عدد خاص
بالمؤتمر الليبي الدولي للعلوم التطبيقية
و الهندسية
27-28- سبتمبر 2022

# Improve Poor ESP System Operated By Surface Choke With The Application Of Variable Speed Drive (VSD), Well (C-88-65) Sarir Field

**Ibrahim Salim Mohamd Hrari**[1]

[1] Zawia Higher Institute For Oil and Gas Science and Technology
[2] Sabratha University – Faculty of Engineering,
IbrahimHrari@gmail.com

## Abstract

Unlike other artificial lift systems, Electric Submersible Pumps, (ESPs) are inflexible as a specific pump has a unique restricted Recommended Operating Range, (ROR).

Most deviations from (ROR) is due to availability considerations and/or design inaccuracies. When such situation is faced, there are three possible solutions (a): Pump redesign or (b): Operating the unit at a different frequency using a Variable Speed Drive (VSD), however in case of oversized pumps, using a well head choke is a simple common used solution on site. The surface choke forces the unit to operate at its ROR by restricting the flow rate. However, such solution causes high hydraulic loss across chokes leading to remarkable waste of energy which inters affects the economy of the production system.

The paper manifests the influence of controlling the flow rate of an over sized pump (40 stages extra) using surface choke on the power loss by calculating the excessive head generated the pump which was 1159 ft and the consequent upstream pressure was 695 psi and the pressure wasted across the choke was 445 psi to make the pump produce 2000 STB/d with a well head pressure of 250 Psi. Furthermore, it introduces an alternative better solution lies in using VSD and obtaining 42.38 Hz as the required frequency at which the pump should be operated to meet the desired conditions (flow rate (q) & well head pressure Pwh).

**Keywords:** Wellhead choke, system analysis, efficiency, optimization, total dynamic head, Variable Speed drive, nodal analysis and electrical submersible pumping.

## الملخص

تعتبر المضخات الغاطسة الكهربائية غير قابلة للتعديل من حيث معدل الجريان الذي تم تصميمها لإنتاجه، وهي بذلك تختلف عن باقي انواع الرفع الصناعي مثل الرفع بالغاز او مضخة راس الحصان والتي فيها يمكن تعديل معدل التدفق حسب المعدل المطلوب حتى بعد اجراء التصميم وانزاله داخل البئر. للمضخات الغاطسة الكهربائية مدى انتاج لا يمكن الخروج منه لتفادي بعض الامور التشغيلية التي قد تؤدي الى تلف المضخة.

عادة تدعو الحاجة الى تعديل انتاج المضخات وهي داخل البئر نتيجة لأخطاء التصميم الناتجة عن عدم دقة البيانات الداخلة في التصميم خصوصا بيانات انتاجية الابار او نتيجة لإختيار مضخة أكبر من حاجة البئر لعدم توفر المضخة المطلوبة في مخازن الحقل. وفي هكذا حالات يتم التحكم في انتاجها بواسطة الخوانق السطحية, لكن هكذا حل رغم بساطته وكثرة تطبيقه فهو يجعل المضخة ومعدات الابار تعمل تحت ضغط بالإضافة الى فقدان للطاقة عبر الخوانق ويعد كل ذلك خسائر.

كحل بديل اكثر ملائمة يتم تطبيق جهاز لتعديل التردد (Variable speed drive VSD) الذي يضمن انتاج المعدل المطلوب دون الحاجة لإستعمال الخوانق وفي هكذا حالات يستعمل بدل عن (Switch board).

تبين هذه الورقة مدى استنزاف الطاقة الناتج عن استخدام الخوانق للتحكم في معدل انتاج مضخة تم تصميمها اكبر من حاجة البئر لعدم توفر الخيار الامثل, واتضح انه هناك 1159 قدم يقع استنزافها عند رأس البئر لجعل المضخة تنتج 2000 برميل سطحي/يوم وبضغط رأس بئر يساوي 250 رطل/بوصة مربعة. الورقة تبين ايضا انه بواسطة استخدام (VSD) يمكن تعديل معدل انتاج نفس المضخة ليكون 2000 برميل سطحي/يوم وبنفس ضغط رأس البئر دون الحاجة لإستخدام الخانق السطحي بتقليل التردد من 50 هرتز الى 42.38 هرتز.

## 1. Introduction

Setting up a lift system with a fluid producing capacity matches the well productivity it is installed in is the aim of any artificial lift design. It is crucial for a production design engineer to know the probable liquid rate in order to implement the mechanical design of the lifting equipment. In other words, the designer needs a precise estimate on the production rate attainable from the given well to avoid design inaccuracies. A mismatch of the designed and actually produced liquid volumes is a common result of improperly assumed well rates. [1]

Improper estimation of possible well rates leads to discrepancies between design and actual well rates and assuming improper design procedures are resulted. The consequences of over -, or under-sized artificial lift systems can lead to the following:

When over-sized, well productivity is over estimated, the operational efficiency of the unit cannot reach the designed levels; mechanical damage may also occur due to down-thrust (for floater impeller pump). [2]

However, In case it is under-rated, the well's productivity is under estimated, production loss is resulted and consequently less profit and mechanical damage may occur due to up-thrust.

In the industry, it is very often happens for artificial lift installations to be over-, and under-designed, and professionals know how to deal with such situations. Unlike some lifting methods such as gas lift or beam pumps where it is relatively easy to adjusted their lifting capacity in quite broad ranges after installation, ESP installations, do not tolerate design inaccuracies due to the fact that any given ESP pump has its unique restricted Recommended Operating Range, (ROR). If used outside its ROR, the hydraulic efficiency of the pump rapidly deteriorates; efficiencies can go down to almost zero. [1]

Operating ESPs under such conditions not only leads to loss of energy and the consequent decrease in profitability but also they soon develop mechanical problems that can lead to a complete system failure. Off down hole situations is the usual outcome and a workover job is required to run a newly designed ESP system with the proper lifting capacity that matches the design rate and well productivity. [3]

The paper demonstrates the detrimental effects of surface chokes on the power efficiency of ESP systems and introduces a better alternative solution lies in the application of VSD. The analysis is provided for wells producing negligible amounts of free gas and is based on the application of NODAL analysis principles to describe the operation of the ESP system. [4]

**CASE STUDY:**

Well (C-88-65) is an oil well in Sarir field operates with ESP. according to our design results the required rate of (2000 STB/d) can be obtained using only 110 Stgs, However, the company installed a pump with 150 Stgs, that is might be due to availability considerations. Consequently, it is required to adjust the Choke in order to keep the production rate in the expected work over results.

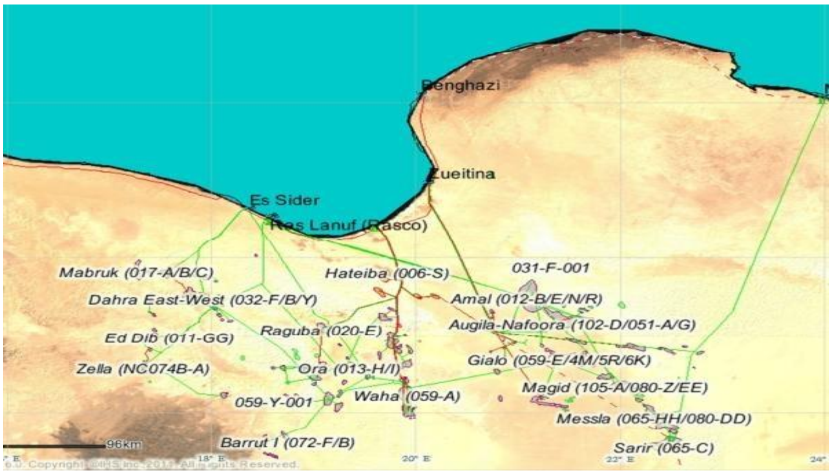


Figure- 1: sarir Field Location map

## 2. Review Current system design

According to the company design results only 110 stages of SN-2600 pump are required to produce the required rate of 2000 STB/d (3292 b/d). However, and due to availability considerations, an oversized pump with 150 stages (88 + 62) housing of SN-2600 is installed and a surface chock is used to control the pump rate at the workover result.

## 3. Methodology

The analysis requires reviewing the current system by implementing an ESP design to find out how many stages are required to meet the design rate. Having done that, the excessive head that the current unit generates can be obtained which in terns is used to fine the power wasted across the choke. Once the excessive head is obtained the Affinity laws can be applied to obtain the required frequency at which the pump with 150 stages should be operated to produce 2000 STB/d (3292 b/d) without using surface choke, and avoid the consequent power loss. Methodology involves: **1)** ESP design depending on the desired requirement, **2)** Choke back the current unit, and **3)** Applying the Affinity laws to obtain the required frequency for the current pump to be operated at to produce the desired rate with no choking back. Finally, a quick Look analysis on the pump performance at calculated frequency using Prosper Software is implemented. Following are the used flow chart and data:

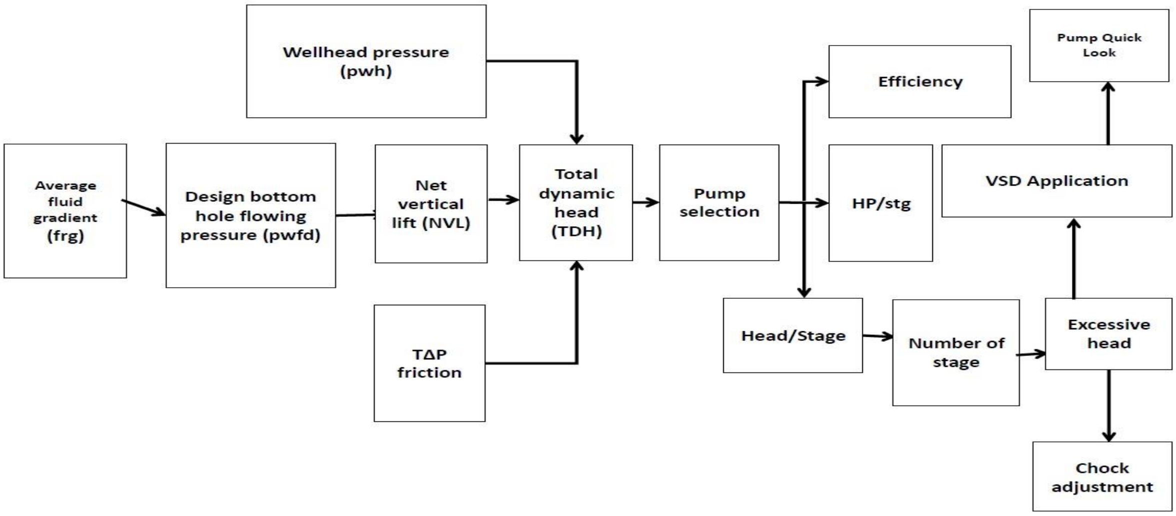


Figure- 2: Methodology flow chart

**Table - 1: Well, reservoir, fluid and production data**

| Parameter | value |
|---|---|
| **Field** | **Sarir** |
| **well** | **C-88-65** |
| **Operating frequency, Hz** | **50** |
| **Well data** | |
| **Datum, (ft)** | **8639** |
| **Casing (ID), in** | **6.366** |
| **Tubing (ID), in** | **2.992** |
| **Current Pump (ESP)** | **SN-2600** |
| **Actual no. of stages** | **150 housing (88+62), (choked back)** |
| **Production and Reservoir data** | |
| **Total desired fluid rate, STB/d** | **2000** |
| **Total fluid rate at Pump intak, b/d** | **2392** |
| **Well head pressure, psi** | **250** |
| **Oil formation volume factor, bbl/stb** | **1.3** |
| **Water formation volume factor, bbl/stb** | **1.04** |
| **Static reservoir pressure, (psi)** | **2700** |
| **Saturation pressure, (psi)** | **535** |
| **Pump sitting depth, ft** | **5000** |
| **PI, (stb/d/psi)** | **6** |
| **Water cut, (%)** | **40** |

| Water specific gravity | 1.1085 |
|---|---|
| Oil API, (◦) | 60 |
| Gas liquid ratio (R), cf/bbl | 200 |

## 4. Results

### a) ESP design:

- Fluid gradient calculation (fgr)

$$fgr = \left(\left(wo * \gamma w\right) + \left(Oc * \gamma o\right)\right) * 0.433 = 0.8868 * 0.433 = 0.384\, psi/ft$$

- PWF at design flow rate:

$$PWFd = \Pr - \frac{qd}{PI} = 2700 - \left(\frac{2000}{6}\right) = 2366.7\, psi$$

- Net vertical lift (NVL):

$$NVL = Datum - \left(\frac{Pwfd}{Fgr}\right) = 8639 - \left(\frac{2366.7}{0.384}\right) = 2475.7\, Ft$$

- Calculation of total pressure drop due to friction ($T\Delta pf$):

$$T\Delta pf = \left(\frac{\Delta p\ friction\ (chart) ft}{1000\ (ft)}\right) * psd\ (ft) = \left(\frac{18.48}{1000}\right) * 5000 = 92.4\, Ft$$

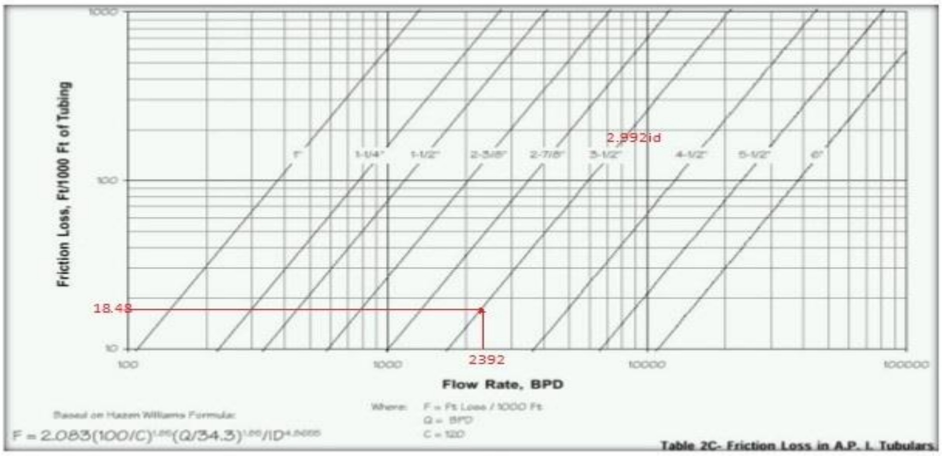


Figure- 3: Friction loss in the tubing chart. [4]

- Well head pressure (pwh) (ft)

$$Pwh\ (ft) = \left(\frac{pwh}{fgr}\right) = \left(\frac{250}{0.384}\right) = 651\, ft$$

- Total dynamic head (TDH):

$$TDH = (NVL + \Delta pf + Pwh)\,(ft)$$
$$= 2475.7 + 92.4 + 651$$
$$= 3219\,ft$$

- Pump selection:

SN-2600 is selected as it would fit inside the casing and produce the required rate at (ROR).

$$Qo = Qt * (1 - wc) * Bo$$
$$= 2000 * (1 - 0.4) * 1.300$$
$$= 1560\, bbl/day$$
$$Qw = Qt * wc * Bw$$
$$= 2000 * 0.4 * 1.040$$
$$= 832\frac{bbl}{day}$$
$$Qt = Qo + Qw$$
$$= 1560 + 832$$
$$Qt = 2392\ bbl/day$$

- At Qt of (2392 b/d), (380 m3/d), and using Pump Performance curve PPC we obtain the following:

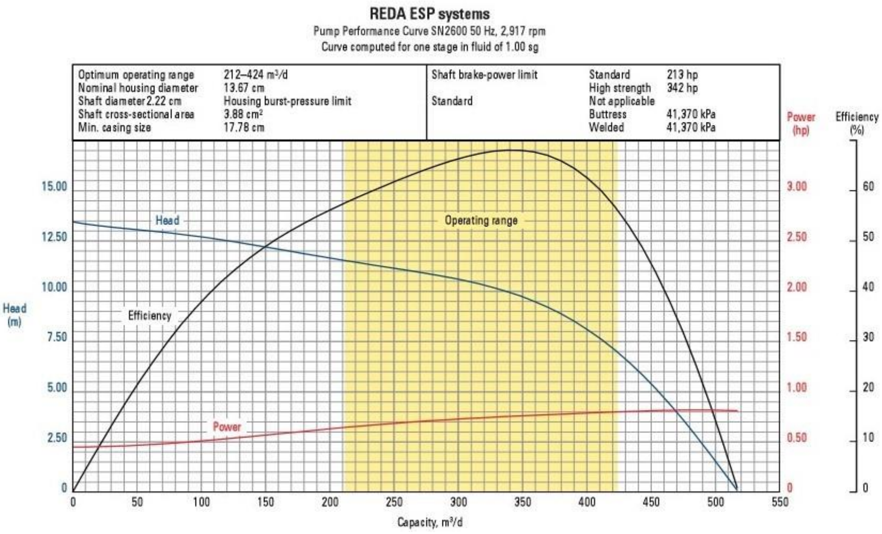


Figure- 4: Pump performance carve SN-2600 50HZ. [5]

$\frac{Head}{Stage} = 8.899\frac{m}{stage}$ $\frac{HP}{stage} = 0.79\ hp$ $Efficincy = 66\%$

$$\frac{head}{stage}(ft) = 8.899 \ * 3.28$$

$$= 29.19 \ ft$$

- Required No.of stages:

$$no.of \ stage \ = \left(\frac{(TDH)}{\left(\frac{head}{stage}\right)}\right) = \left(\frac{3219}{29.19}\right) = \ 110 \ stage$$

The required rate of 2392 bbl/d (380 m3/d) can be obtained using only 110 Stgs. However, to produce the same rate using 150 stages, one of the following scenarios should be applied; surface choke or VSD.

**b) Choke adjustment**

According to the design results, to produce 2392 b/d (380 m3/d) at 50 Hz, 110 stages are required but with 150 stage the rate would be 440 m3/d, which is out of the ROR. And to make the pump produce at its ROR, we must adjust the chock following this procedure:

At 50 Hz, one stage of SN2600 would give 29.19 ft/stage = $\frac{29.19}{3.28}$ = 8.899 m/stage to produce 380 m3/d.

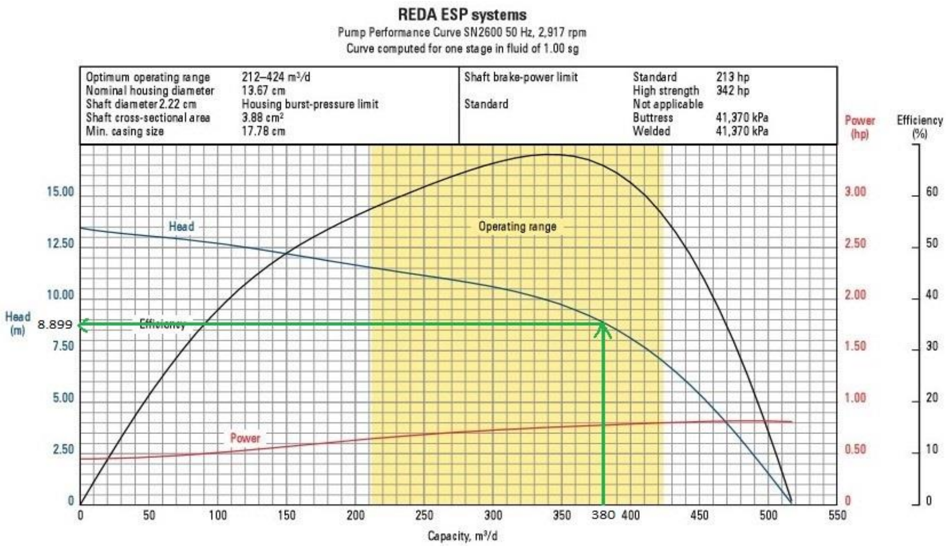


Figure - 5: Head corresponding 380 m3/d.

So, 150 stages would generate ahead of $150 * 8.899 = 1335 \ m$

$$= 1335 * 3.28 \ = 4378 \ ft \ , \qquad head \ generated \ with \ 150 \ stage$$

The excessive head generated equals:

$$4378\ ft - 3219\ ft = 1159\ ft$$

$$1159\ ft * 0.384\ ft/psi = 445\ psi$$

- This excessive head must be wasted at chock restriction.
- So the chock must be adjusted to maintain upstream pressure of 695 psi and downstream (whp) of 250 psi.

Then according to Gilbert equation, choke size is:

$$Htp = \frac{435 * q * R^{0.546}}{S^{1.89}} \rightarrow S^{1.89} = \frac{435 * q * R^{0.546}}{Htp}$$

Where,
Htp = tubing head pressure, psi
R = Gas liquid ratio, M cf/bbl
Q = flow rate, bbl/d
S = choke size, in (part of 64). [6]

$$S^{1.89} = \frac{435 * 2392 * 0.2^{0.546}}{695} \rightarrow S = 30" \rightarrow \left(\frac{30}{64}\right)^{"}$$

**c) Application of VSD to control pump flow:**

To obtain the frequency at which the motor should operate to produce 380 ft3/d using 150 stages, the following procedure is followed:

**1)** find excessive head, due to using 150 stgs, in (m):

$$\text{excissive head} = \text{TDH with 150 stage} - (\text{Actual calculated TDH})$$

$$\text{excissive head} = 4378 - 3219 = 1159\ \text{ft}$$

$$\text{excissive head} = \frac{1159}{3.28} = 353.35\ \text{m}$$

**2)** Find (head/stage) corresponding to the excessive head:

$$\frac{\text{head}}{\text{stage}} = \frac{\text{excissive head}}{\text{no. stage}} = \frac{353.35}{150} = 2.355\ \text{m}$$

**3)** Find the (head/stg) that gives 380 m3/d using 150 stgs:

$$8.899 - 2.355 = 6.544\ \text{m}$$

**4)** Using the Affinity laws, the frequency corresponding to (6.544 m) can be obtained as follows: [7]

$$\text{head at (Hz)} = \text{head at (50)} * \left(\frac{\text{Hz}}{50}\right)^2.$$

$$6.544 = 8.899 * \left(\frac{\text{Hz}}{50}\right)^2$$

$$\text{Hz} = 42.87 \text{ hz}$$

So, by adjusting motor frequency at **42.87** Hz, 150 stages would produce 380 m3/d.

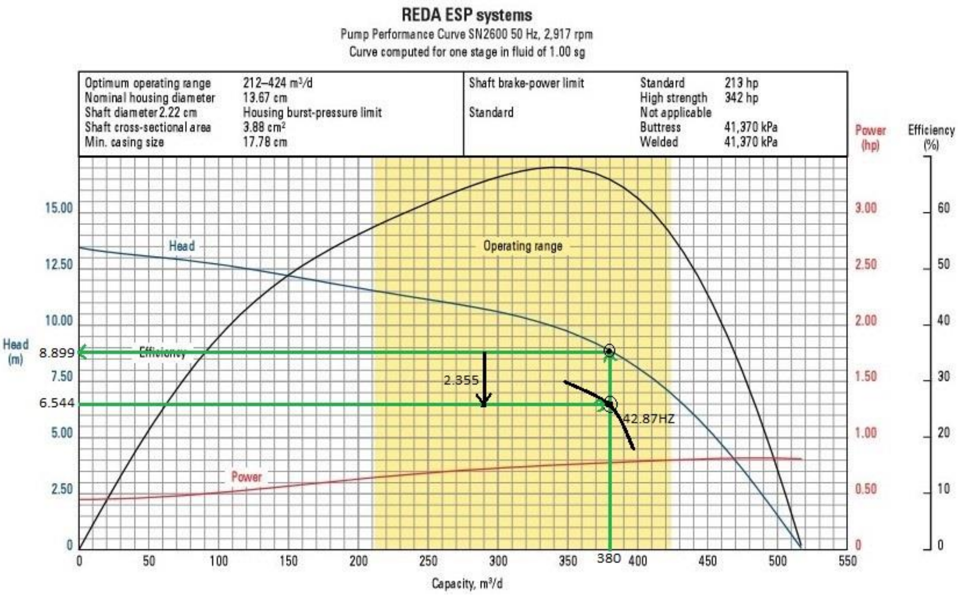


Figure- 6: fequency reduction procedure

- **Pump performance and quick look analysis using prosper software**

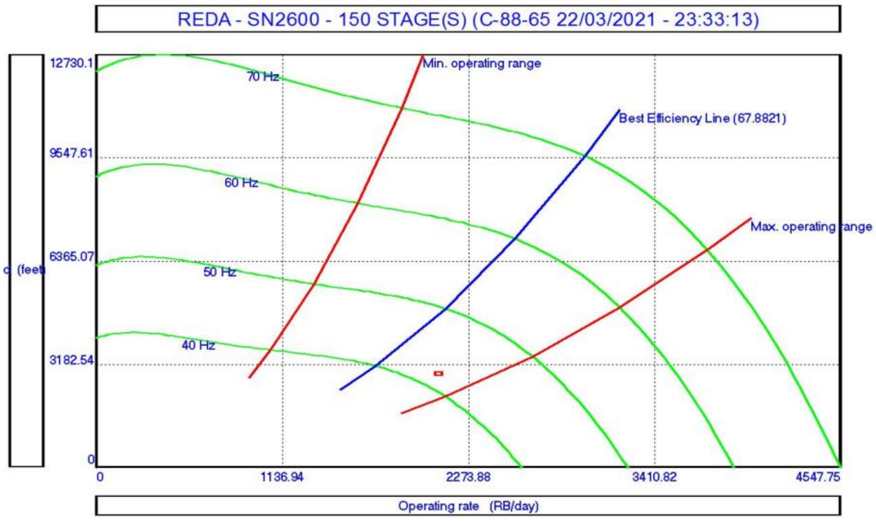


Figure- 7:Pump performances curve showing operating point at 42.15HZ.

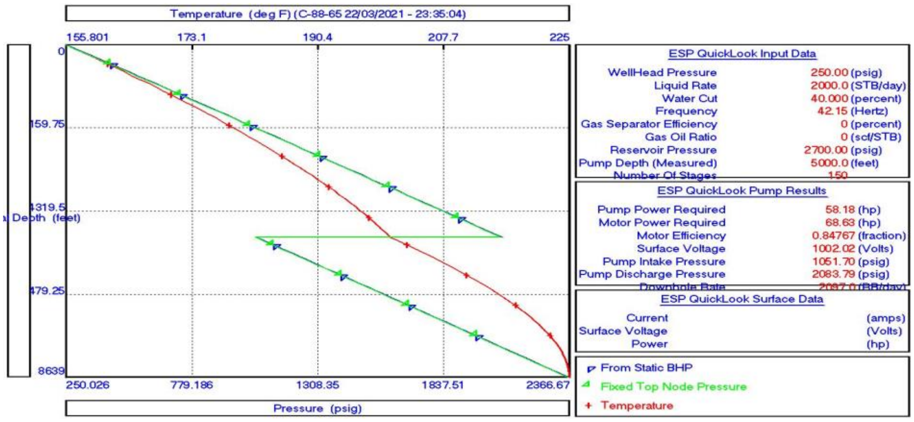

Figure- 8:Pump quick look analysis applying VSD

## 5. Conclusion

To produce the required rate of 380 m3/d using SN-2600 only 110 Stgs are required. However, the company installed SN-2600 with 150 Stgs which would be producing out of the (ROR); 430 m3/d. To control well flow at the required rate, and according to the company design sheet, the chock needs to be adjusted at (30/64) to main tain an upstream pressure of 695 psi which interns maintain a downstream pressure (Pwh) of 250 psi.

According to Prosper software results operating the pump at (42.15) Hz, (which is very close to 42.87 obtained from hand calculations), by applying VSD would make the pump produce at the required conditions with out choking back the pump which is considered a better solution in terms of power saving, protect well flow equipment from being subjected to high pressure and longer pump run life.

**Acknowledgment**

First and foremost, I would like to thank all the crew members in The Zawia Higher Institute for Oil and Gas Science and Technology for their encouragement and endless support in doing this paper. I would also like to thank the Arabian Gulf Oil Company (AGOCO), for their support without which I wouldn't have achieved my goal beyond doing this paper.

At last but not in least, we would like to thank everyone who helped and motivated us to work on this paper.

**References**

[1]. Takacs, G. (May 2009). Electrical submersible pump manual: design, operations, and maintenance. published by Elsevier Inc.

[2]. Brown, K. E. (1980). The Technology of Artificial Lift Methods. Tulsa Oklahoma: Vol. 2b PennWell.

[3]. Bearden, J. (August 2007). Petroleum Engineering. SPE.

[4]. Centrilift. (1999). The Nine Step. Claremore Oklahoma.
[5]. production-technology. (n.d.). Retrieved from https://production-technology.org/pump-performance-curves/.
[6]. Craig B. Smith, K. E. (2016). Energy Management Principles (Second Edition).