flow instabilities for all well types. Transmitter signals are routed back to the software that converts the signals to oil, water and gas flows, which are trended to show the well producing pattern. The ultimate effect is to flag low and off production, allowing operators to take immediate corrective action. This can enable production enhancement due to proactive remedial measures and increased pump life, caused by improved surveillance. (Fig-2)

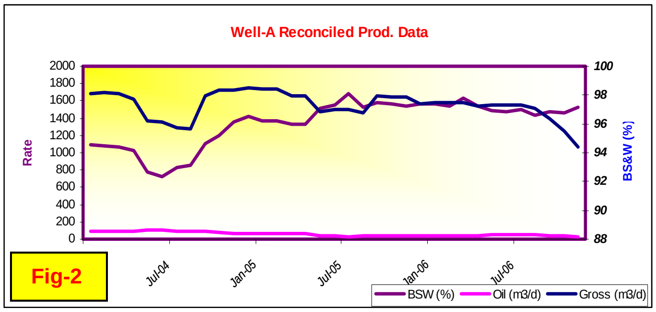


Fig-2

Gradient Traverse Plots are used for data validation and ESP system diagnosis. The data, as primarily rendered by down hole sensor, like pressure, temperature and amps, in conjunction with all aspects of well design (well inflow, fluid properties, completion design, desired rates & cost etc) form the basis of these plots. The technique utilizes the Gradient Traverse Plot to present the well bore pressure and depth data in a typical format, to help identify the feature controlling the well behavior. Two elements, the well inflow performance and fluid dynamics, primarily define the shape of any Gradient Traverse Plot. The concept is applied to the multi step process, to validate ESP performance, well and reservoir data. (Fig-3)

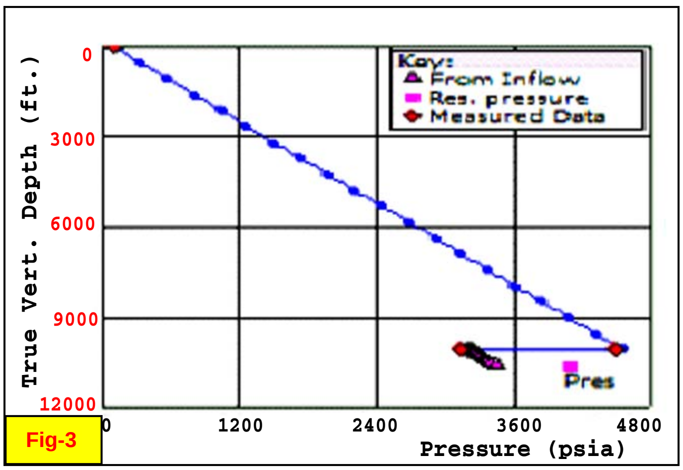


Fig-3

Well Operating Trends & Analysis

Trends consist of a set of plots, based on time series data. The information collected by the network system and portrayed on the host PC. The data items comprise ESP Electrical & Operating data as, Wellhead Pressure (TWHP), Production Rate (Rate), Down hole Fluid Level (FL), Pump Intake pressure (PIP), Pump Discharge Pressure (PDP) & ESP Operating Current (A) etc. The performance of a well can be monitored vs. time. If the values are constant, it's stable. And if FL & PIP values are gradually increasing, A & PDP are dropping, this may be normal pump wear or Pump intake blockade, and if drop rapidly, this may be an indication of problem (Pump shaft ruptured etc.). Similarly gradual motor temperature rise associated with rapid drop in TWHP & constant level of Amperage & PDP, is an indication of tubing leak (for summary refer Table-1)

The performance of various wells in the same field & completed in same reservoir, can be compared with each other to help identify those, requiring attention. It may be reasonable to assume that the artificial lift performance of similar wells in an oil field should exhibit similar performance. If some wells are clearly out performing, this may be an indication of opportunity for the wells underperforming, and significant gains can be realized.

Case Histories

Well-B (ESP Worn Out)

This well was originally completed as horizontal ESP producer in Feb-1999, wherein ESP was resized in Aug-2001. Well kept operating smoothly, until Dec, 2005, having its Run life of 1593 days, whereat Gross Production rate was reported dropped to 900 m3/d from 1800 m3/d.

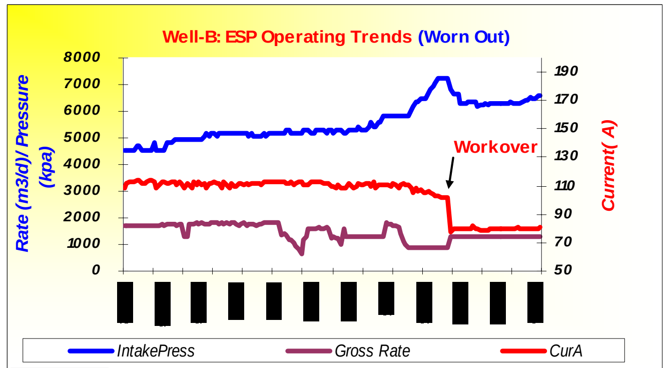


Fig-4

An ESP operating trend analysis, over its run life, was cried out, which indicated:

TWH: Dropped by 50%

Operating Current: Dropped by 5%

Shut-Off Head: dropped 10%.

It was interpreted as pump worn out, due to its prolonged run life. Well was worked over in Jan/06, ESP was replaced and it resulted in 68% increase in the Gross Production rate, whereas net oil production was almost doubled.

Well-C (Pump Intake Blocked)

This well was completed in March-1995 as horizontal ESP Producer. In May 2000, the well was sidetracked, ESP operated for 1533 days at time of analysis. The ESP was pulled out pre-emptively. On pulling out, pump intake was found intensely blocked by produced sand.

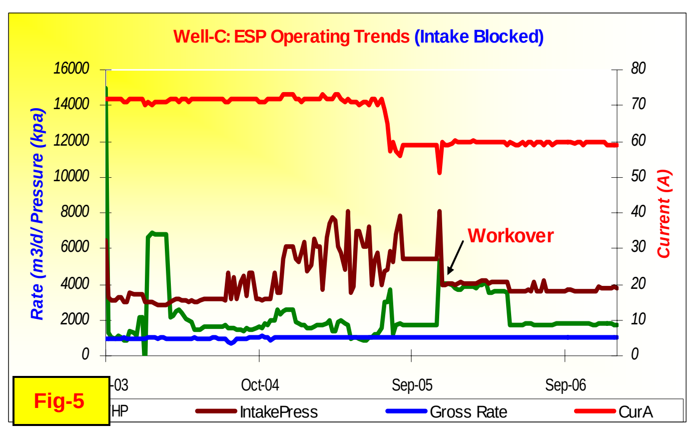


Fig-5

The well was initially producing Gross Rate: 925 m3/d, which dropped to 673 m3/d (-27%), over its Run life. The pump kept running normally by Nov.04, whereat it started cutting sand to 60 gm/m3 and PIP was recorded fluctuating vigorously, Amps exhibit slightly dropping trend, until it was worked over. On studying the well history, it was found that the ESP was landed at a High Dog Leg Severity Point (3^{O}-12^{O}) and the bottom completion zone had unconsolidated sand, completed without any sand control device. In a subsequent work over the bottom zone was plugged off, the pump was replaced and landed at a higher level. The well revived its production potential by +58% and runs smoothly.

The Gradient Traverse Plot

The Gradient Traverse plot is an approach applied to analyze the ESP System by its design parameters, performance monitoring and failure analysis. All these three features are closely inter-related to draw a broader picture of any such System. The Design data (well inflow, fluid properties, completion design & desired rate etc.) can help to understand a typical operating environment of an ESP System. The same technique can be further propagated to validate the well & reservoir data to help design the ESP custom fit to well parameters.

Traditionally, the Amp. Chart and Fluid Level are the key tools, applied indirectly, to figure out Motor Load and Pump Intake Pressure of any ESP System. The recent development of Digital Down Hole Gauges has facilitated the direct measurement of these, as well as, much more operating features. To understand any ESP System, one of these parameters (as summarized in table-2), is needed to be picked up, that functions comparatively more sensitively in responding to any changes in the operating conditions. Any ESP installed in well corresponds to an integral well system. The well bore inflow is exclusively a well characteristic, whereas, the out flow is characterized as Pump properties, the point whereat both these curves intersect, defines the well operating point.

The well behavior resulting from any change in operating parameter can be best defined by the changes in its well bore pressure gradient plot.

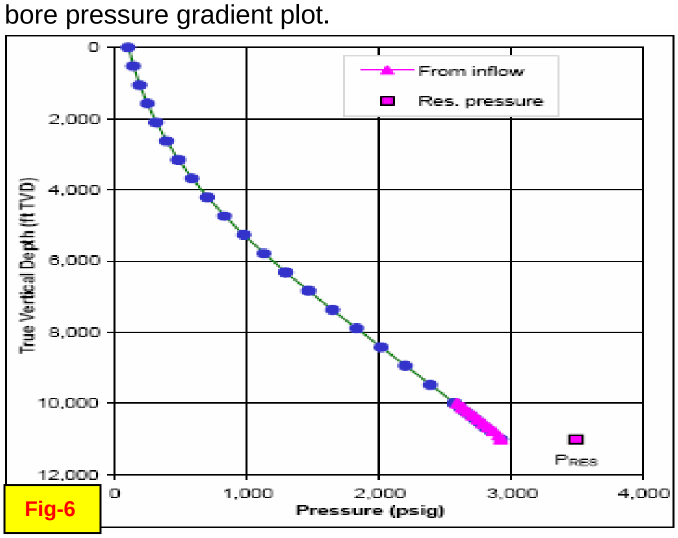


Fig-6

Fig-6 demonstrates a well Operating at the parameters:
Rate: 1700 bpd, SBHP: 3500 psi, WHP: 100 psi. BS&W: 0%
The curve is observed to be fairly straight below 6000 ft.

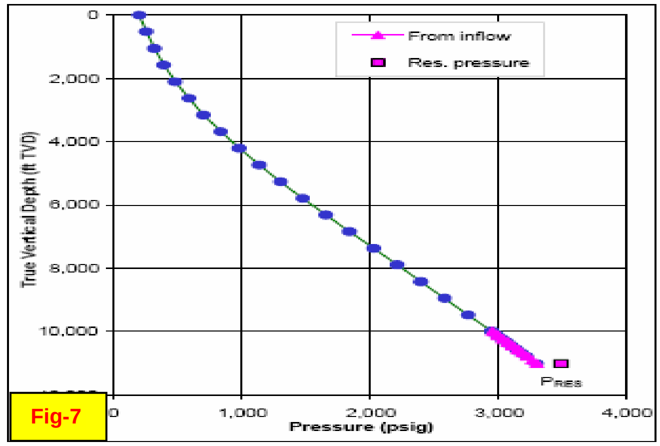


Fig-7

The WHP is changed to 200 psi, in Fig-7, the production is reduced to 565 bpd, and the gradient line has shifted to right. The BHP is increased resulting in lesser drawdown and smaller pump intake.

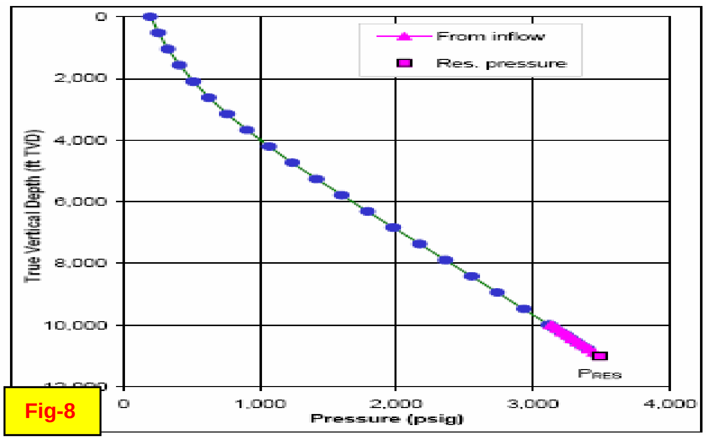


Fig-8

Fig-8 displays the gradient traverse plot of the same well, but BS& W increased to 12 %. The Static BHP is almost equivalent to hydrostatic pressure of the fluid column, drawdown is nil, and well will not flow.

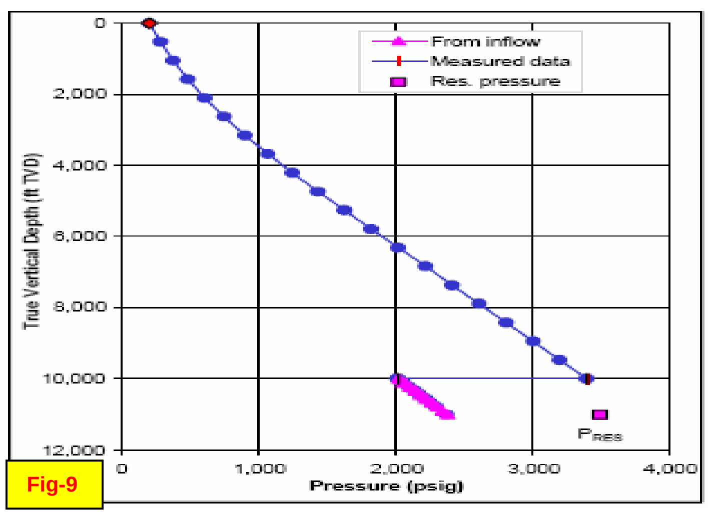


Fig-9

Fig-9 is the same well, but producing with the ESP. The well having heavier fluid column (12 % W.C) now can produce to surface, because of the drawdown induced by the ESP. The production rate is increased to 3300 bpd. The Head generated by the ESP causes PIP to be reduced. The line indicating the flow below pump level is shifted to the left, causing comparatively lower FBHP, and making the well to flow at considerably higher rate. The ESP Sucks, rather than it pushes. The feature controlling the well behavior can thus be profoundly illustrated by Gradient Traverse Plots.
Since the flow in well bore is caused by the pressure effects, the most sensitive parameters, which respond to any changes down hole are (i)-Pump Discharge Pressure & (ii) - Pump Intake pressure. The Shape of Gradient Traverse Plot of an ESP operated well is primarily defined by these two prime features.

ESP Analysis /Data Validation

The ESP operation performance can be best analyzed by using Gradient Travers Plot in conjunction with its operating parameters as:

- Pressure, Pump Intake/Discharge
- Temperature, Pump Intake and Motor
- Amps and well bore flow
-

The analysis process starts at wellhead top proceeding downwards as:

- Work out FBHP at Pump Discharge Level, by Gradient plot.
- Match Calculated vs. measured Pump Discharge Pressure.
- Match Pressure Drop across Pump, results in Pump Intake Pressure
- Work out Flowing Bottom Hole Pressure
- Match calculated FBHP with Well inflow data.
-

Above Pump: The measured (known data) shall be WHP & PDP, which corresponds to Starting and End point of curve above pump. The fluid density and tubing friction losses govern the slope of curve. The production data collected by another system (Eprom etc.) can be matched with measured WHP & PDP to determine water cut, GOR, frictional losses and fluid gradient at Pump Discharge head, and Fluid Properties Data (PVT) is possible to validate.

Across Pump: On the same principal, the known parameters across the pump are PIP & PDP. The pressure differential generated by pump is the direct function of Frequency, Flow, and no. of pump stages, fluid gradient and pump efficiency. Frequency and Flow are normally known. The pressure differential across pump can be converted to Head and plotted on the Pump Curve. In case it aligns with the Pump Curve, the data is validated. But in case of its misalignment, the parameters directly related in generating pump head shall be looked into as: frequency, flow, no. of stages (i.e. broken pump shaft), viscosity of emulsion effects.

Below Pump: The PVT data is since already validated above pump, it shall be simple to model the flow profile from Pump intake to the reservoir top and calculate Flowing Bottom Hole Pressure. This can be matched with the Well inflow performance data to validate PI.
The data summarized in table-3 can thus be derived from Gradient Traverse Plot and validated. This information can then be confidently utilized for well performance prediction, production optimization etc.

Case Histories

Well D- Failure Prevention

The ESP in Well-D failed merely two hours after installation due to low reservoir influx.Fig-10 indicates a typical Trend Plot. Well is installed with a VSD.

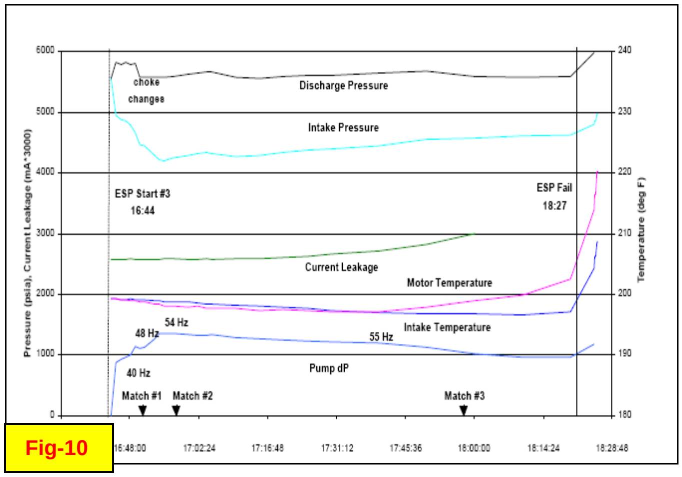


Fig-10

Pump intake pressure started dropping immediately after start up. Later well stream was choked at surface, resulting increase in pump discharge pressure. Increasing Frequency (48-54 HZ) reduced the Pump intake pressure, causing higher drawdown at well bore and normally it shall increase flow rate at Pump Intake. Whereat, the decline in PIP is not due to increasing flow in this case, but due to low reservoir inflow. The frequency is further increased to 55 HZ at 17:40 hrs, the PIP continues to decline and motor temperature starts rising rapidly. The ESP eventually failed due to motor overheating.

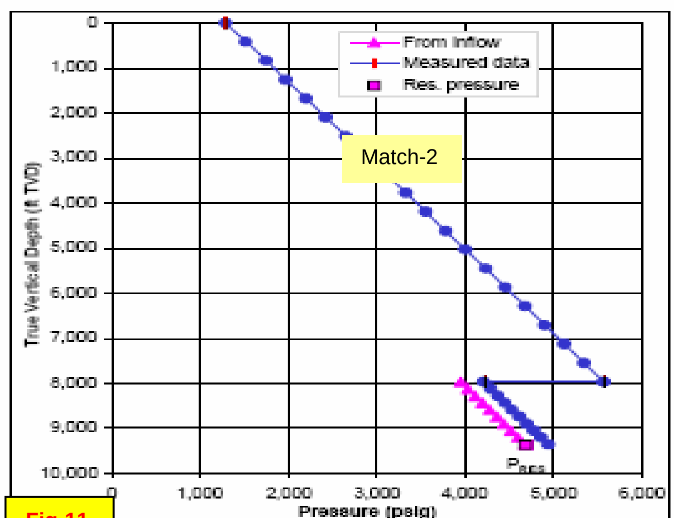


Fig-11

Fig-11 shows the Gradient Traverse Plot drawn at point-2 of Trend Plot (Fig-10). Even though the reservoir pressure is 150 # higher than well bore pressure, the well won't flow. This is indicated by the Pump Head Curve (Fig-12); the well is at "NO Flow" state. All the parameters are yet normal (pump undamaged at this stage); the Head generated by pump conforms to the Head Curve.

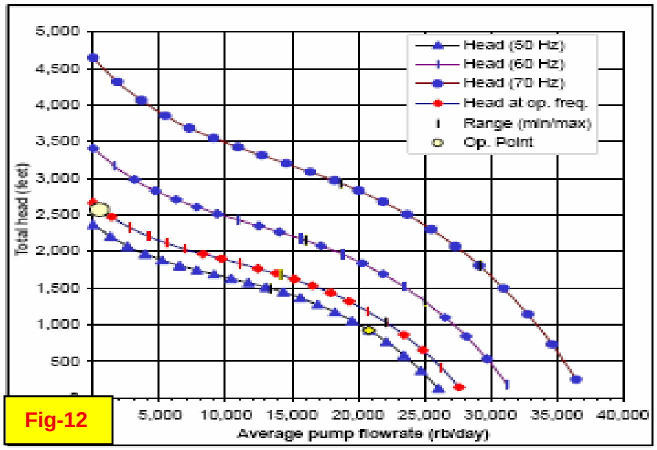


Fig-12

To make the well flow, it needs further higher draw down or drop in Pump Intake Pressure. It could be achieved either by reducing the wellhead pressure (by 200 #) or by increasing the frequency to 58 HZ) and pump could be saved, whereat neither of these actions were taken.

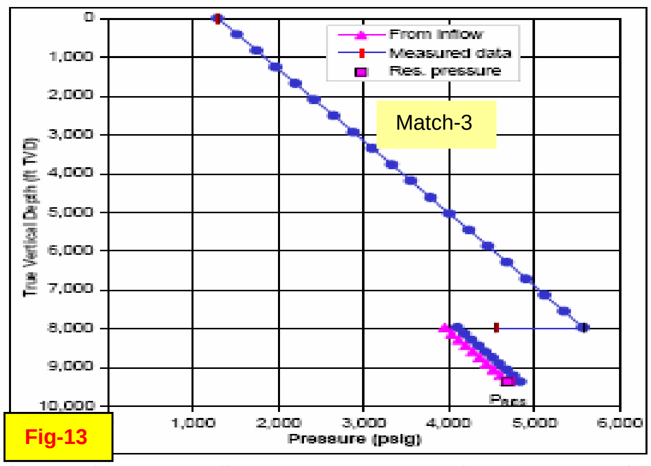


Fig-13

Fig-13 shows Gradient Traverse Plot drawn at Match-3 of Trend Plot (Fig-10), wherein the frequency is increased to 55 Hz. The Pump head has decreased (Refer Fig-14), and no longer conforms to anticipated head curve.

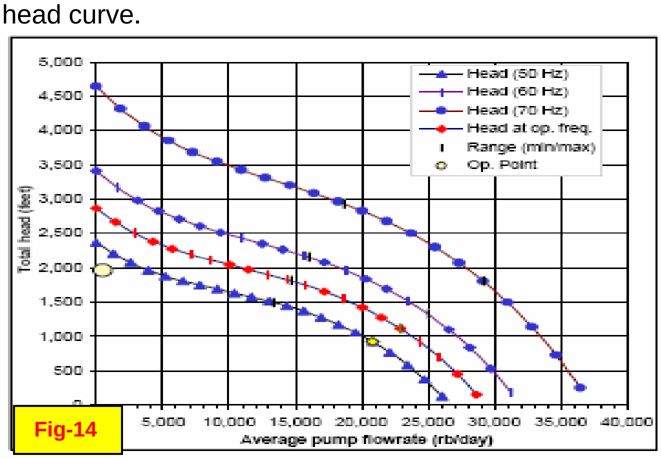


Fig-14

This is an indication of pump damage (impellers and diffusers). The ESP could run further 30 min. before it failed. The well had not enough reservoir drawdown at any point of its run time to make it flow, which proved to be a fundamental reason of failure. This analysis was conducted post failure. Had both these tools (Trend and Gradient Traverse Plot) available at Live Pump State, the failure could be avoided.

Well-E
ESP Failure Analysis & Data Validation

The ESP in this well was installed/ started on Jan, 4, 2005. The ESP failed after 6 days due to gas locking and oversized Pump design.

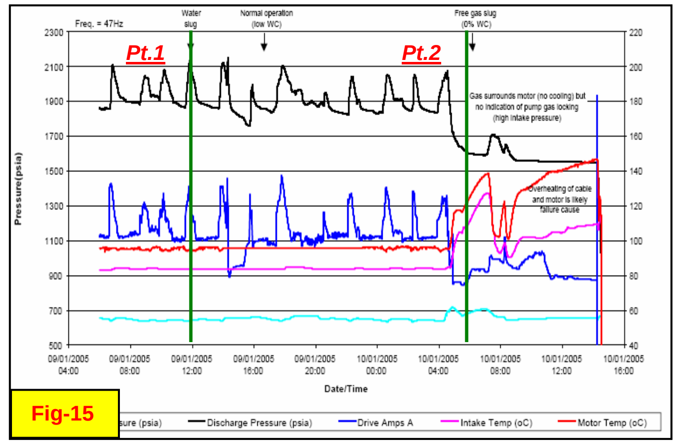
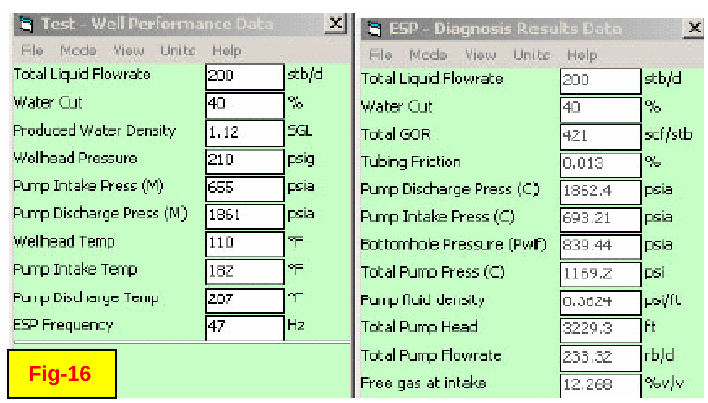


Fig-15

Fig-15, illustrates the last 2 days of ESP run life. Pump runs normal, but cyclic water slugging in the well stream is observed every 2 hours during the run time. On 10th Jan, 04:30 hours (Pt.2), significant change in well behavior is realized, the PDP and Amps drop rapidly, an alarming indication of reduction in fluid density (Gas Slugs appearing in well stream). Well data indicates rise in GOR. The gas is evolved in the annulus due to drop in annulus pressure. Immediately afterwards, the Motor and Pump Intake Temperature starts rising (due to reduced fluid velocity pass motor, possibly because of Gas accumulation in the annulus/motor vicinity).The cable and/or motor failed due to overheating and loss of winding/cable insulation.



Test - Well Performance Data

Total Liquid Flowrate	200	stb/d
Water Cut	40	%
Produced Water Density	1.12	SGL
Welhead Pressure	210	psig
Pump Intake Press (M)	655	psia
Pump Discharge Press (M)	1861	psia
Wellhead Temp	110	°F
Pump Intake Temp	182	°F
Pump Discharge Temp	207	°F
ESP Frequency	47	Hz

ESP - Diagnosis Results Data

Total Liquid Flowrate	200	stb/d
Water Cut	40	%
Total GOR	421	scf/stb
Tubing Friction	0.013	%
Pump Discharge Press (C)	1862.4	psia
Pump Intake Press (C)	693.21	psia
Bottomhole Pressure (Pwf)	839.44	psia
Total Pump Press (C)	1169.2	psi
Pump fluid density	0.3624	psi/ft
Total Pump Head	3229.3	ft
Total Pump Flowrate	233.32	rb/d
Free gas at intake	12.268	%v/v

Fig-16

Fig-16, indicates, analysis of data collected at Pt.1 (Fig-15) the well performance data validation is carried out by the diagnosis data which confirms PDP, WHP and BS&W match each other.

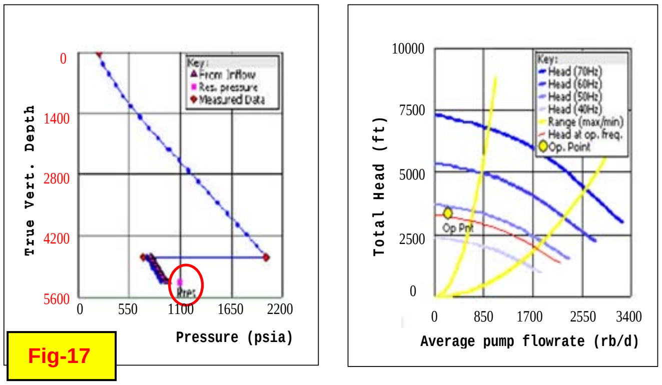


Fig-17

Fig-17 indicates that the pump operation aligns with the Head Curve, which validates Flow rate and density data. Pump operates down thrust. The inflow is modeled using Vogel correlation, and PI is calculated: 0.7 bpd/psi, whereas, the PI: 5.0 bpd/psi is initially considered in ESP Design data. The Pump is continuously running down thrust, due to lower than anticipated PI figure.

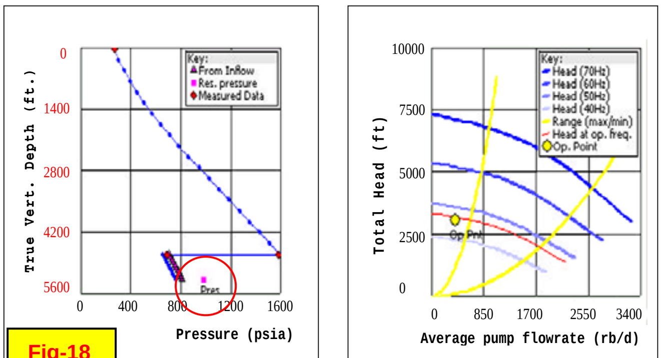


Fig-18

Fig-18 Shows data collected at Pt.2 (Fig-15), the data is validated, but well bore pressure is less than Reservoir pressure, which is an indication of gas accumulation in the annulus. The pump eventually was gas locked and failed due to overheating.

Size of the Prize

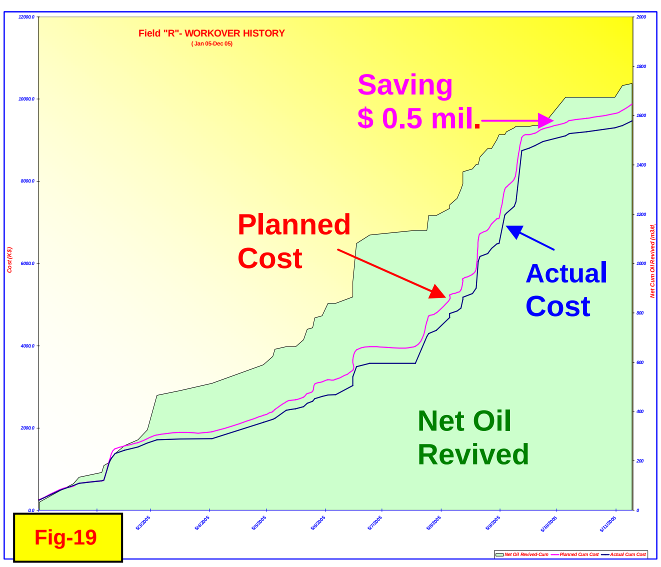


Fig-19

During Calendar year, 2005, 76 wells were worked over in Field "R", wherein ESP history was analyzed using this technique. The reinstallations were carried out in this perspective of lessons learnt. Total 1952 m3/d Net Oil could be revived, with 100 m3/d gain as part of optimization & saving of $ 0.5 min was attained, as a result of this concept (Fig-19).

Fig-20 Illustrates ESP run life gain from year 2002-2006 in same field "R". ESP run life is improved from 675 days in 2002 to 914 days in 2005, a 7% rise in run life per annum.

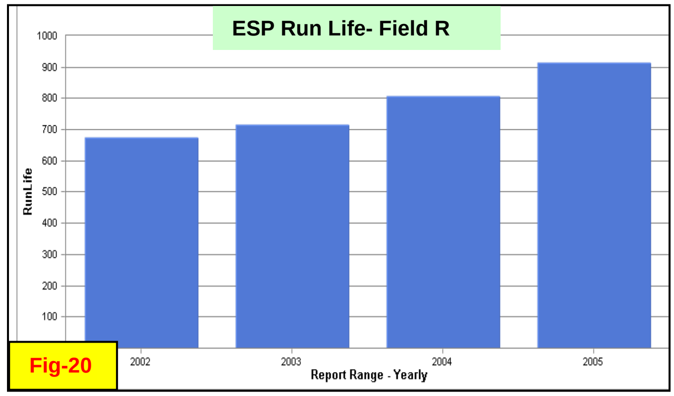


Fig-20

Conclusion

A tailor made ESP sizing can be attained by aligning the ESP performance and the well bore characteristics. Historic ESP operating trends can yield the guidelines for improved pump operation and design in future. The Trends Plot when studied in conjunction with Gradient Traverse Plots can help in health check of design data, as well as ESP analysis. The reward is an outcome of a customized ESP Sizing. Pre-emptive measures are intensely important to keep the pump running, saving heavy work over cost and extensive loss of production. ESP Operating Trend analysis tool can render this vision. ESP Diagnosis and Well Data validation has always been a tricky business, which can be reasonably carried out by such process.

References:

1- "Field View" Operating Manual
2- PDO-Case Histories
3- "PSI" Operating Manual
4- Reda Service Manual
5- Kermit Brown: Tech. of Artificial Lifting
6- Demystifying ESP's, by A.J. Williams

Table-1

ESP Data Trends
Symptoms and Diagnosis

Symptoms	Diagnosis
Pump Op. Current Drops	**Pump Worn Out**
PIP Increases	
Dyn. Fluid Level Rises	
Measured Shut Off Head reduced	
FTWP dropped	
Pump Op. Current Drops	**Pump Intake Blocked**
Well Flow Rate Dropped extensively	
PIP Increased	
Dyn. Fluid Level Rises Gradually	
Measured Shut Off Head Normal	
FTWP Dropped	
Pump Op. Current Drops	**Tubing Leak**
Well Flow Rate Dropped extensively	
PIP Increased	
Dyn. Fluid Level Rises Gradually	
Motor Temperature rises abruptly	
FTWP Dropped	
Measured Shut Off Head Normal	
Pump Op. Current Drops	**Well Pumped Off**
Well Flow Rate Dropped extensively	
PIP decreased	
Dyn. Fluid Level drops Gradually,	
Motor Temperature rises gradually	
FTWP Dropped	
Measured Shut Off Head Normal	
Pump Op. Current Drops	**Pump Gas Locked**
Well Flow Rate Dropped extensively	
PIP fluctuates with gaseous intake condition.	
Dyn. Fluid Level Rises Gradually, equals Static Fluid Level at longer run	
Motor Temperature rises gradually	
FTWP Dropped	
Measured Shut Off Head Abnormal	
Pump Op. Current Drops	**Broken Pump Shaft**
Little or no Flow at surface	
PIP Increases suddenly	
Dyn. Fluid Level Rises suddenly, equals Static Fluid Level	
Motor Temperature rises suddenly	
FTWP Dropped suddenly	
Measured Shut Off Head highly Abnormal	
Pump Op. Current increases	**Obstruction in Flow line**
PIP increases	
Dyn. Fluid Level Rises	
Motor Temperature rises suddenly	
FTWP Dropped suddenly	
Measured Shut Off Head normal	
FTWP increase suddenly	

Table-2

ESP Data Analysis

Surface Parameters		Sub Surface Parameters	
Abbrev.	**Name**	**Abbrev.**	**Name**
WHP	Wellhead Pressure	**PDP**	Pump Discharge Pressure
WHT	Wellhead Temperature	**PIP**	Pump Intake Pressure
-	Choke Setting	**PIT**	Pump Intake Temperature
Gross	Total Flow Rate	**PDT**	Pump Discharge Temperature
Net	Net oil Rate	**MOT**	Motor Oil Temperature
-	Gas Rate	**MWT**	Motor Windings Temperature
-	Water Rate	**-**	Vibrations
GOR	Gas Oil Ratio	**-**	Current leakage
-	Fluid Density	**Gross**	Total Flow Rate
HZ	Frequency		
A	Amps		
V	Volts		

Table-3
Data Validation Scenarios

Above Pump	Across Pump	Below Pump
PVT	Flow Rate	FBHP- Flowing Bottom Hole Pressure
Water Cut	Frequency	PI-Productivity Index-
Fluid Sp. Gr.at Pump Discharge	No. of Pump Stages	
Tubing GOR	Viscosity and Emulsion Effects	
Friction Effect	Fluid Sp. Gravity at Pump Intake	
	Free Gas % age at Pump Intake	
	Operating Point at Pump Curve	