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ANALYSING THE EFFECT OF SAND PRODUCTION ON ESP RUN TIME.

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Abstract

The use of electrical submersible pump in artificial lift system poses a challenge for oil and gas engineers especially when optimization of the project is needed to minimize cost and maximize profits. The major challenge faced by engineers is ESP equipment failure. The failure could result from gas, equipment mechanical failure or sand erosion accumulation. This paper focusses on analysing the effect of sand production (by using velocity of eroded particle) on ESP run time. More so, a live field case study of a consolidated sandstone reservoir in the Niger delta area was used to discuss ESP failures and how to increase the longevity of the ESP units. Key parameters such as mass flow rate and velocity of eroded particles were used as a node to analyse sand production. Also, ESP run time was monitored using Finnie's equation which was incorporated in a computer program. A commercial software – Prosper – was employed to calculate for impeller speed as well as fluid density. Furthermore, an analytical solution that computes ESP failure time was implemented using a computer program developed with python. Results from analysis revealed that reducing operating frequency from 70Hz to 61Hz caused a corresponding decrease in the velocity and mass flow rate of eroded particle (sand production). It was also observed that the ESP failure time experienced a delay upon reduction of ESP operating frequency.

Keywords**:** ESP run time, sand production, mass flow rate, velocity of eroded particles, operating frequency

1.0 INTRODUCTION

The electrical submersible pump systems deliver an effective and economical way of lifting crude from great depths under varied well conditions [1] However, Sand production in ESP systems is caused mainly by sand accumulation in the cavities of pump stages or by erosion of the impeller blades [2]. These accumulations can cause damage to equipment's either surface or subsurface. Because of the difficulty in avoiding this problem, sand screens or gravel packs are usually installed downhole. However, they could eventually cause plugging of the fluid flow path and reduces the oil flow rate. The performance of an ESP system under sand erosion conditions is a crucial topic for operators and servicing oil companies because the economic profits obtained from the oil production depend on the expected run lifetime of the system. According to Emmanuel et al. [3], the impeller size and design, speed rotation, electric motor capacity as well as thermodynamic and fluid properties are deterministic that affect the performance of Electrical Submersible Pumps (ESP).

Also, the presence of free gas at the pump intake is produced by either exposed gas sands, secondary gas cap, producing the wells below bubble point pressure or at reservoir depletion. The presence of such free gas affects the performance of the pump by reducing the flow rate of the oil. ESPs can handle free gas up to approximately 20% volume fraction without gas separation or gas handling equipment [4]. Higher levels of free gas at the pump intake require the use of gas separation and/or gas handling systems [5]. ESP motor failure is often caused by an increase in the temperature of the ESP motor or operating at very deep wells with high temperature profile. In an attempt to boost production by increasing the flow rate, the operating frequency of the ESP motor is increased. However, the result is an elevated temperature profile inside the ESP motor which, if coupled with high well temperature could result in failure of the ESP motor [5].

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Moreover, this paper discusses how sand production through mass flow rate of eroded particle, influences Electrical Submersible Pump (ESP) run life. The appropriate equations and analytical solutions for mass flow rate and ESP failure time would be presented and discussed. Following are the major objectives of this paper:

1. To compute the mechanical properties of the ESP system using PROSPER software prior to mass flow rate and velocity calculations.
2. To implement Finnie's equation in calculating mass flow rate and velocity of eroded particles using a computer program developed with python
3. To investigate the effect of mass flow rate in a typical ESP system on ESP run time.

2.0 THEORY AND DEFINITIONS

The operating life of an ESP pump will always vary depending on the fluid and well conditions. One of the most critical factors affecting ESPs reliability is the complex fluid properties and their variation with the well life. Recall, that fluid from the reservoir often contains gas and even corroded sand. Failure models of the pump are usually affected by the dominant presence on one or more of these phases. Several studies have been focused on comprehending failure mechanisms to improve the overall life of the pump.

Hisham et al. [6] analysed 501 ESPs which were installed in Kuwait-Saudi Arabia during 1998-2001. To understand and characterize failures, Morrison et al. [7] investigated different pump designs and established a commonly applied failure mode for the ESPs. During initial analysis, it was observed that gas significantly affects the wear mechanism of the pump in the presence of sand.

Ahbay et al. [8] conducted experimental work on the ESPs reliability in the presence of gas and eroded sand. It was observed that Presence of sand had a profound effect on the wear mechanism across various components of pump. Presence of gas mainly affected the wear across impeller and bearings. Impeller blades significantly eroded causing the primary reason for pump performance degradation. However, to improve the reliability of the seal section, two approaches were considered. The first one is to increase the tolerance of the mechanical seals to large vibrations while operating with low pressure differentials. Alternatively, the second approach is to evaluate the feasibility of using process-fluid lubricated thrust bearings. Multiple materials and designs will be evaluated in a vertical test rig capable of producing 40,000 lbf of thrust and test the bearings to failure.

Hisham et al. [6] presented the performance of electrical submersible pumps in the Wafra Field in the divided zone of Kuwait-Saudi Arabia. Main reservoirs in this field include Wara/Burgan sandstones and Ratawi carbonates. ESPs completions in the Wara sands presented the biggest challenge to reduce ESPs failure due to high sand volume erosion. The reservoirs were also shrouded with excessive gas production which is also a prerequisite for the ESPs failure.

The divided zone produces using artificial lift (Sucker rod and Electrical Submersible pumps). Hisham et al. [6] analysed the performance of the electrical submersible pumps in the period of 4 years started in 1998 until December 2001. The total number of failure of the pump was 251 and common failures were documented as follows;

1) Motor failures(40%)
2) Pump failures(22%)
3) Cable failures(26%)
4) Others(12%)

2.1 Sand erosion analysis

The performance of ESP systems in the presence of sand erosion is a crucial issue for well operators and oil servicing companies because the economic profits of oil production depends entirely on the run time of the ESP systems.

Potential sand productions in unconsolidated formation or fractured shale result in reduced ESP run time and company revenue. The following are 2 main problems of sand production;

1) sand accumulation in the cavities of the pump stages and
2) erosion of the pump impeller.

Summarily, the causes of sand production in a production system are as follows;

1. unconsolidated nature of the formation
2. lower formation strength
3. mechanical rock failure
4. increase in reservoir drawdown pressure
5. water breakthrough and
6. Changes in production rate.

Categorically, sand production is quite difficult to control; hence sand screens and gravel pack installations are used to curtail the problem. However, they increase the risk of reducing the flow rate.

3. METHODOLOGY

Finnie [9] developed an analytical model to predict sand erosion rates of the ESP systems. His model assumes that a solid particle has a velocity and a mass; which in turn define the momentum of the solid particle. When the particle hits the eroded material surface, a rate change of momentum happens in the solid particle; this rate change of momentum becomes a force according to Newton second law.

The analytical solution to estimate the mass removed from the eroded material surface, m are

$$m = \frac{M_s V_s^2}{2}\left(\frac{\rho_m}{\sigma_x \varphi}\right)\{\sin 2\propto\ -3(\sin\propto)^2\};\ \propto\leq\ 18.5^o \qquad (1)$$

$$m = \frac{M_s V_s^2}{6}\left(\frac{\rho_m}{\sigma_x \varphi}\right)(cos\ \propto)^2;\ \propto\geq\ 18.5^o \qquad (2)$$

The two pertinent values required in the application of the above model are the velocity of the solid particle, V_s and the impingement angle $\propto$.

The erosion rate is a function of several variables. Among all the dependent variables, the velocity of the solid particle (sand) is considered as a key parameter. Thus, reducing the angular velocity (operation frequency) of the impeller minimizes the damage of the impeller and consequently extends the run life of the ESP system. The problem for solid velocity calculations involves a two- phase liquid solid flow.

The velocity of the solid particle is given by

$$V_s = \varkappa\left(\omega r - \frac{q_l}{2\pi r h \tan\beta}\right) \qquad (3)$$

$$\text{Where } \varkappa = \left\{\frac{1+\sqrt{C_s\{(\frac{\rho_s}{\rho_l})^2-1\}+1}}{\frac{\rho_s}{\rho_l}-1} + C_s\right\}\left(\frac{1}{1-C_s}\right) \qquad (4)$$

The parameter $\varkappa$ is a dimensionless variable and is a function of solid concentration and the ratio of solid density to fluid density. Equations 3 and 4 are based on the steady-state solution of the Navier-Stokes equation in two dimensions (radial and tangential) and the application of the velocity triangle expressions.

Case study

This methodology is applied to a field case study in the Niger delta area, Nigeria. The field is a consolidated sandstone reservoir located onshore. The data used for analysis in this paper are illustrated in Table 1 and figure 1a and figure 1b. Figure 1a shows the mechanical and fluid thermodynamic fluid data for the ESP system to be analysed.

Table 1: Input parameters for ESP design

Head required	3722.76ft	**σ_x = horizontal stress,**	**42166135.85pa**
Number of pump stages	129	α, *impingement angle,*	18º
Angular velocity	417.3rad/s	φ	2 (recommended by Finnie)
Liquid rate	3939.6stb/d	Measured Solid volume fraction	0.04247
Sand flow rate anticipated	2857.19lbm/day	Blades set	45degrees or 0.7854rad.
Density of sand	2.65g/cc	Impeller blade thickness	0.5inch or 0.013m
Average fluid density	49.84051lb/ft^3	Impeller blade velocity	21.7m/s
Number of impellers	129		

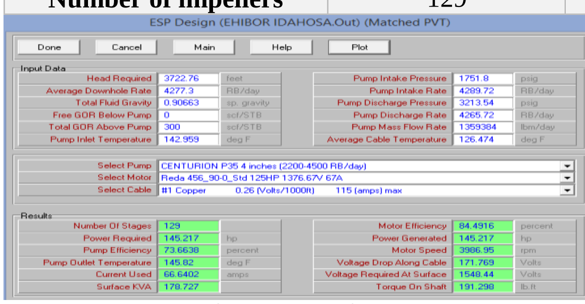

Figure 1a: Data extract from prosper software

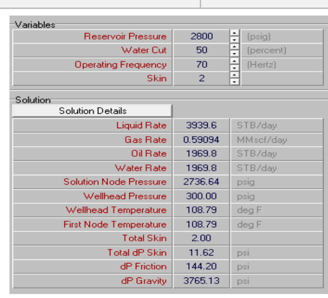

Figure 1b: Data extract from prosper software

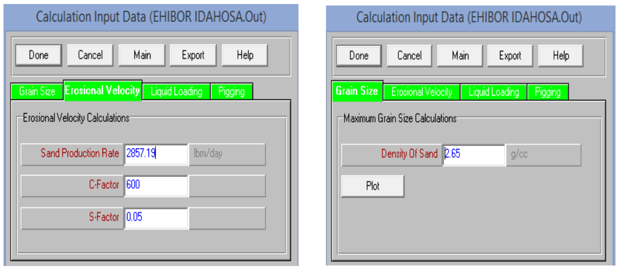

Figure 1c: data extract from prosper software

Impeller diameter

The impeller represents the main element in the centrifugal pump system. Produced liquids, after being subjected to great centrifugal forces caused by the high rotational speed of the impeller, lose their kinetic energy in the diffuser where a conversion of kinetic to pressure energy takes place. Amongst other factors, the liquid producing capacity of the ESP depends on the diameter of the impeller and its design (specific speed).

The following equations help us determine these two parameters of the impeller, impeller diameter and impeller specific speed. These parameters will be used in our analytical solution.

Impeller specific speed, $N_s = \frac{3.65\, N\sqrt{Q}}{H^{\frac{3}{4}}}$ (5)

Impeller diameter, $D_2 = \frac{60}{\pi N}\sqrt{\frac{2gH}{\varphi}}$ (6)

Where $\varphi = \frac{gH}{{U_2}^2}$ (7)

The definitions of the parameters are;

N = motor speed, rpm

Q = discharge rate, lb/m

H = head, m

U = blade velocity, m/s

G= 9.81m/s

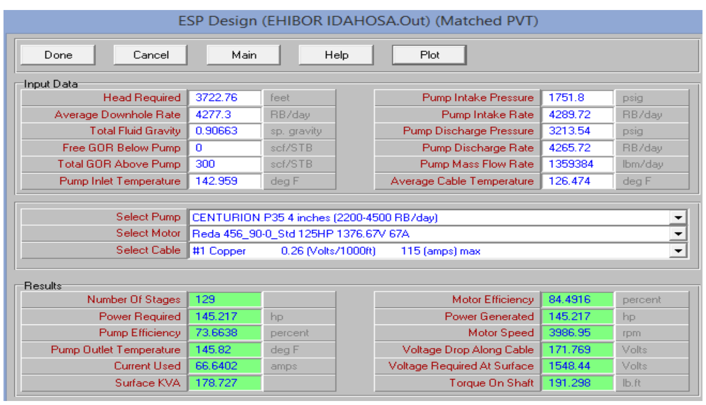

Figure 2: computations performed from prosper software

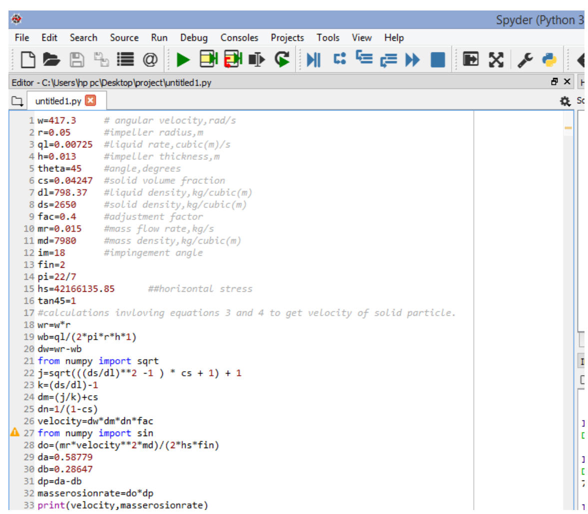

Figure 3. Python code to calculate velocity and erosion rate

N = 3986.95rpm;Q = 4289.72bbl/d or 2.98bbl/m; H = 3722.76ft or 1135.4m

The calculations are performed using excel and the results for the specific speed and impeller diameter is shown below;

Specific speed = 128.4m/s; Impeller diameter = 0.1039m; Impeller radius = 0.05m

The analytical solution will be performed using python. The python code is shown in the diagram below. The summary of the data required is shown in figure 3.

The result of the calculation for velocity and erosion rate are shown in Figure 4;

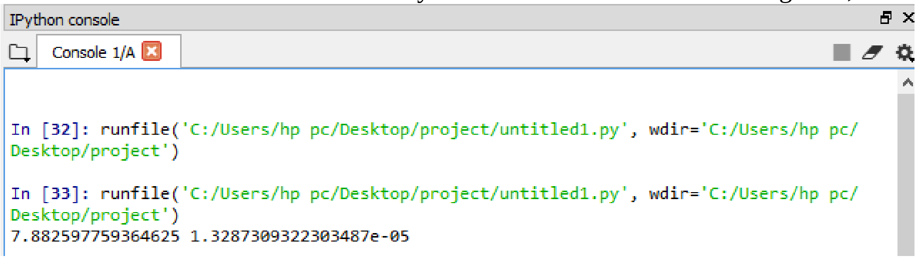

Figure 4: Result of velocity and erosion rate

The analytical solution was done with Microsoft Excel. The calculated velocity of the solid particle at the blades and the shrouds of the impeller are 19.7m/s. However, an adjustment factor of 0.4 is used to correct any inaccuracy in the calculated velocity of the solid particle. This is because the analytical solution gives a higher value compared to the simulation model; hence the need for the adjustment factor to ensure there is consistency between both trends (simulation model).

Assume mass of 2.3kg of an impeller, hence the mass for 129 impellers is 296.7kg.

With the data given above, the mass erosion rate is however calculated and plotted in the figure below as mass removed vs. time.

Recall that

Mass erosion rate (kg/s) = $\frac{mass}{time}$

From the calculated analytical values, the mass erosion rate is given by $1.329 \times \frac{10^{-5}kg}{s}$. Hence, using various values of impeller mass; the time can be calculated from the equation above. Note that, the time (seconds) has to be converted to days by dividing by 86400. The table of values generated is as shown in Table 3.

Table 3: ESP run time and mass flowrate

Mass,Kg	Time, days
0	0.00
50	43.54
100	87.09
150	130.63
200	174.18
250	217.72
300	261.27
350	304.81

The graph of time (vertical) against mass (horizontal) is thus plotted to determine the trend.
However, by interpolation we arrive at 258.4days as shown in Figure. 5 below.

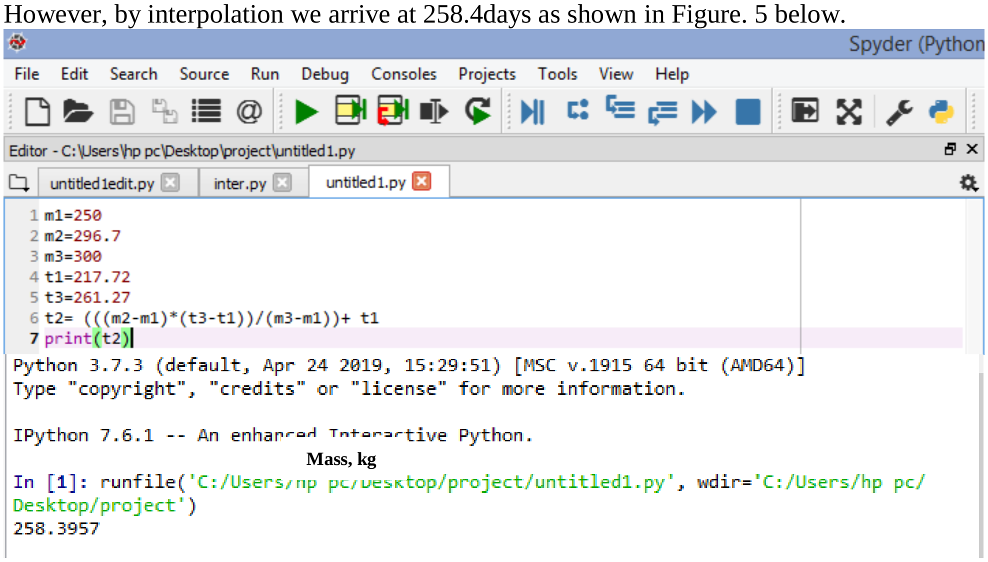

Figure 5: Interpolated result for days to failure of ESP of 70Hz

Discussion

From analyses performed an increase in the velocity of particle eroded causes an increase in the mass erosion rate. Recall that the velocity of the eroded particle is determined using equation 3.

From this equation, the velocity is increased by increasing the value of the angular velocity, ω. The angular velocity is given by the formula, $\omega = \frac{2\times\pi\times N}{60}$ where N is the motor speed of the ESP pump unit. Hence increasing the pump motor speed increases the angular velocity and vice-versa [3]. To minimize the damage done on the impeller, we reduce the mass erosion rate by reducing the velocity of the eroded particles. This can be achieved by reducing the operating frequency of the pump. This will reduce the motor speed, hence reducing the angular velocity. From our model, a frequency of 70Hz was used. Analysis using a frequency of 61Hz showed that the
Motor speed = 3502.6rpm
Head = 3722.76
Pump stages = 166

The angular velocity is calculated to give = 366.8rad/s
Assuming a mass of 2.3kg for an impeller, the mass of 166 impellers is 381.8kg. Upon calculation using the python code as in the previous case and changing the angular velocity for 61Hz to be 366.8rad/s the solution for the mass rate of the eroded particle is 1.000487590693417e-05. Recall that for the 70Hz frequency, the mass rate of eroded particle was found to be 1.3287309322303487e-05. We notice the reduction in the eroded mass particle. We must then Table 4 shows results for the time and the mass of particle eroded.

Table 4: ESP failure time for 61Hz **frequency**

mass,kg	time,days
0	0.00
50	57.84
100	115.68
150	173.53
200	231.37
250	289.21
300	347.05
350	404.90
400	462.74
450	520.58
500	578.42

The graph of time (vertical) against mass (horizontal) is thus plotted to determine the trend (See fig. 6).

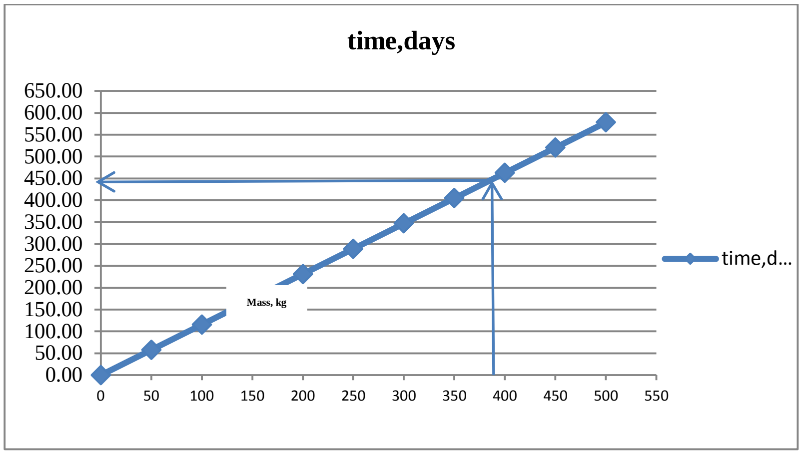

Figure. 6: Time versus mass plot

The total mass for 166 impellers is 381.8kg (2.3kg per impeller), hence from the diagram it was observed that the estimated run time of the equipment is about 450days due to erosion of the impellers. However, by interpolation we arrive at 442days.

CONCLUSION

a) An analytical equation (Equations (3) and (4)) was used to estimate the solid particle velocity in the tangential direction, which in turn provides a key input to use the Finnie's model (Equations 1 and 2) to determine the sand erosion rate.
b) This model was successfully applied to a field in the Niger Delta area.
c) The ESP equipment failure time operating at a frequency of 70Hz is 258days.
d) Reducing the frequency to 61Hz delayed the ESP failure time to 442days.
e) It was concluded that the operating frequency can reduce the impact of sand erosion problem in the ESP system by delaying the time to failure.

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