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START UP SIMULATION AS A NEW TROUBLESHOOTING TOOL FOR ESP LIFTED WELLS

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Abstract

Standard electrical submersible pump's (ESP) troubleshooting is based on anmeter charts patterns. One of those typical patterns is the trace associated with the automatic restart sequences performed by the variable speed driver (VSD) due to under and over load protection. The problem becomes more complex to diagnose when the shut down time is unpredictable and no typical pattern matches with the field chart, besides nodal analysis cannot be applied because the steady state is far beyond to be reached. Since no standard troubleshooting tool is suitable for this case then a new approach based on transient acoustic levels is proposed. These transient levels must be compared with the theoretical levels obtained numerically as solutions of the dynamic balance equations. In this way a better match of the well can be performed. The new approach was applied in "La Concepción Field" in western Venezuela to diagnose two problematic wells, where standard analysis tools were useless and considerable production was deferred due to unpredictable behavior. Field's results showed that the new approach is a good complement to the standard ESP troubleshooting because additional information can be obtained making easier the diagnosis process.

1. Introduction

The basic tool for ESP troubleshooting is the anmeter chart. Field engineers analyze this chart, they read amperage magnitudes but the most important information in the chart is the pattern's shape. Normal and many abnormal operational conditions can be identified just looking and recognizing the patterns. One of those typical patterns is the trace associated with the automatic restart sequences performed by the variable speed driver (VSD) due to under and over load protection. However, troubleshooting can be a difficult task if no typical pattern matches with the field char or the failure is not regular, for example the well can run 10 days and fail, or just few hours. With this erratic behavior the operator can not stay at the well in to wait for a failure and check the VSD and operating conditions in that instant.

Even assuming that it was possible to identify the problem, the inflow performance relationship (IPR) is required to establish the new operational parameters or to design and install a new completion. The unstable rate does not allow calculating accurately the productivity index, which defines, along with the reservoir pressure, the IPR curve. It is important to keep in mind that nodal analysis cannot be applied because the steady state is far beyond to be reached.

It is clear that only two processes can be analyzed: Starting1,2 up or shutting down the ESP. Considering that the shut down event is unpredictable, then the only way to analyze the ESP is during the restart process. To accomplish this objective it is convenient to set the VSD in manual restart; with this procedure transient response can be analyzed after a selected long shut in period, the engineer restarts the VSD at well location and takes transient acoustic levels and additional data. These transient levels must be compared with the theoretical levels obtained numerically as solutions of the dynamic balance equations previously established. In this way a better match of the well can be performed. The new approach was applied in "La Concepción Field" in western Venezuela to diagnose two problematic wells, where standard analysis tools were useless and considerable production was deferred due to unpredictable behavior. Field's results show that it is convenient to complement the standard ESP troubleshooting with the new technique because

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additional information can be obtained making easier the diagnosis process.

2. Theoretical Approach

The transient behavior and numerical solution of the starting process requires suitable initial conditions. Choosing t=0 as the instant when the ESP is started, then the liquid or static level in the tubing is equal to the level in the annulus, and the intake pressure (P_{IP}) is equal to the discharge pressure (P_D).

$$\begin{aligned} &P_{IP}(0) = P_D(0) \\ &\Delta P_P(0) = 0 \\ &Y_{LT}(0) = Y_{LA}(0) = \frac{P_r}{\rho_L g} - (Y_{Perf} - Y_{Pump}) \end{aligned} \tag{1}$$

Bottom Hole initial conditions are: Nor gas neither liquid is coming from the reservoir, initial bottom hole pressure equal to reservoir pressure.

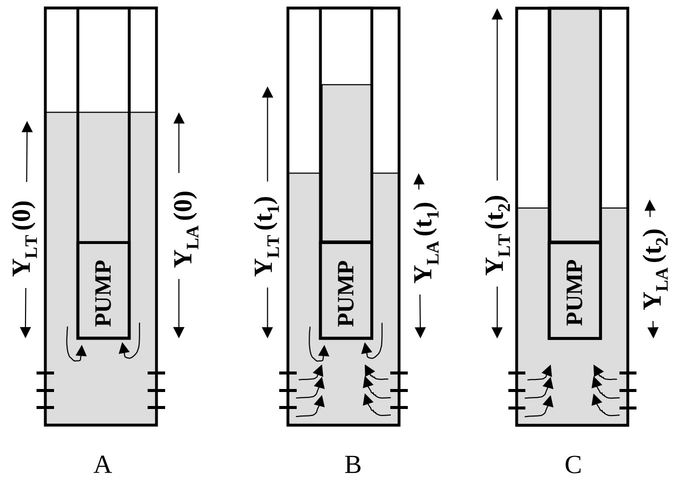

Fig.1. Transient levels at different times.

As time goes on the tubing and annulus levels changes. Initially the liquid only comes from the annulus (fig 1.a) because the bottom hole flowing pressure is equal to the reservoir pressure, thus no liquid can come from the reservoir. As the annulus level reduces the reservoir productions increases so the pump handles liquid coming from the annulus and the reservoir (fig 1.b). Finally when the system reaches its equilibrium no more liquid comes from the annulus and the pump handles only fluid coming from the reservoir. Only after this condition is reached standard nodal analysis can be applied.

For a given pump (*MODEL*), the manufacturer provides the performance curves (head, power and efficiency). Knowing the frequency (*f*), the number of stages (N_{stage}) and the pump's pressure gain $\Delta P_p(t)$ it is possible[3] to determine the current total flow rate (liquid+gas) through the pump Q_{TP} (t).

$$Q_{TP}(t) = Q(\Delta P_P(t), N_{stage}, f, MODEL) \tag{2}$$

During the transient response the instantaneous liquid rate handled by the pump is equal to the reservoir's instantaneous rate plus the rate associated with the annulus' variation level (fig.1). In the following equations the levels are referred to the pump's intake depth.

$$Q_{LP}(t) = Q_{L\,\mathrm{Res}}(t) + Q_{LA}(t) = Q_{L\,\mathrm{Res}}(t) - \frac{A_A}{5.615}\frac{dY_{LA}(t)}{dt} \tag{3}$$

Using a first order derivative approximation the new level can be estimated

$$Y_{LA}(t+\Delta t) = Y_{LA}(t) + \frac{5.615}{A_A}\left[Q_{L\,\mathrm{Res}}(t) - (Q_{TP}(t) - Q_{GP}(t))\right]\ \Delta t \tag{4}$$

Knowing the liquid level in the annulus the Pump's intake pressure and the bottomhole flowing pressure can be calculated.

$$\begin{aligned} P_{IP}(t+\Delta t) &= P_{GWHA} + \rho g Y_{LA}(t+\Delta t) \\ P_{wf}(t+\Delta t) &= P_{GWHA} + \rho g Y_{LA}(t+\Delta t) + \rho_L g (Y_{Perf} - Y_{Pump}) \end{aligned} \tag{5}$$

The reservoir transient rate should be obtained by solving the diffusivity equation[2], but for an easier understanding of this approach Vogel´s inflow performance (pseudo steady state) is evaluated at transient pressures.

$$Q_{L\,\mathrm{Res}}(t+\Delta t) = \frac{PI \cdot P_r}{1.8}\left(1 - 0.2\frac{P_{wf}(t+\Delta t)}{P_r} - 0.8\frac{P_{wf}^2(t+\Delta t)}{P_r^2}\right) \tag{6}$$

The tubing's variation level and the pump's discharge pressure can be calculated from the instantaneous pump's liquid rate.

$$\begin{aligned} Y_{LT}(t+\Delta t) &= Y_{LT}(t) + \frac{5.615}{A_T}(Q_{TP}(t) - Q_{GP}(t))\quad \Delta t \\ P_D(t+\Delta t) &= P_{WHT} + \rho g Y_{LT}(t+\Delta t) + \mathit{friction} \end{aligned} \tag{7}$$

Both levels are bounded, the difference is that annulus level is decreasing and tubing's level increasing. Therefore, if the tubing level reaches the wellhead, its value is fixed equal to the pump's depth. By the other hand, if the annulus level reaches the pump (pump off condition) its value is fixed equal to zero.

Assuming a separation efficiency the actual free gas rate into the pump is calculated[3]. This value depends on the gas oil ratio (*GOR*), the solution gas (R_s), the pressure (P_{ip}) and temperature (T_{ip}) at the pump's intake.

$$Q_{GP}(t) = (1 - \eta_{sep})(GOR - R_{S\,@\,Pip,Tip})Q_{L\,\mathrm{Re}\,s}(t)\,\frac{14.7}{5.615(P_{IP} + 14.7)} \cdot \frac{(460 + T)Z_{@\,P,T}}{520} \tag{8}$$

Pump's Power consumption is also given by manufacturer's specifications.

$$BHP_{TP}(t) = BHP\ (Q_{TP}(t), N_{stage}, f, MODEL) \tag{9}$$

Knowing the previous variables (eq.1 – eq.9) the current, Voltage, actual multiphase gradient, actual multiphase annulus level can be calculated easily.

With the new intake (eq. 5) and discharge pressure (eq.7) the whole procedure can be recalculated giving the time evolution of the system.

3. Results

The previous equations were applied in two wells in La Concepción field. In both cases the amperage chart resolution was not good enough to assure the gas lock condition. Besides an IPR estimation was required in case of workover for the selection and design of a new artificial lift method. Both wells showed an erratic behavior, sometimes they could run for two weeks and sometimes just few hours.

3.1. Case 1

Well A completion is shown in figure 2. The casing runs up to the shoe at 4.000 ft, where begins a 2.000 ft open hole section. A 104-stage ESP (model REDA GN1300) with a 200 HP motor, no downhole pressure sensors were available.

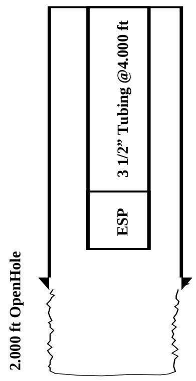

fig.2. Well Completion

After presenting erratic behavior at different operating frequencies, the well was shut in for two weeks. Then a sonolog test was run just before starting the pump, which gave the reservoir pressure and the initial tubing and casing level (there is not a check valve at the pump's discharge). After starting the pump at 55 Hz, three sonologs were run to determine the dynamic levels 30, 60 and 180 minutes later. By tuning the productivity index, the levels in the casing at those times where matched. Figure 3 shows the variables behavior for the best match corresponding to the PI of 0.98 BPD/psi. Since there are many variables with different units, in the figures 3 and 4 the units are shown in the legend and the Y axe only shows the magnitude.

Once the inflow was estimated then the program was run for different frequencies, allowing the following diagnose. The motor and the number of stages was over sized for the well inflow. The analysis showed that for frequency lower than 55 the power was extremely low producing a failure in the VSD. By the other hand for frequency of 50 Hz or higher the pump off condition is reached after few hours. The reason for the erratic failure time was the shut in period. The higher the shut in period the higher the failure time because of the phase redistribution and the pressure build up near well bore

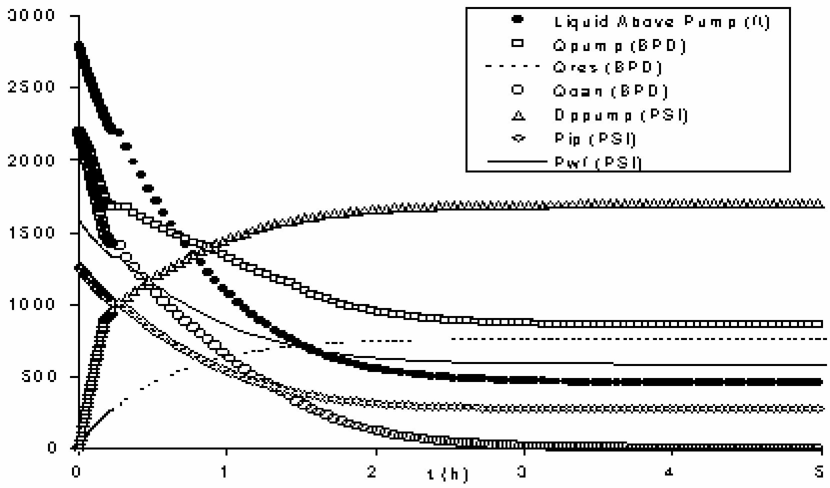

Fig.3. Variables behaviour for Well A.

A Progressing Cavity Pump (PCP) at 4000 ft was installed with a 700-feetx3 inches tubing tail for avoiding a longer rod and improving gas separation since the top layer was expected to increase gas production. After the workover the well has operated properly for one and a half year.

3.1. Case 2

Well B has a similar completion than Well A. The casing runs upto the shoe at 4.000 ft, where begins a 2.000 ft open hole section. The main difference is the ESP. A 100-stage ESP (model REDA DN1750) with a 90 HP motor, no downhole pressure sensors were available. The well was also shut in for two weeks, and the same sonolog tests were taken. The inflow productivity index was estimated in 0.54 BPD/psi.

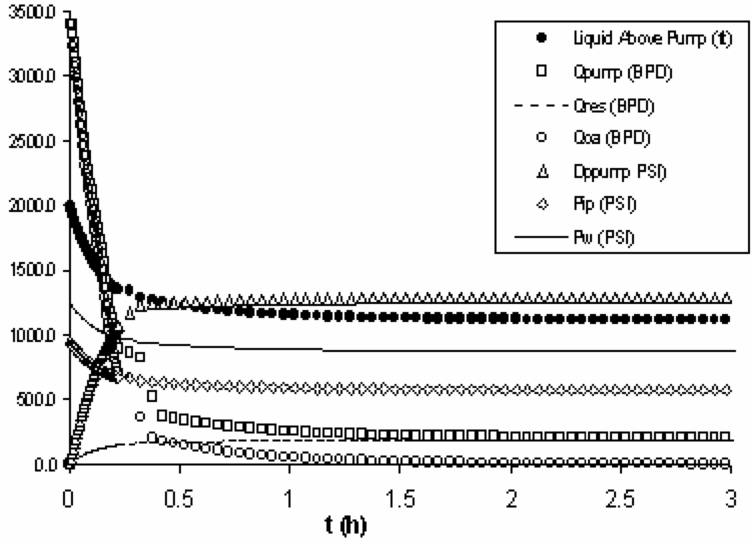

Fig.4 Variables behaviour for Well B.

After running the program for different frequencies the following diagnose was determined. The pump's stage was oversize for the flow rate but the number of stages was under sized. Thus, for low frequencies there is not enough head and for high frequencies the pump off condition is reached after few hours.

It is interesting to point out that the failures in both wells were caused by the ESP, but for different sizing reasons. Even both wells have similar number of stages the stage model in well A generates almost twice head than the stage in well B, and the stage in well A handles 30% less rate than the stage in well B.

Also in well B a PCP at 4000 ft was installed with a 700-feetx3 inches tubing tail. After the new artificial lift system, the well has been working properly for one year.

4. Conclusions and Recommendations

The analysis of the star up ESP´s process can enhance the troubleshooting task by giving not only ESP information but also reservoir inflow data.

An equivalent study can be perform for shutdown, but the task analysis of this process is harder because the pump works as a turbine, initial conditions are not so trivial and shutdown failure is unpredictable.

Installing pressure sensors at pump's intake and discharge would improve the matching proposed in this paper by reading the measurements instead of estimating those values with a sonolog test.

5. Nomenclature

A_A = Annulus Area, ft^2 [m^2]
A_T = Tubing Area, ft^2 [m^2]
BHP_T = Pump´s Power consumption, Hp [W]
PI= Productivity index, BPD/psi [m^3/d-kPa]
$P_{IP}(t)$= Instataneous pump´s intake pressure, psi [kPa]
$P_D(t)$= Instataneous pump´s discharge pressure, psi [kPa]
P_{GWHA} = Gas pressure at wellhead in the annulus, psi [kPa]
P_{WHT} = Tubing wellhead pressure, psi [kPa]
P_r = Reservoir pressure, psi [kPa]
$P_{wf}(t)$ = Instataneous Bottomhole flowing pressure, psi [kPa]
$\Delta P_P(t)$= Instataneous pump´s gain pressure, psi [kPa]
$Q_{LP}(t)$= Pump´s Instantaneous Liquid flow Rate, BPD [m^3/d]

$Q_{GP}(t)$= Pump´s Instantaneous Gas flow Rate, BPD [m^3/d]
$Q_{TP}(t)$= Pump´s Instantaneous Total flow Rate, BPD [m^3/d]
$Q_{LRes}(t)$=Reservoir´s Instantaneous Liquid flow Rate,BPD[m^3/d]
$Q_{LA}(t)$= Anular´s instantaneous Liquid flow Rate, BPD [m^3/d]
Y_{LA} (t) = Annulus instataneous 100% Liquid Level, ft [m]
Y_{LT} (t) = Tubing instataneous 100% Liquid Level, ft [m]
Y_{Perf} = Perforation´s depth, ft [m]
Y_{Pump} = Pump´s depth, ft [m]
ρ_L = Liquid Density, lbm/ft^3 [Kg/m^3]

6. References

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