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Troubleshooting Techniques for Electric Submersible Pumps (ESPs)

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Abstract
Electric Submersible Pumps (ESPs) are a widely preferred solution for artificial lift, particularly in high water-cut wells. This study investigates troubleshooting and optimization techniques for ESP installations, with a focus on the applications of Advanced Gas Handlers (AGH) and Variable Speed Drives (VSD). It examines two case studies: the Waha field equipped with an AGH and the Sarir field employing an oversized pump. The primary objectives include leveraging AGH capabilities to reduce tubing costs and enhance production rates, as well as optimizing oversized pump performance while evaluating the impact of surface chokes on ESP power efficiency compared to VSD adjustments. Using Prosper software for simulation and performance evaluation, along with Affinity laws to analyze pump behavior under varying conditions, the study offers valuable insights. Findings for the Waha field indicate that the current installation of the AGH at a pump depth of 5,340 ft is unnecessary, as the gas-liquid ratio can be effectively managed with a standard pump intake. Relocating the pump to a shallower depth of 2,800 ft is recommended, resulting in a production rate of 4,272.3 bbl/d, controlled gas fraction of 39% within AGH capacity, and significant cost savings on cable and tubing. In the Sarir field, an oversized pump was initially regulated using a 36" choke to achieve a target production rate of 2,834 STB/d at 150 psi wellhead pressure. However, adjusting the pump speed via VSD to 43.9 Hz proved more efficient, saving an excess head of 616 ft and reducing power consumption, thus enhancing operational performance without

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relying on surface chokes. This study underscores the effectiveness of AGH and VSD technologies in optimizing ESP operations. Strategic adjustments to pump depth and speed can significantly improve production efficiency and reduce operational costs, particularly in high water-cut environments.

Keywords: Electric submersible pump, Advanced Gas Handler, Variable Speed Drive, Wellhead choke.

تقنيات استكشاف الأخطاء وإصلاحها للمضخات الغاطسة الكهربائية

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الملخص

المضخات الغاطسة الكهربائية (ESPs) تُعتبر حلاً مفضلاً على نطاق واسع لرفع النفط الصناعي، خاصة في الآبار ذات النسبة العالية من الماء إلى النفط. تبحث هذه الدراسة في تقنيات استكشاف الأخطاء وإصلاحها وطرق تحسين أداء الأنظمة التي تستخدم المضخات الغاطسة الكهربائية، مع التركيز على تطبيقات أجهزة معالجة الغاز المتقدمة (AGH)وأجهزة التحكم بسرعة المضخة .(VSD) تتناول الدراسة حالتي استخدام: حقل واحة المزود بجهاز AGH وحقل السرير الذي يستخدم مضخة كبيرة الحجم .تشمل الأهداف الرئيسية الاستفادة من قدرات جهاز AGH لتقليل تكاليف الأنابيب وزيادة معدلات الإنتاج، بالإضافة إلى تحسين أداء المضخة الكبيرة مع تقييم تأثير الصمامات السطحية (chokes) على كفاءة استهلاك الطاقة للمضخات الغاطسة مقارنة بتعديلات سرعة المضخة باستخدام جهاز VSD .اعتمدت الدراسة على برنامج Prosperلمحاكاة الأداء وتقييمه، بالإضافة إلى قوانين التآلف لتحليل سلوك المضخات تحت ظروف متغيرة، مما أتاح تقديم رؤى قيمة. أشارت النتائج المتعلقة بحقل واحة إلى أن تثبيت جهاز AGH الحالي على عمق مضخة يبلغ 5,340 قدمًا غير ضروري، حيث يمكن إدارة نسبة الغاز إلى السائل بفعالية باستخدام مضخة قياسية. ومن المُوصى به نقل المضخة إلى عمق أقل يبلغ 2,800 قدم، مما يؤدي إلى تحقيق معدل إنتاج يبلغ 4,272.3 برميل يوميًا، مع التحكم في نسبة غاز تبلغ 39% ضمن قدرة جهاز AGH ، بالإضافة إلى تحقيق

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وفورات كبيرة في تكاليف الكابلات والأنابيب.وفي حقل السرير، تم في البداية تنظيم أداء المضخة الكبيرة باستخدام صمام سطحي (choke) بحجم 36 بوصة لتحقيق معدل إنتاج مستهدف يبلغ 2,834 برميل نفط ثابت يوميًا (STB/d) عند ضغط رأس البئر يبلغ 150 رطلًا لكل بوصة مربعة. ومع ذلك، أثبت ضبط سرعة المضخة باستخدام جهاز VSD إلى 43.9 هرتز أنه أكثر كفاءة، حيث تم توفير ارتفاع إضافي يبلغ 616 قدمًا وتقليل استهلاك الطاقة، مما عزز الأداء التشغيلي دون الاعتماد على الصمامات السطحية . تُبرز هذه الدراسة فعالية تقنيات AGH و VSDفي تحسين عمليات المضخات الغاطسة الكهربائية. وتشير النتائج إلى أن التعديلات الإستراتيجية على عمق المضخة وسرعتها يمكن أن تعزز بشكل كبير كفاءة الإنتاج وتخفض التكاليف التشغيلية، خاصة في البيئات ذات النسبة العالية من الماء إلى النفط.

الكلمات المفتاحية :المضخة الغاطسة الكهربائية، جهاز معالجة الغاز المتقدم، جهاز التحكم بسرعة المضخة، الصمام السطحي.

1. Introduction

1.1. Advanced Gas Handler (AGH)

Electric submersible pumps perform at highest efficiency when pumping liquid only because the presence of free gas at the pump intake has a negative effect on the pump's performance, reducing liquid rates and pressure added by the pump. ESPs are perhaps the most efficient and economical lift method on a cost-per-barrel basis; however, their capacity and efficiency are limited by depth and high GOR [1]. In ideal conditions, wells producing gassy fluids would be produced at pump intake pressures (PIPs) above the well fluid's bubble point pressure so that there is no free gas present at the pump suction [2]. An AGH unit is a special multistage centrifugal pump that can handle up to 45% of free gas at its suction. The AGH does not separate gas from the liquid but homogenizes the gas-liquid mixture so that it behaves very similar to a single-phase fluid and poses no problem to the pump [2].

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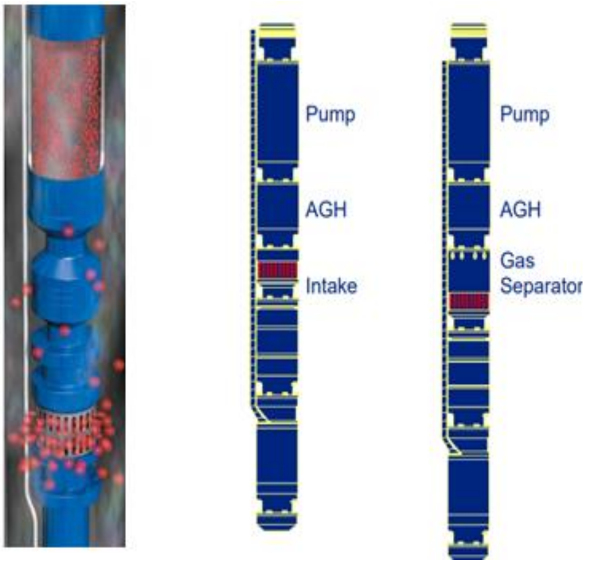

Figure 1: Advanced gas handling device installations [3].

The main goal of an AGH design is to produce from wells that are considered too gassy for the pump by avoiding gas-locking, which can lead to disruptions in the work operations and possible premature mechanical failure if not properly controlled [4]. AGH components provide a way to produce at higher rates, which allows the production of free gas that can help lift the fluids in the tubing by reducing the weight of the fluid column. Additional advantages include no surging and gas-locking in wells and lower bottom hole pressure [5]. When implementing an AGH device, it is normally installed down hole in series below a multistage ESP system pump [5]. AGH can be used with a standard intake or with a gas separator. The choice will depend on how much free gas will be present at the intake for producing condition and on whether there is a packer preventing gas production up the annulus [4, 6].

1.2. Variable Speed Drive (VSD)

VSDs have become a standard part of Electrical Submersible Pump systems. The operational flexibility created by VSDs allows for standardized pump designs, a wider operating range and improved electrical efficiency [7]. A VSD unit is an ESP surface equipment. It connects to the ESP motor and controls the pump’s rotational speed. VSDs are designed with separate power and control sections. This allows field staff to troubleshoot control, communication, or instrumentation issues safely without exposure

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to dangerous voltage sources [8]. VSDs are used to provide a controlled startup of the ESP and to adjust the ESP operating point (speed) to suit the well characteristics, which change over time. The use of a fixed speed motor would require frequent ESP change outs to match the changing well conditions [9].

Figure 2: Variable Speed Drive (VSD) [10].

Compared to other artificial lift systems, ESP's liquid capacity cannot be changed because each specific ESP pump has a unique restricted Recommended Operating Range, (ROR). If it is used outside the specified range, pump and system efficiencies rapidly decline resulting in mechanical issues leading to a complete system failure ending in a workover job. Deviations from (ROR) are ultimately due to poor designs or circumstances concerning availability. In such cases, the possible solutions to eliminate these problems are replacing the pump with the proper Recommended Operating Range or using a VSD unit. However, using a wellhead choke is another widely used solution.
The main objective of installing a choke is to control the flow rate and pressure of the produced hydrocarbon at the wellhead. The surface choke forces the ESP unit to operate within its Recommended Operating Range by restricting the flow rate. However, this results in significant hydraulic losses across the chokes leading to wasted power. VSDs can be used to easily address the issues of undersized or oversized pumps leading to inefficient energy usage and shorter pump life. The VSD unit changes the frequency of the electric current driving the ESP motor which significantly alters the pump's head performance. The use of VSDs to supply power to ESP systems offer numerous benefits, the most

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essential one being the ability to utilize the provided equipment in a significantly wider range of liquid rates compared to what the standard 60 Hz power supply offers. The consequences of flawed designs, inaccurate information on well inflow conditions, etc., can easily be resolved if ESP speed can be adjusted to the desired level. By reducing the electrical frequency driving the ESP system to a level where the head developed by the pump is equal to the head required to produce the desired rate the choke is no longer needed to adjust the pumping rate [9].
This study was conducted on two wells; one in Waha field with an AGH device installed, and the other in Sarir field with an oversized pump. The objective of this paper is to:

- Take advantage of the AGH device's abilities.
- Minimize tubing cost and achieve higher production rates by setting the pump at a shallow depth.
- Control the rate of an oversized pump.
- Highlight the negative effects of surface chokes on the power efficiency of ESP systems in comparison to using VSD.

2. Previous Studies

Several previous studies about operation troubleshooting of Electric Submersible pumps (ESPs) specifically that related to gas dealing strategy and controlling oversized pumps as listed below:
Chengjian Li; Zongzhao Liu; Zhai Yang; Yinzheng Wang presented a paper in 2000 addressing the application of a single VSD driving several ESPs in offshore heavy oil. SZ36–1 oil field is the largest developed offshore heavy oil field in China, located in Liaodong Bay of Bohai, where the winter temperatures are extremely low, and the water depth is about 30 m. The combined actions of heavy oil, power supply system failure, low air temperature and cold sea water make it difficult to restart ESPs after shutdown. What's worse, 1~2 sets of the ESP motors were damaged each time when restarting.
The conventional switchboard control mode dominated the vast majority of ESP surface equipment. This mode is unable to soft-start the ESP motor and damaged motor was the expected result when restarting. VSDs, however, could provide soft-start function and match with the production demands of heavy oil wells.
Now, ESPs can be softly started with the aid of the VSD. The device can control multi-ESPs, thus reducing the areas of space-taking ESP surface equipment. So far, 3 sets of this system have been installed

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in SZ36–1 oil field, controlling 40 ESP wells. The average run life of ESP in this field has been increased from about 360 days to 460 days [11].

In 2003 Hisham A. Mubarak, Farooq A. Khan, and Mehmet M. Oskay presented an article on the analysis and solutions of ESP failures, with a case study in Ratawi field, Kuwait. A gas handler device was deployed to regulate gas production when several cases of "Gas Lock" was faced where the annulus (casing & tubing or tubing & pump) were full of gases. The purpose of a gas handler device was to pressurize the gas back into solution and produce it with the oil through the pump [12].

Ismail Mahgoub, Mohamed Shahat, and Sayed Abd el fattah provided an overview of ESP Applications in Western Desert of Egypt in 2005. Khalda field was suffering from gas production resulting in ESP gas locking problems, and the potential for handling the massive amount of gas using the modern ESP technologies to solve the issue of gas production and subsequently increase ultimate recovery was examined.

The ESP string was equipped with a gas handler device to maintain the gassy wells operating during production. The total cumulative oil that was produced since utilizing this new technique was ± 10.4 MMSTB till the end of the year of 2004 [13].

In 2008 V. G. Bedrin, M. M. Khasanov, Rinat Khabibullin, V. A. Krasnov, A. A. Pashali, K.V. Litvinenko, V. A. Elichev, Mauricio Prado conducted a comparison on high GLR ESP technology at the Russian Oil and Gas Technical Conference in Moscow.

Rosneft Oil Company carried out field testing of ESP conditioning technologies in high GOR wells under the project Systems of New Technologies during 2006 and 2007. The tests conducted at the oil fields were characterized by high liquid ratios.

Field tests proved that ESP could operate successfully with the pump intake gas fraction up to 75%. In addition, it was estimated that more than 100 wells would benefit from ESP gas handling technologies in Purneftegas alone, yielding significant economic impact for the company, increasing oil production by more than 700 tons/day [14].

Suat Bagci, Murat Kece, and Jocsiris Nava published a paper at the International Oil and Gas Conference and Exhibition in China, Beijing in 2010 outlining the challenges we face using ESPs in high free gas applications. This study demonstrated the applications of

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Electric Submersible Pumps using a variety of gas handling technologies based on actual field data for five wells.

The paper confirmed that ESP could operate successfully with the pump intake gas fraction up to 75% through the use of appropriate gas handling technologies and was concluded that some high PI wells will benefit from ESPs with gas separation and/or gas handling systems when operating at flowing bottom hole pressures significantly below the bubble point pressure. For all wells, however, ESPs with gas separation systems can provide a better means of unloading the liquids and achieve the production targets at the design conditions [15].

In 2011 Gabor Takacs released a study on improving system efficiencies of ESP installations controlled by surface chokes. The paper addresses the negative effects of wellhead chokes and highlights the benefits of using a VSD. This study focuses on improving efficiency, reducing energy consumption, and enhancing ESP performance.

Calculations were performed on a group of wells from the same field to increase the efficiency of ESP wells on surface choke control. The application of VSD units was assumed and the required operational frequencies were determined. The total electrical power requirement for the studied group of wells has significantly reduced to almost one-third of the original, going from 606 kW down to 211 kW. Results clearly indicate that using VSDs to control the production rate of ESP wells is a far more effective solution than the wellhead choking adopted in field practice [16].

Ibrahim Hrari presented a paper in 2022 on improving poor ESP systems operated by surface chokes with the application of variable speed drives and conducted a case study on well (C-88-65) in Sarir field, Libya. The study talks about the challenges faced when controlling flow rates in oversized ESP pumps using surface chokes and it proposes an alternative solution using VSDs.

Results show that the pressure wasted across the choke was 445 psi, but by using a VSD, the pump can operate at the obtained frequency found by using the Affinity laws which was determined to be 42.38 Hz to meet the required flow rate.

It was concluded that the application of a VSD unit would make the pump produce at the required conditions without choking back the pump which is viewed to be a better option in terms of power saving,

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protecting the well flow equipment from being subjected to high pressures and extending the pump's run life [17].

3. Methodology

Two methodologies are applied in this study; one is totally dependent on applying the Prosper Software, which is a reliable well performance analysis Software, and it is used to optimize or best seize the installation of AGH.
The other is applied to obtain the choke bean size required for choking back the unit and the consequent power loss, as well as introducing the Affinity Laws to obtain the required Hertz reduction as a superior solution to applying chokes for rate control. Both methodologies are demonstrated below by flowcharts.

3.1 Applying AGH:

The following workflow chart, figure (3) describes the Prosper simulation flowchart applied. It starts with common ESP design steps that ends with calculating the total dynamic head required to produce the well at the desired conditions applying gas separation sensitivity at different values of pump sitting depth to see whether a gas dealing device is needed using Dunbar factor chart. This is applied twice at current pump depth to analyze the current pump performance and at assumed depth that gives a gas fraction with in AGH capability. Finally, a comparison of pump performance in both cases is generated.

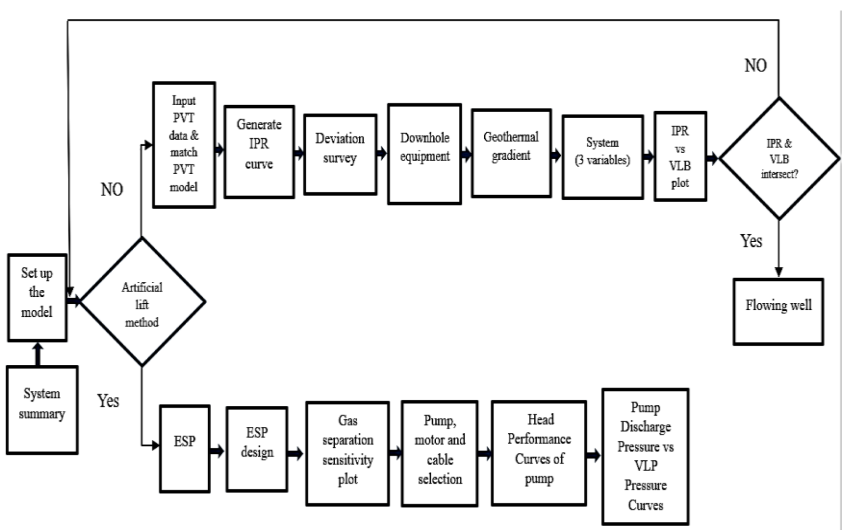

Figure 3: AGH simulation workflow

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3.2 Applying VSD:

Figure (4) demonstrates a flowchart followed for the second case study about controlling the flow rate of an oversized pump. It starts with common ESP design steps that ends with calculating the total dynamic head required to produce the well at the desired conditions. And depending on that the required number of stages is calculated and compared with the currently installed unit. Then the excessive head is calculated and a choke bean size required to cut the production back is obtained applying Gilbert equation. Finally, applying the Affinity laws; equation (2), the required hertz to generate the required head to produce the required rate with the same current number of stages is calculated.

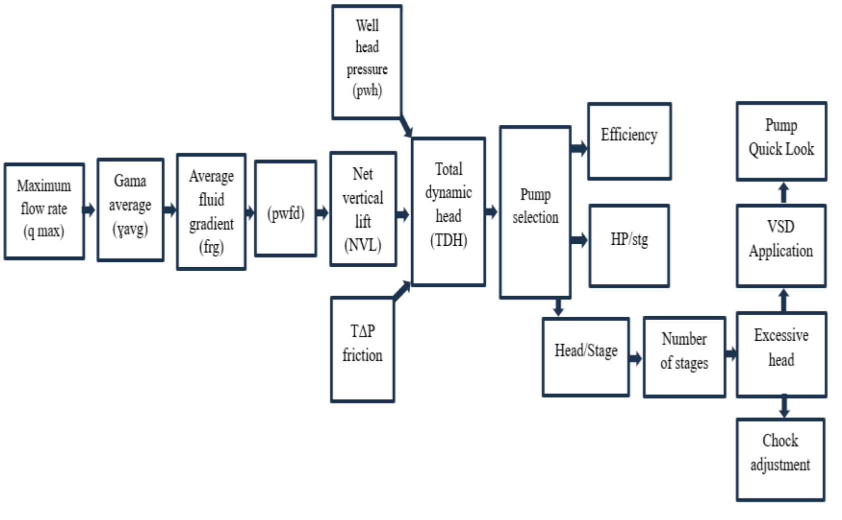

Figure 4: Rate control flowchart

3.3 The Affinity Laws:

The affinity laws, equations (1, 2 and 3) relate variables involved in pump performance such as (head, flow rate, shaft speed) with power [9].

$$\boldsymbol{Flow_{(RPM2)} = Flow_{(RPM1)} \times \left(\frac{RPM2}{RPM1}\right)} \quad (1)$$

$$\boldsymbol{Head_{(RPM2)} = Head_{(RPM1)} \times \left(\frac{RPM2}{RPM1}\right)^2} \quad (2)$$

$$\boldsymbol{BHP_{(RPM2)} = BHP_{(RPM1)} \times \left(\frac{RPM2}{RPM1}\right)^3} \quad (3)$$

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3.4 Used data

Table 1: Well, reservoir and fluid data

<table>
<tr><td colspan="3">Advanced gas handeler case</td><td colspan="2">Variable Speed drive case</td></tr>
<tr><td>Field</td><td colspan="2">Waha</td><td>Field</td><td>Sarir</td></tr>
<tr><td>reservoir</td><td colspan="2">Defa Reef</td><td>Perforation depth (ft)</td><td>8548</td></tr>
<tr><td rowspan="3">Perforation</td><td>Top (ft)</td><td>Bottom (ft)</td><td>Casing size</td><td>7"</td></tr>
<tr><td>5530</td><td>5570</td><td rowspan="2">Tubing size</td><td rowspan="2">3.5"</td></tr>
<tr><td>5580</td><td>5620</td></tr>
<tr><td>Casing size</td><td colspan="2">7"</td><td>Allowable oil (stb/d)</td><td>1300</td></tr>
<tr><td>Tubing size</td><td colspan="2">3.5"</td><td>Allowable water (stb/d)</td><td>1300</td></tr>
<tr><td>Reservoir temperature f</td><td colspan="2">158</td><td>Oil formation volume factor (Bo) (bbl/stb)</td><td>1.14</td></tr>
<tr><td>Reservoir pressure (psi)</td><td colspan="2">2320</td><td>water formation volume factor (Bw) (bbl/stb)</td><td>1.04</td></tr>
<tr><td>Productivity index (stb/d/psi)</td><td colspan="2">2.6</td><td>Water gradient (psi/ft)</td><td>0.480</td></tr>
<tr><td>Well head pressure (psi)</td><td colspan="2">200</td><td>oil gradient (psi/ft)</td><td>0.320</td></tr>
<tr><td>Well head temperature f</td><td colspan="2">110</td><td>Reservoir pressure (psi)</td><td>2970</td></tr>
<tr><td>Desired fluid rate (stb/d)</td><td colspan="2">+/- 2500</td><td>Saturation pressure (psi)</td><td>650</td></tr>
<tr><td>Water cut (%)</td><td colspan="2">75</td><td>Productivity index (stb/d/psi)</td><td>15</td></tr>
<tr><td>API gravity</td><td colspan="2">36.5</td><td colspan="2" rowspan="7">Note:
GN-3200 with 110 stages has to be installed due to availability considerations. Perform production test, Sonolog and adjust the chock in order to keep production rate in pump capacity range.</td></tr>
<tr><td>Gas oil ratio GOR (scf/stb)</td><td colspan="2">330</td></tr>
<tr><td>Bubble point pressure (psi)</td><td colspan="2">1372</td></tr>
<tr><td>Gas gravity</td><td colspan="2">0.78</td></tr>
<tr><td>Water gravity</td><td colspan="2">1.04</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
</table>

4. Results and Discussion

Results of both cases; optimizing unit depth to obtain full use of installing AGH and controlling the flow rate by applying both surface choke and VSD are manifested below.

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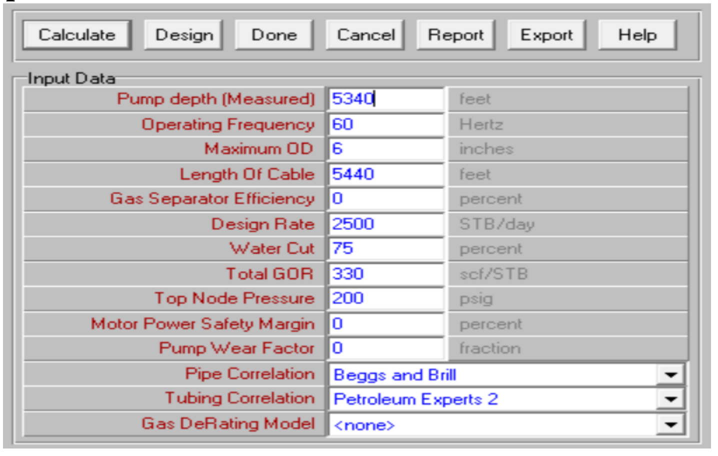
4.1 Results of AGH application:

4.1.1 Pump performance at current installation depth of 5340 ft:

✓ **Input data.**



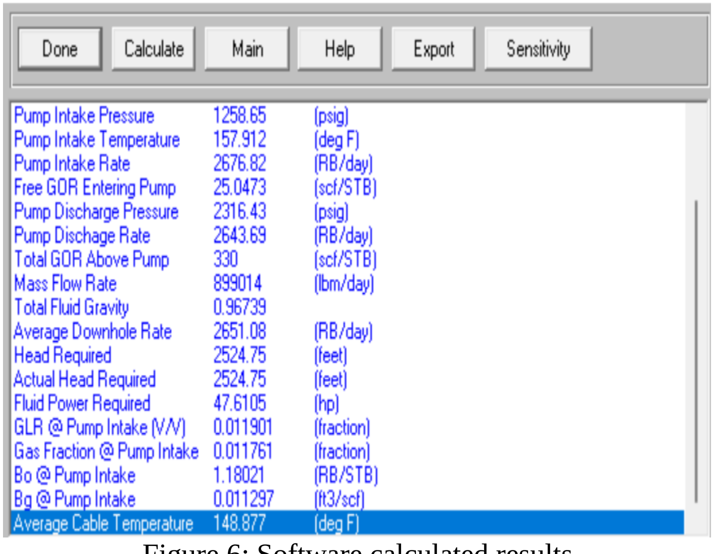
Calculate | Design | Done | Cancel | Report | Export | Help

Input Data

Pump depth (Measured)	5340	feet
Operating Frequency	60	Hertz
Maximum OD	6	inches
Length Of Cable	5440	feet
Gas Separator Efficiency	0	percent
Design Rate	2500	STB/day
Water Cut	75	percent
Total GOR	330	scf/STB
Top Node Pressure	200	psig
Motor Power Safety Margin	0	percent
Pump Wear Factor	0	fraction
Pipe Correlation	Beggs and Brill	
Tubing Correlation	Petroleum Experts 2	
Gas DeRating Model	<none>	

Figure 5: Input data

✓ **Software calculated results**



Done | Calculate | Main | Help | Export | Sensitivity

Pump Intake Pressure	1258.65	(psig)
Pump Intake Temperature	157.912	(deg F)
Pump Intake Rate	2676.82	(RB/day)
Free GOR Entering Pump	25.0473	(scf/STB)
Pump Discharge Pressure	2316.43	(psig)
Pump Discharge Rate	2643.69	(RB/day)
Total GOR Above Pump	330	(scf/STB)
Mass Flow Rate	899014	(lbm/day)
Total Fluid Gravity	0.96739	
Average Downhole Rate	2651.08	(RB/day)
Head Required	2524.75	(feet)
Actual Head Required	2524.75	(feet)
Fluid Power Required	47.6105	(hp)
GLR @ Pump Intake (V/V)	0.011901	(fraction)
Gas Fraction @ Pump Intake	0.011761	(fraction)
Bo @ Pump Intake	1.18021	(RB/STB)
Bg @ Pump Intake	0.011297	(ft3/scf)
Average Cable Temperature	148.877	(deg F)

Figure 6: Software calculated results

Figure (6) shows a gas fraction of 0.011761 at the current pump depth which is within the applicability range of a standard intake and using AGH is not necessary as it can be seen in Dunbar factor graph, figure (7) the operating pressure is above the Dunbar factor line.

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- ✓ **Gas separation sensitivity:**

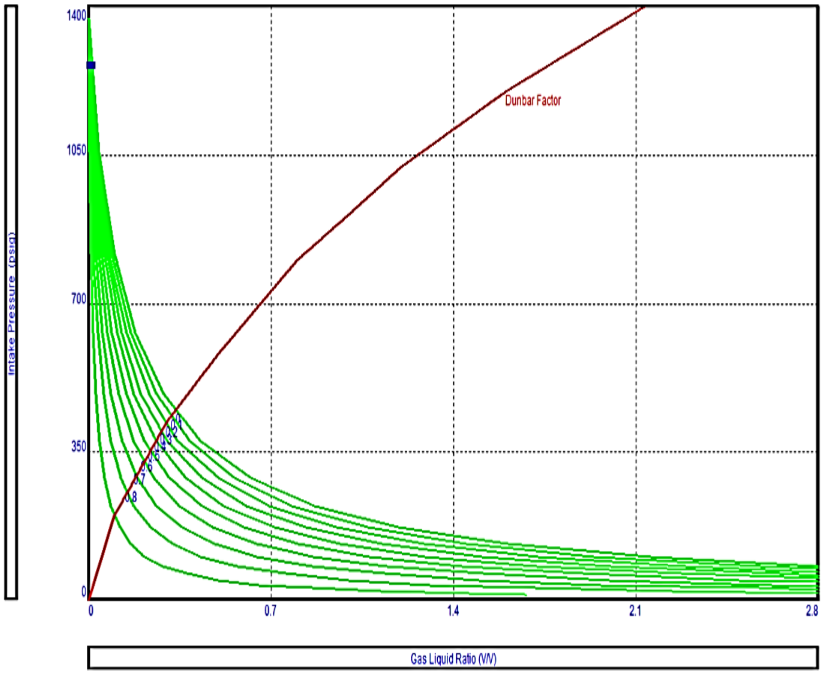

Figure 7: Gas separation sensitivity

- ✓ **Design results:**

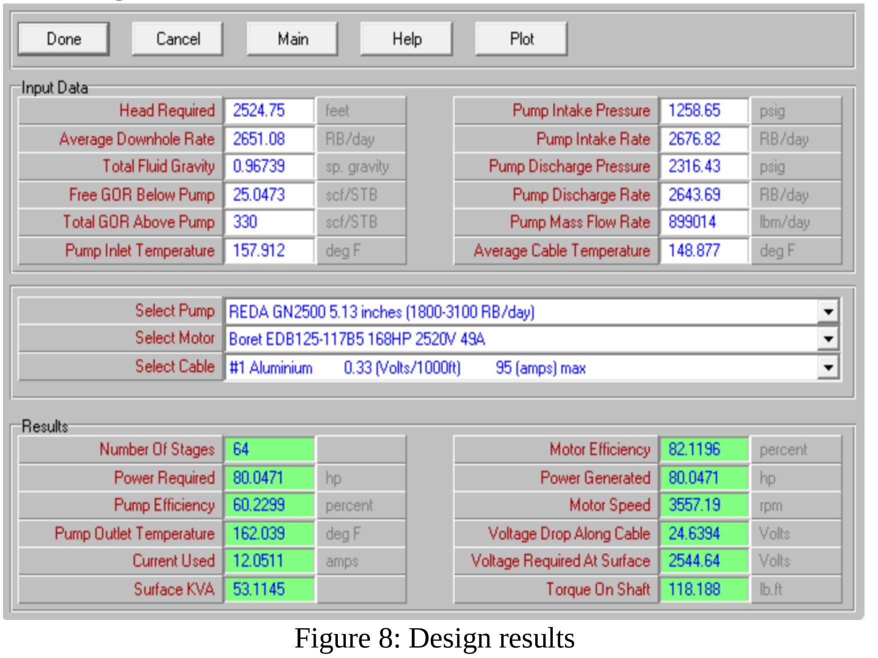

Figure 8: Design results

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✓ **Pump performance:**

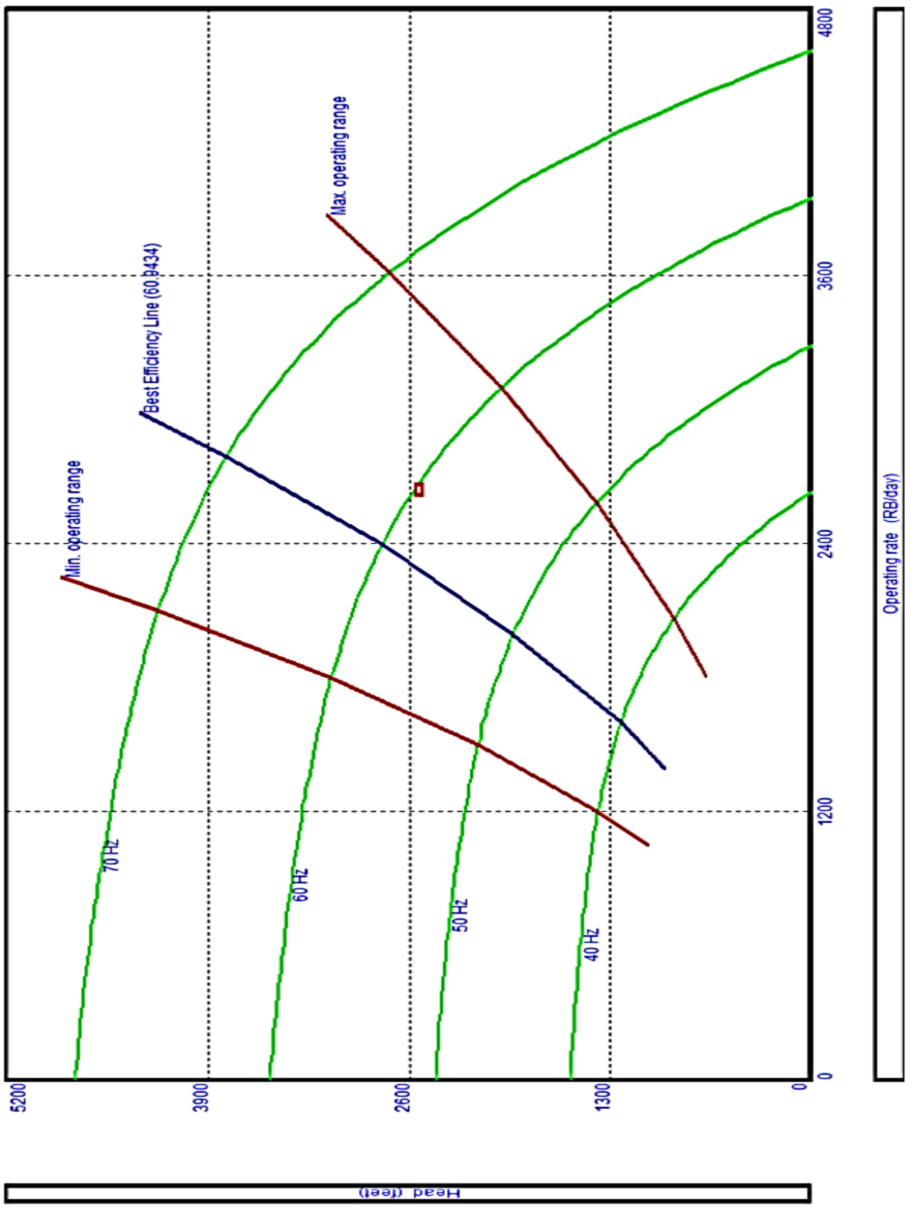

Figure 9: Pump performance

The following figure, figure (9), shows pump performance curve at the current condition with 64 stages as design results show in figure (8). It's obvious that the pump is operating within the recommended range.

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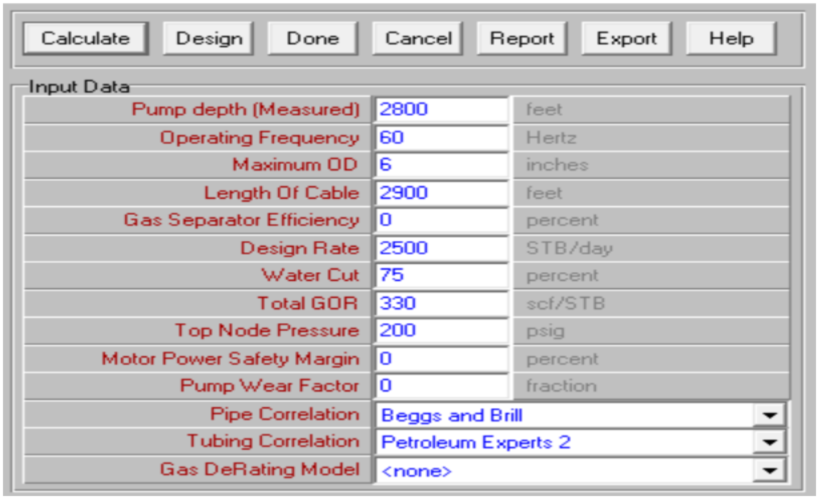
4.1.2 Pump performance at shallower installation depth of 2800 ft:

✓ **Input data with zero gas separation efficiency.**


Calculate | Design | Done | Cancel | Report | Export | Help

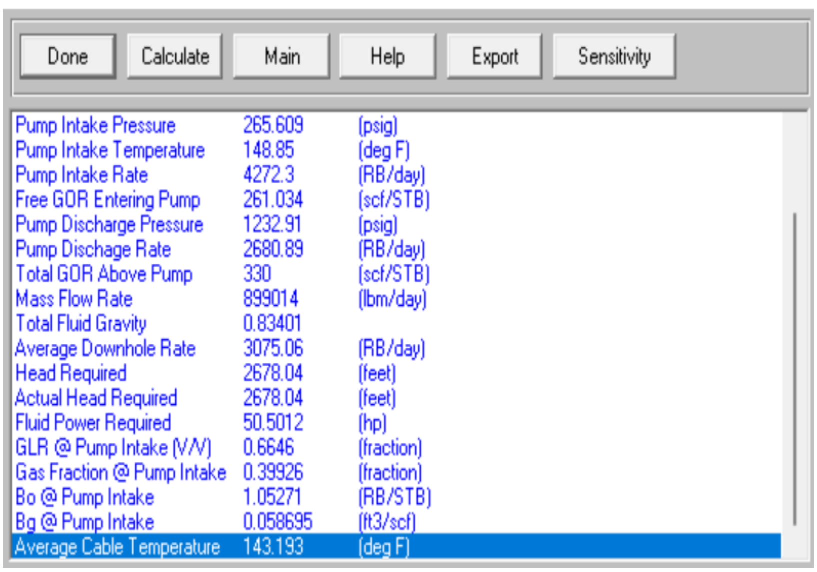
Input Data

Pump depth (Measured)	2800	feet
Operating Frequency	60	Hertz
Maximum OD	6	inches
Length Of Cable	2900	feet
Gas Separator Efficiency	0	percent
Design Rate	2500	STB/day
Water Cut	75	percent
Total GOR	330	scf/STB
Top Node Pressure	200	psig
Motor Power Safety Margin	0	percent
Pump Wear Factor	0	fraction
Pipe Correlation	Beggs and Brill	
Tubing Correlation	Petroleum Experts 2	
Gas DeRating Model	<none>	

Figure 10: Input data

Figure 10 above shows the input data with shallower pump depth of 2800 ft with the assumption of zero % separation efficiency as AGH is installed.

✓ **Software calculated results.**


Done | Calculate | Main | Help | Export | Sensitivity

Pump Intake Pressure	265.609	(psig)
Pump Intake Temperature	148.85	(deg F)
Pump Intake Rate	4272.3	(RB/day)
Free GOR Entering Pump	261.034	(scf/STB)
Pump Discharge Pressure	1232.91	(psig)
Pump Dischage Rate	2680.89	(RB/day)
Total GOR Above Pump	330	(scf/STB)
Mass Flow Rate	899014	(lbm/day)
Total Fluid Gravity	0.83401	
Average Downhole Rate	3075.06	(RB/day)
Head Required	2678.04	(feet)
Actual Head Required	2678.04	(feet)
Fluid Power Required	50.5012	(hp)
GLR @ Pump Intake (V/V)	0.6646	(fraction)
Gas Fraction @ Pump Intake	0.39926	(fraction)
Bo @ Pump Intake	1.05271	(RB/STB)
Bg @ Pump Intake	0.058695	(ft3/scf)
Average Cable Temperature	143.193	(deg F)

Figure 11: Software calculated results

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Figure (11) shows the calculated results with AGH installation, a gas fraction of 0.399 at shallower pump depth of 2800 ft which manifests the maximum percentage that AGHs can handle. And as it can be seen in Dunbar factor graph, figure (12) the operating pressure is below the Dunbar factor line at zero separation efficiency indicating the need to use AGH.

- ✓ **Gas separation sensitivity:**

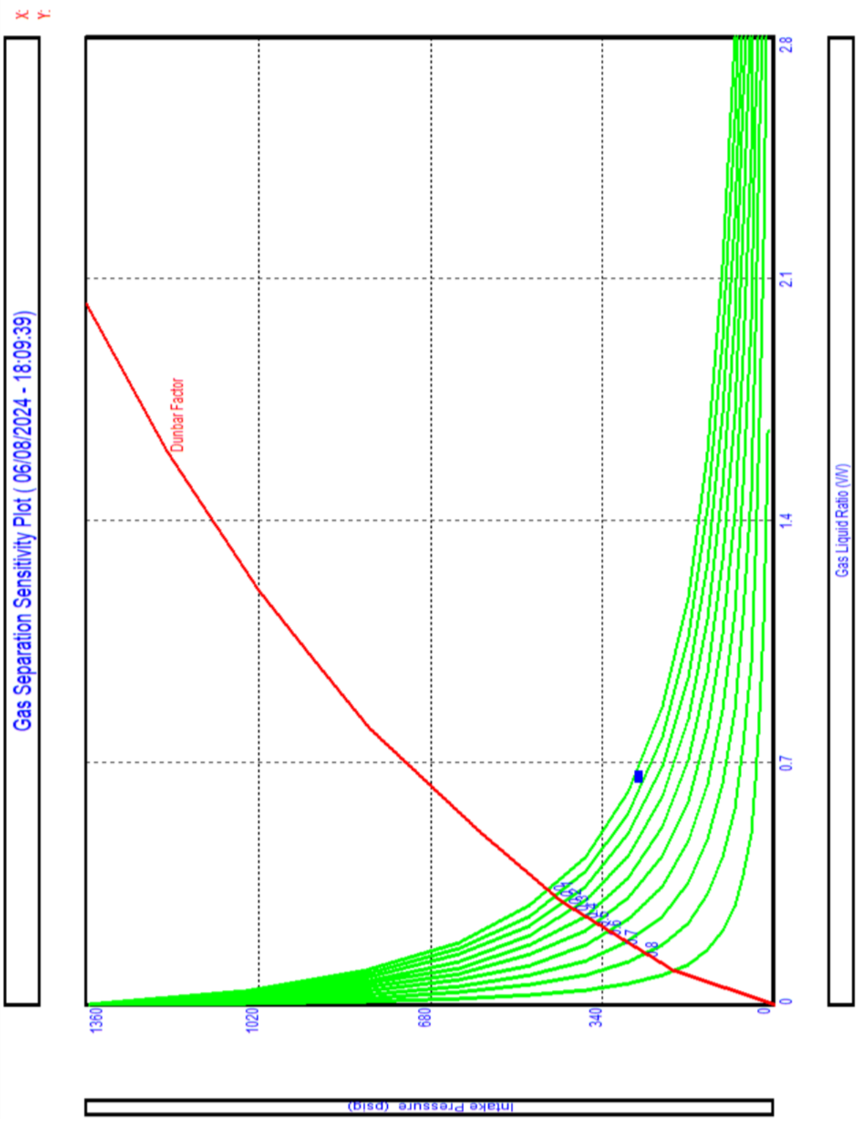

Figure 12: Gas separation sensitivity

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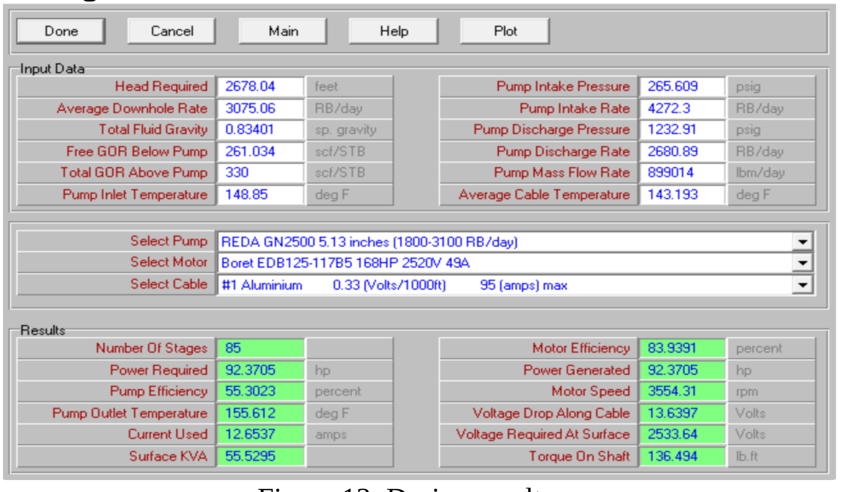
✓ **Design results:**



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Input Data

Head Required	2678.04	feet	Pump Intake Pressure	265.609	psig
Average Downhole Rate	3075.06	RB/day	Pump Intake Rate	4272.3	RB/day
Total Fluid Gravity	0.83401	sp. gravity	Pump Discharge Pressure	1232.91	psig
Free GOR Below Pump	261.034	scf/STB	Pump Discharge Rate	2680.89	RB/day
Total GOR Above Pump	330	scf/STB	Pump Mass Flow Rate	899014	lbm/day
Pump Inlet Temperature	148.85	deg F	Average Cable Temperature	143.193	deg F

Select Pump	REDA GN2500 5.13 inches (1800-3100 RB/day)
Select Motor	Boret EDB125-117B5 168HP 2520V 49A
Select Cable	#1 Aluminium 0.33 (Volts/1000ft) 95 (amps) max

Results

Number Of Stages	85		Motor Efficiency	83.9391	percent
Power Required	92.3705	hp	Power Generated	92.3705	hp
Pump Efficiency	55.3023	percent	Motor Speed	3554.31	rpm
Pump Outlet Temperature	155.612	deg F	Voltage Drop Along Cable	13.6397	Volts
Current Used	12.6537	amps	Voltage Required At Surface	2533.64	Volts
Surface KVA	55.5295		Torque On Shaft	136.494	lb.ft

Figure 13: Design results

The following figure, figure (14), shows pump performance curve at depth of 2800 ft with 85 stages as design results show in figure (13). It's obvious that the pump is operating at the edge of the recommended range but still within the recommended range.

✓ **Pump performance**

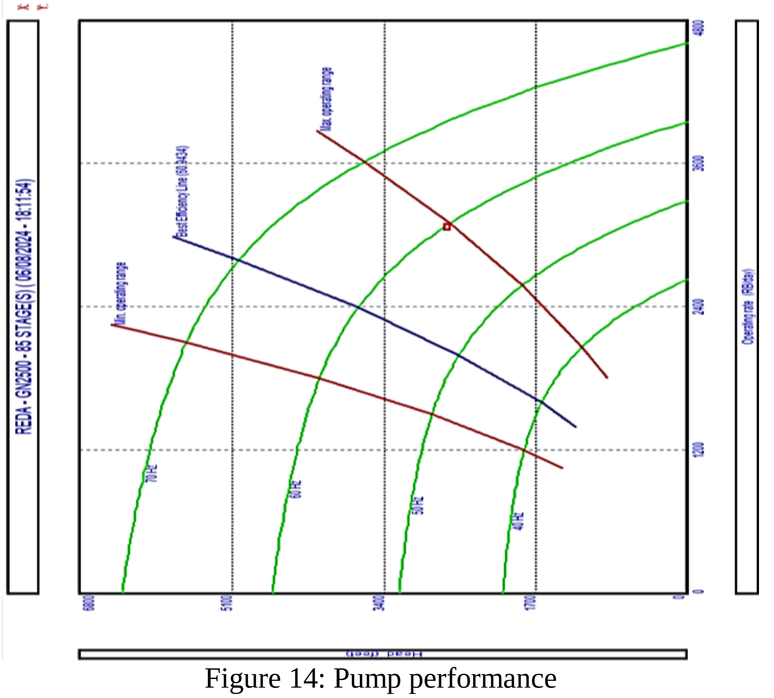

Figure 14: Pump performance

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The results of both current and recommended pump depth are compared in table 2 below:

Table 2: Results comparison

	At current depth of 5340 ft	At depth of 2800 ft
Length of cable (ft)	**5440**	**2900**
PIP (psig)	**1258.65**	**265.609**
Pump intake rate (RB/d)	**2676.82**	**4272.3**
Free GOR entering the pump (scf/stb)	**25.0473**	**261.034**
Head required (ft)	**2524.75**	**2678.04**
Gas fraction at pump intake	**0.011761**	**0.39926**
No. of stages	**64**	**85**

4.2 VSD application results:

Results were obtained according to a total dynamic head **(TDH)** of 2056 feet that is required to produce the required rate of 2834 (bbl/d).

- **Pump selection:**

Based on the casing size and the desired flow rate, (GN3200) pump type is selected.

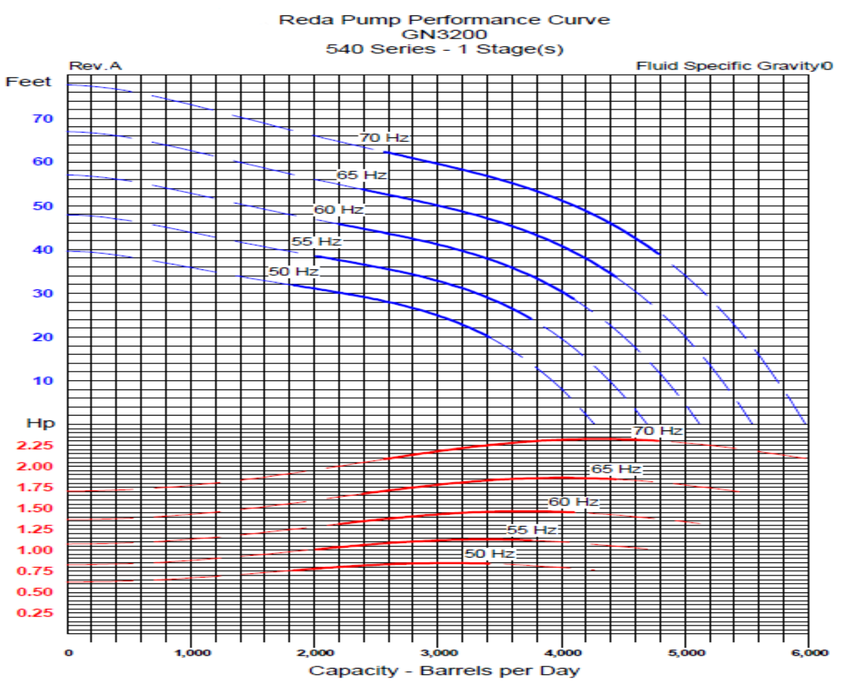

Figure 15: Pump performance curve

$$Head/stage \quad = 26.2\ ft/stage$$

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- **Number of stages:**

$$no.of\ stages\ =\frac{TDH}{\frac{head}{stage}}=\frac{2056}{26.2}\ =78\ stages$$

$$Actual\ no.of\ stages\ =\ 102\ stages$$

The required rate of 2834 (bbl/d) can be produced using only 78 stg, and to produce the same rate (2834 bbl/d) with 102 stg, one of the following methods can be applied.

a. Choke adjustment:

$$\frac{Head}{stage}=\frac{2056}{102}=\ 20.15\frac{ft}{stg}$$

$$Converting\ to\left(\frac{m}{stg}\right):\frac{20.15\ ft}{3.28\ m}\ =\ 6.14\left(\frac{m}{stg}\right)$$

According to chart below, rate is 541 $\left(\frac{m^3}{d}\right)$, $\left(3400\frac{bbl}{d}\right)$ which is at the edge of the ROR.

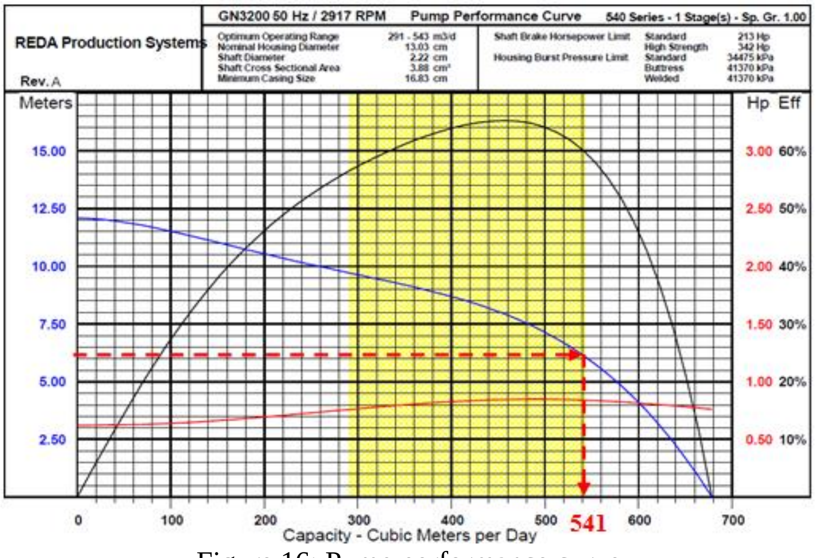

Figure 16: Pump performance curve

$$Head\ generated\ by\ 102\ stgs=102\ *\ 26.2\ \ =\ 2672\ ft$$

$$With\ 78\ stg\ head\ generated\ is\ 2056\ ft.$$

$$(excessive\ head)=2672-\ 2056\ \ =\ 616\ ft$$

$$Excessive\ head\ in\ psi: 616\ ft\ *0.4\frac{psi}{ft}$$

$$=246\ psi\ "must\ be\ wasted\ through\ the\ choke"$$

The choke must be adjusted to maintain an upstream pressure of 396 psi and downstream pressure (Whp) of 150 psi.

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Choke (bean) size calculation using Gilbert equation:

$$Whp = \frac{435R^{0.546}Q}{d^{1.89}}$$

$$d = \sqrt[1.89]{\frac{435 * \left(\frac{100}{1000}\right)^{0.546} * 2834}{396}} = 36/64''$$

b. Application of VSD:

The Affinity Laws are applied to obtain the frequency at which the motor will operate to produce 2834 bbl/d using 102 stg.

$$head/(stage\ )\ corresponding\ to\ excessive\ head\ \ 616/102 = 6\,ft$$

$$head/(stage\ )\ to\ produce\ 2834\ bbl/d\ using\ 102\ stg: 26.2 - 6 = 20.2\ ft$$

The frequency corresponding to 20.2 $ft = head\ at\ 50 * \left(\frac{Hz}{50}\right)^2 \rightarrow$

$$20.2 = 26.2 * \left(\frac{Hz}{50}\right)^2 \rightarrow Hz = 43.9\ Hz$$

$$Adjusting\ the\ motor\ frequency\ to\ 43.9\ Hz, 102\ stg\ would\ produce\ 2834\left(\frac{bbl}{d}\right).$$

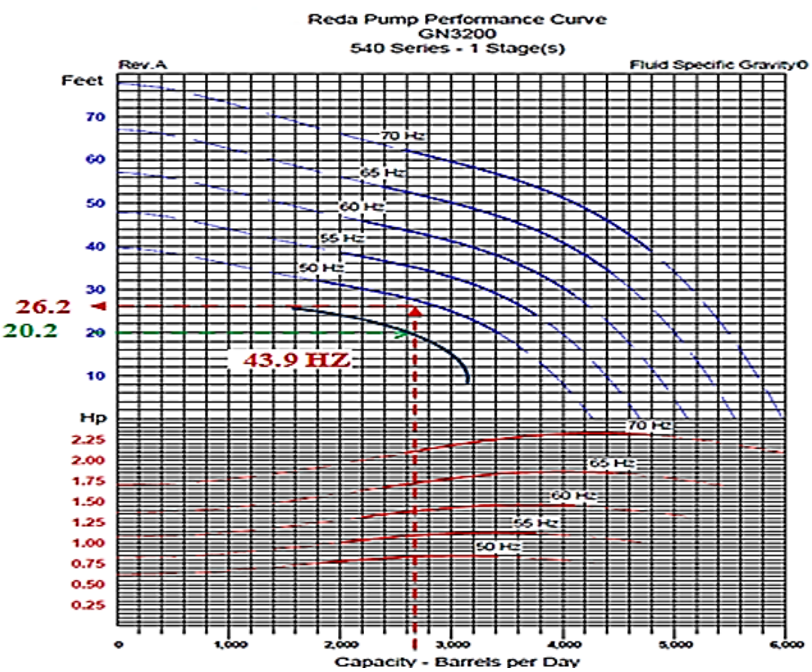

Figure 17: Pump performance curve

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5. Conclusion

According to Prosper software results, gas fraction entering the pump at the initial depth of 5340 ft is 1.17%. Therefore, using an AGH device is not required. And since it was intended to install the device regardless, results indicate that installing the AGH device at a lower depth of 2800 ft shows a significant increase in production rate. Setting the pump at 2800 ft poses no issues regarding free gas entering the pump even when the pump intake pressure is below bubble point, as AGHs can handle up to 45% of free gas at its intake, and Software results show that at this depth free gas entering the pump is 39%. Regarding the VSD case study, to produce the desired rate of 2834 bbl/d using (GN3200) pump, only 78 Stgs are required. However, given its lack of availability, the company installed a pump with 102 Stgs and instructed to adjust the choke to maintain the production rate within the pump's capacity range. According to Gilbert equation, 36" bean size should be used to produce the required rate. Applying the Affinity Laws, a frequency of 43.9 HZ was obtained to run the motor to produce the desired rate of 2834 bbl/d using the currently installed number of stages 102 Stgs. Final results clearly indicate that significant electric power savings are possible if production control is executed by VSDs rather than the present practice of using surface chokes.

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