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An approach to account ESP head degradation in gassy well for ESP frequency optimization

V.A. Krasnov, Rosneft; K.V. Litvinenko, BashNIPIneft; R.A. Khabibullin, RSU of oil and gas

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Abstract

The majority of Western Siberia oil wells in Russia equipped by electric submersible pumps (ESP). Nowadays the common practice is to operate oil well with ESP as close to its production potential as possible. This strategy allows achieving maximum oil rates and economic efficiency according to Vogel's inflow relationship.

Main limiting factor to decrease BHP and increase well's oil production is an ability of ESP to work with high free gas fraction at pump intake. It is well known that ESP fails to generate pressure drop with high gas fraction at pump intake. However, there is no appropriate mathematical model to account it in ESP design properly.

It is often assumed that ESP works well with gas fraction at pump intake below critical and cannot operate with gas fraction at pump intake above critical. Critical gas fraction varies for different ESP types and manufactures from 25% to 35% and even 50% for ESP with gas handling devices like MVP from Centrilift, AGH or Poseidon from Schlumberger. Using this assumption one can conclude that affinity law should work well for ESP with gas fraction below critical. Nevertheless, it is often observed on wells with high gas fraction that increasing of ESP rotating frequency does not affect BHP and production as it predicted by affinity law.

This paper discusses an approach to describe an abnormal well behavior after frequency change. It shows that correlation for ESP head degradation as in SPE 117414 combined with nodal analysis technique allows to predict well behavior with high free gas fraction. It also allows optimizing energy consumption by ESP by varying ESP rotating frequency. Field cases discussed.

Nodal analysis overview

Nodal analysis introduced by Mach, Proano and Brown [Brown 1984] and described in detail in [Brown 1984] is a powerful tool for oil well performance analysis. It is widely used for self-flowing well and artificially lifted wells analysis and design. However, nodal analysis usefulness in not fully utilized yet. One of the nodal analysis advantages – is its ability to present ESP and well performance characteristics in graphical form. Charts and plots allows analyzing solution obtained and its sensitivity to initial data. Often it is useful to present same data using different plots highlighting different aspects.

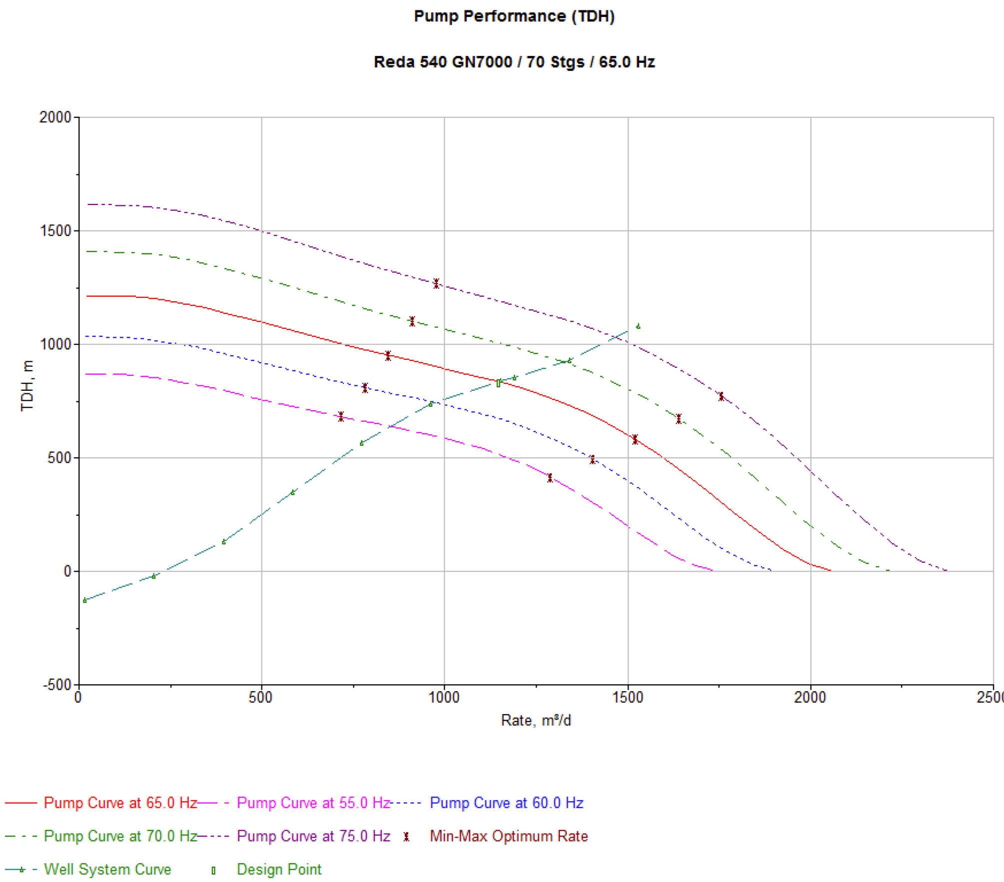

Figure 1—Well system curve example (plot from pump design software)

Oil well with ESP can be described using different tools. Most widely used tool is a well system plot used for ESP design. Well system plot combines pump performance curves and well system curve (Figure 1). Well system curve show difference in the outflow head and inflow head.

Well system plot is convenient for selecting pump type, number of stages and frequency because it utilize pump performance curves provided by pump manufacturers.

Other tool is nodal analysis plot for ESP well. Placing analysis node at bottom hole we can separately plot inflow curve, often based on Darcy's law with Vogel correction [Vogel] and pump intake curve. Pump intake curve shows pressure difference in well from bottom to top including casing, pump and tubing.

In contrast to well system plot, nodal analysis plot focuses to well performance analysis instead of pump performance. It depends on pump performance characteristics but uses indirectly and requires its conversion from head to pressure drop. Calculating pressure drop from head developed by pump become complicated with presence of free gas fraction at pump intake. Free gas decrease gas-liquid mixture density and decrease pressure drop developed by pump even assuming ESP can produce its head. Following example from [Brown 1984], one can find that for some specific well increasing number of stages in ESP will lead to decreasing intake pressure and increasing of rate (Figure 3).

Inspection of Figure 3 shows that, beyond 5375 stbl/d, the number of stages as the horsepower requirement increase very fast without significant gain into production rate [Brown 1984]. Same EPS's behavior can be found on nodal analysis plot Figure 2 Increasing number of stages by the same number give less gain into solution production rate with increasing of overall stages number due to multiphase nature of flow in pump at low intake pressure. However, well system plot (Figure 1) cannot provide this

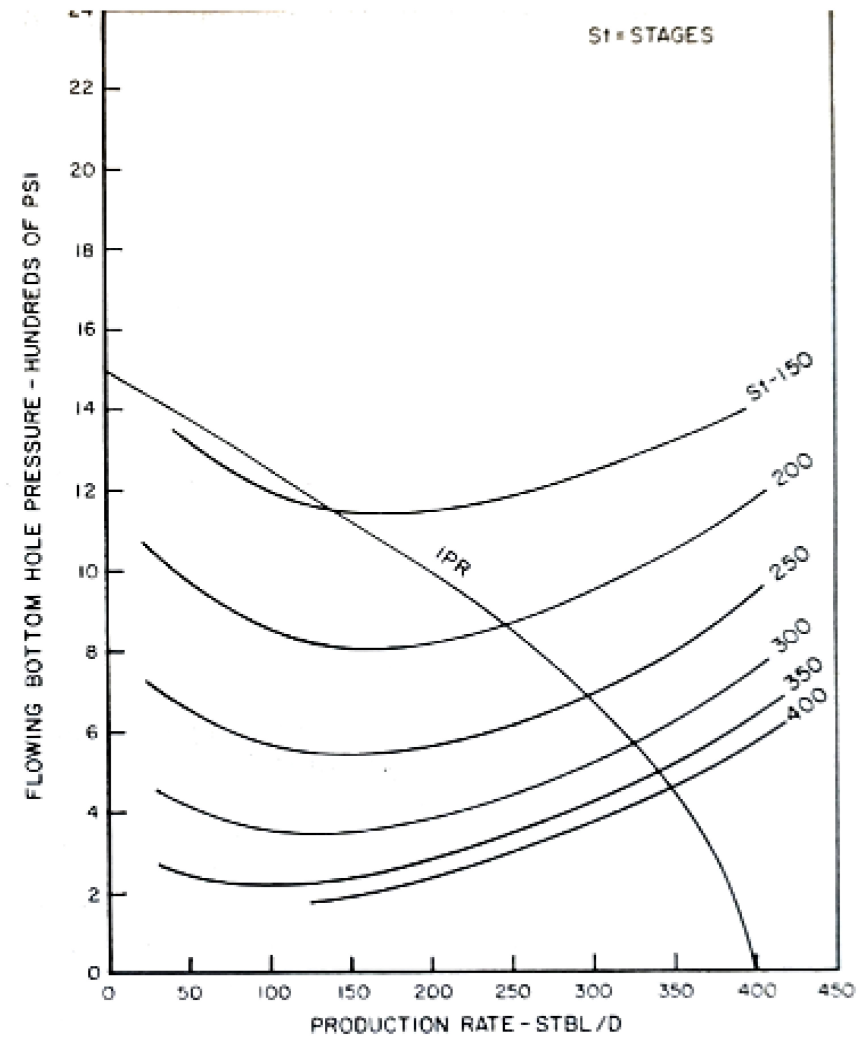

Figure 5.40 Intake Curves for an Electric Submersible Pump in Well #2 (Pumping Liquid and Gas)

Figure 2—Nodal analysis plot (from [Brown 1984])

information because of using non-modified pump characteristics. With same effectiveness, we could discus frequency change in ESP installation instead of changing number of stages.

We have used dependency on number stages here, following Brown's book, to show that calculating pump intake curves, taking into account multiphase flow is not quite a new concept. Moreover, Gabor has provided detailed algorithm for pump intake curve calculation in his book [Gabor 2009 p. 276 -277], although he has mentioned its complexity and necessity of computer software. However, for some reasons nodal analysis plot with ESP intake curve is not widely used in industry. For example, many of popular pump design and analysis software can draw well system plot but cannot draw nodal analysis plot with ESP intake curve.

Below we will show an example of using pump intake curve and nodal analysis plot for analyzing well working with high gas fraction at pump intake. Combined with ESP head degradation model in can predict ESP behavior well.

It is well known that ESP behavior can highly affected by presence of free gas in pump. Short overview of gas influence can be found is SPE 117414 for example. Field and laboratory studies show that ESP loses its ability to develop pressure drop in presence of free gas [Drozdov 2008, Duran 2004].

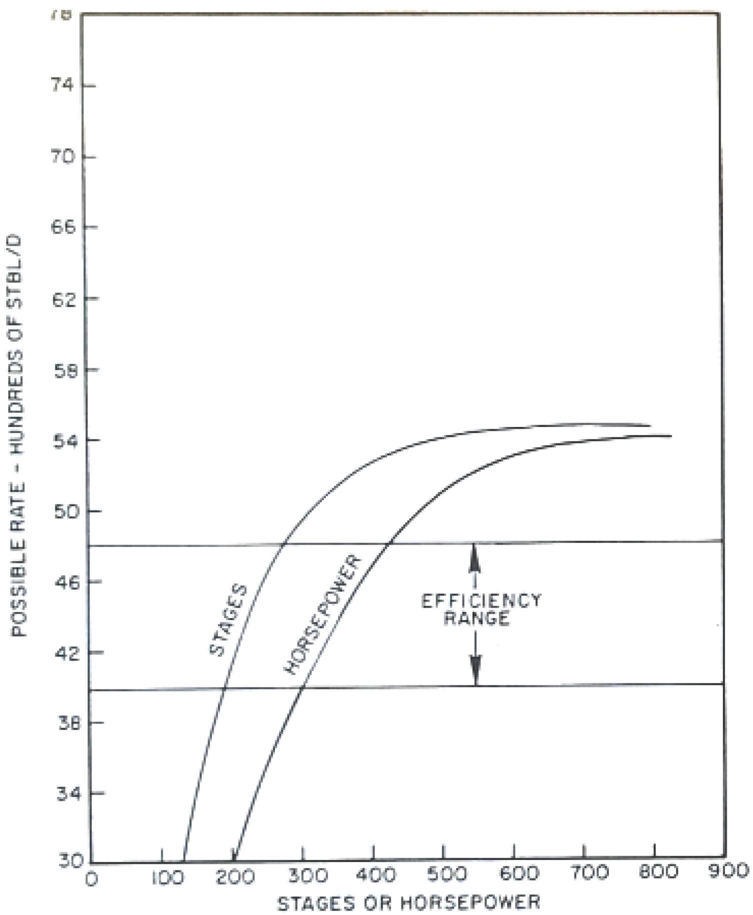

Figure 3—Possible production rate vs number of stages (from [Brown 1984])

Besides decrease in gas-liquid mixture density discussed above - ESP also lose its ability to develop head. This phenomenon can be described as head degradation. In this papers ESP head degradation model presented by [Bedrin 2008] is used due to its simplicity. It illustrated by Figure 5.

Quadratic form of ESP head degradation model simplify ESP intake curve calculations. Following [Bedrin, 2008] degradation coefficient for standard ESP can be expressed like

$$K_{\deg} = -9\beta_{\alpha x}^{2} + 0.6\beta_{\alpha x} + 1$$

Where $K_{\deg}$ – dimensionless degradation coefficient, and $\beta_{\alpha x}$– gas fraction at pump intake. Taking into account ESP head degradation an algorithm proposed by [Gabor 2004] can be upgraded as presented at Figure 6. The only change here is applying correction for ESP head degradation.

The algorithm are as follow:

1. Assume some rate q1
2. Assume gas liquid ratio (GLR) valid for the flow in tubing
3. Calculate pressure gradient in tubing using some multiphase flow correlation (we used Ansari correlation [Ansari 1994]). Pressure gradient calculation will give a discharge pressure.
4. Calculate pump intake pressure from ESP characteristic. Stage-by-stage calculation taking into account gas and oil volume factors required. It is assumed that ESP develop its head due to its characteristic.

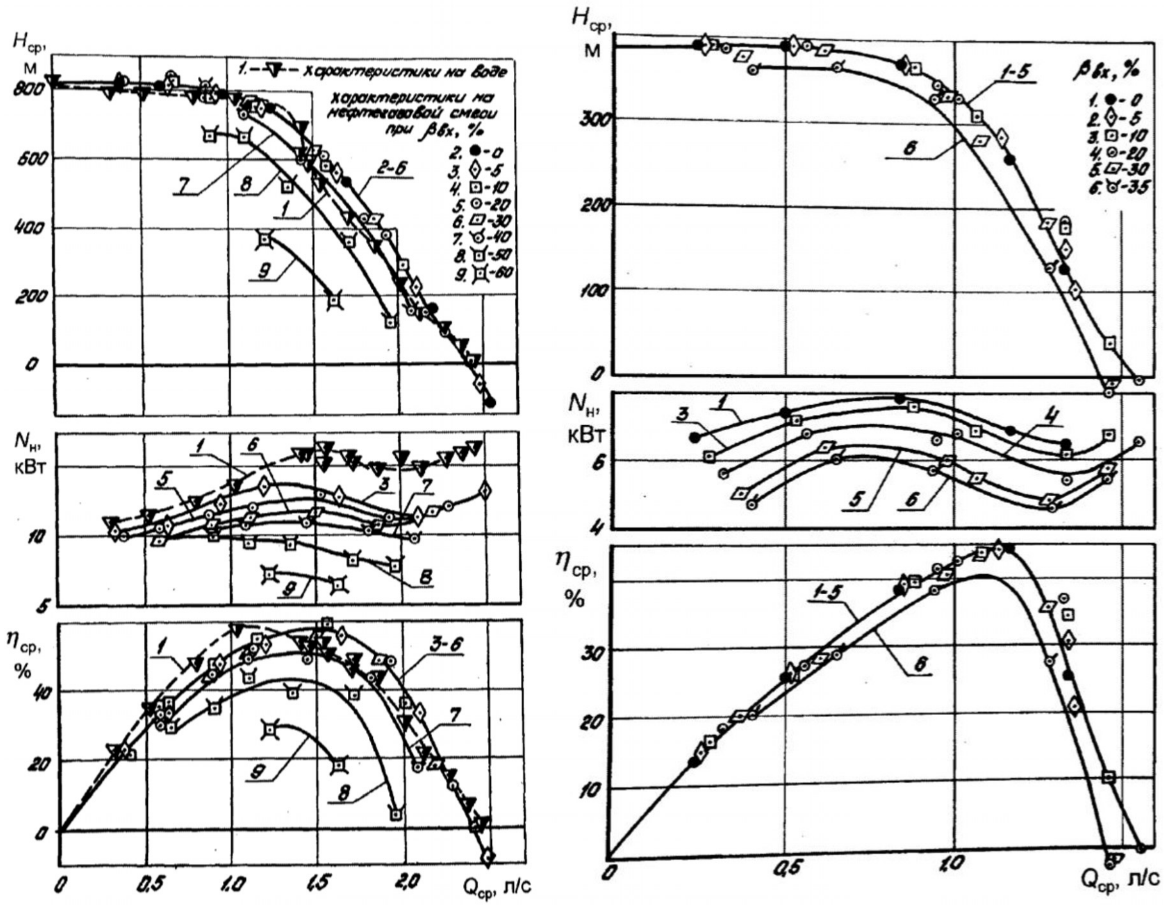

Figure 4—ESP head degradation from laboratory tests. Upper plot – head vs rate, middle plot – power vs. rate, lower plot – efficiency vs. rate [Drozdov 2004]

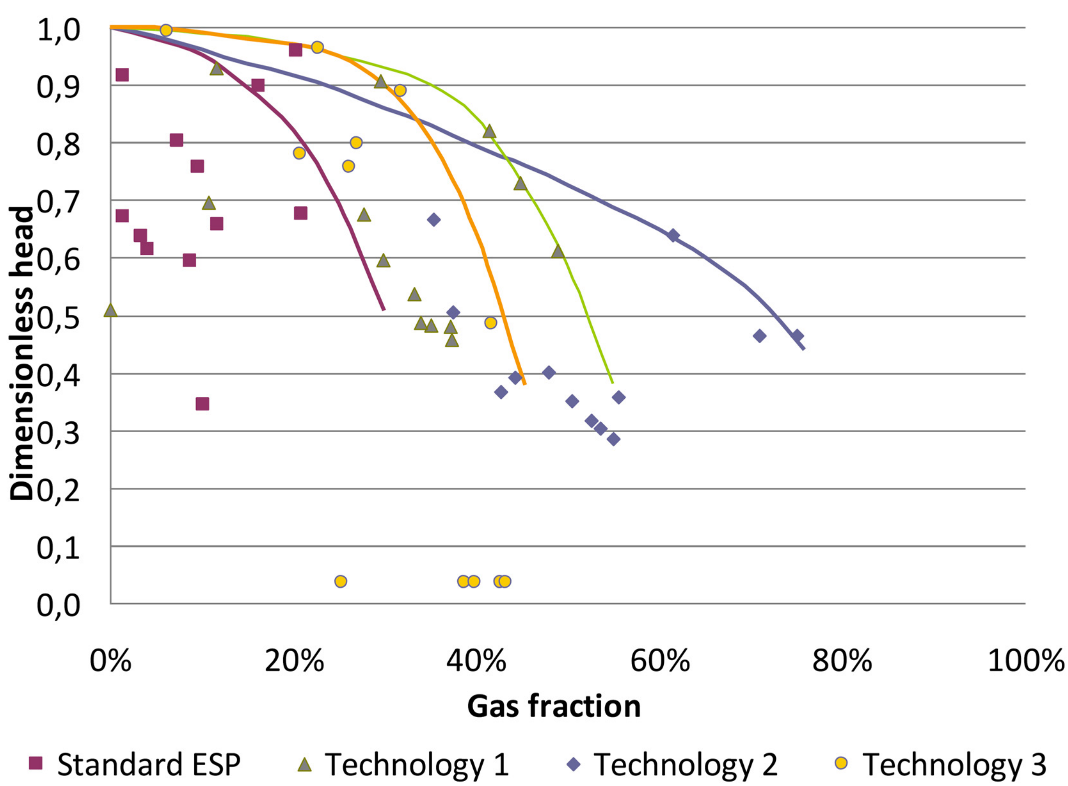

Figure 5—ESP head degradation from field case study [Bedrin 2008]

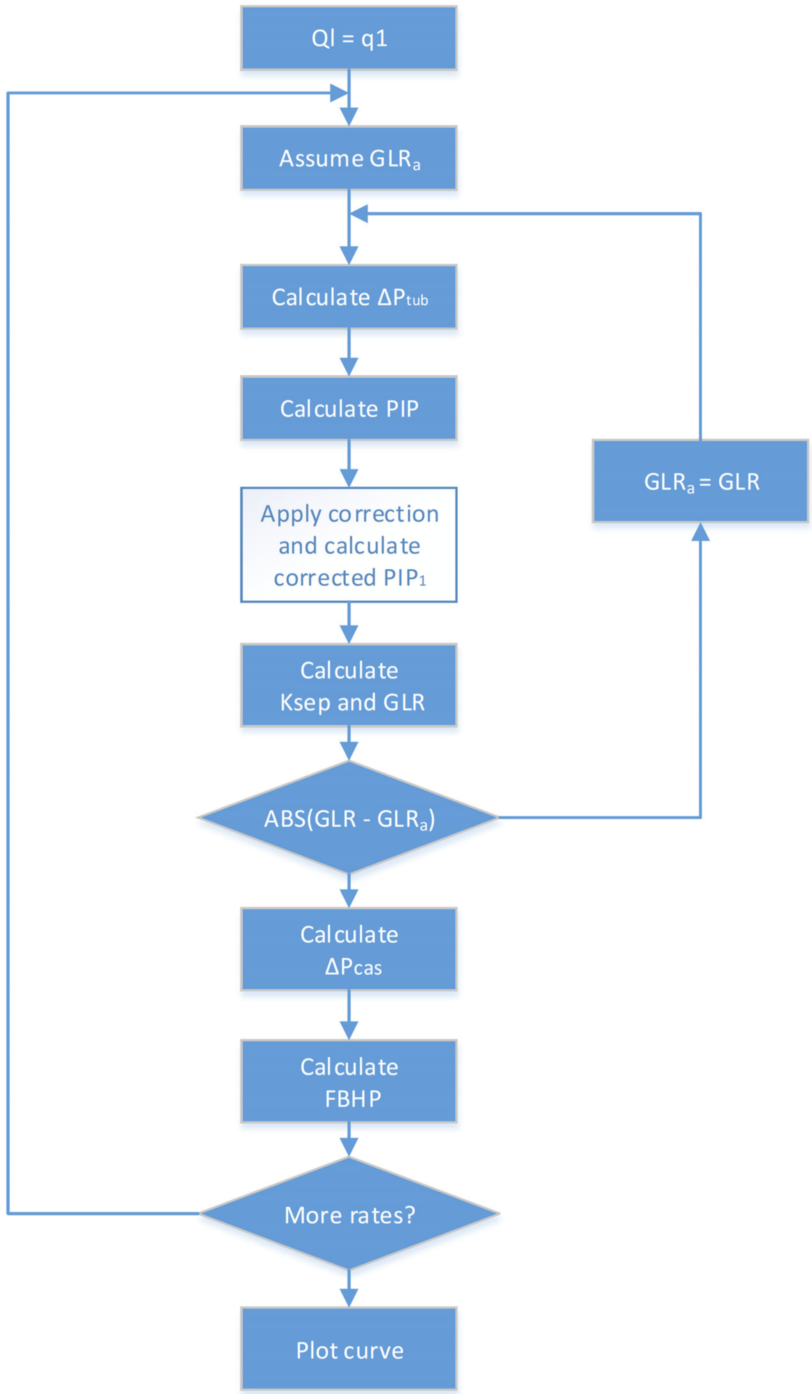

Figure 6—Flowchart for calculating pump intake curve (adopted after [Gabor 2004])

5. Apply head degradation correction to pump pressure drop according [Bedrin 2008]. It will give a pump intake pressure.
6. Calculate gas separation efficiency at pump intake (natural and forced) by some algorithms. Marquez correlation for separation efficiency [Marquez 2003] and gas separator test results [Drozdov 2008] used. Using separation efficiency new GLR in tubing can be estimated
7. Compare difference between new and old GLR. If it is not small enough repeat calculation from step 3. If it is small enough proceed next step.

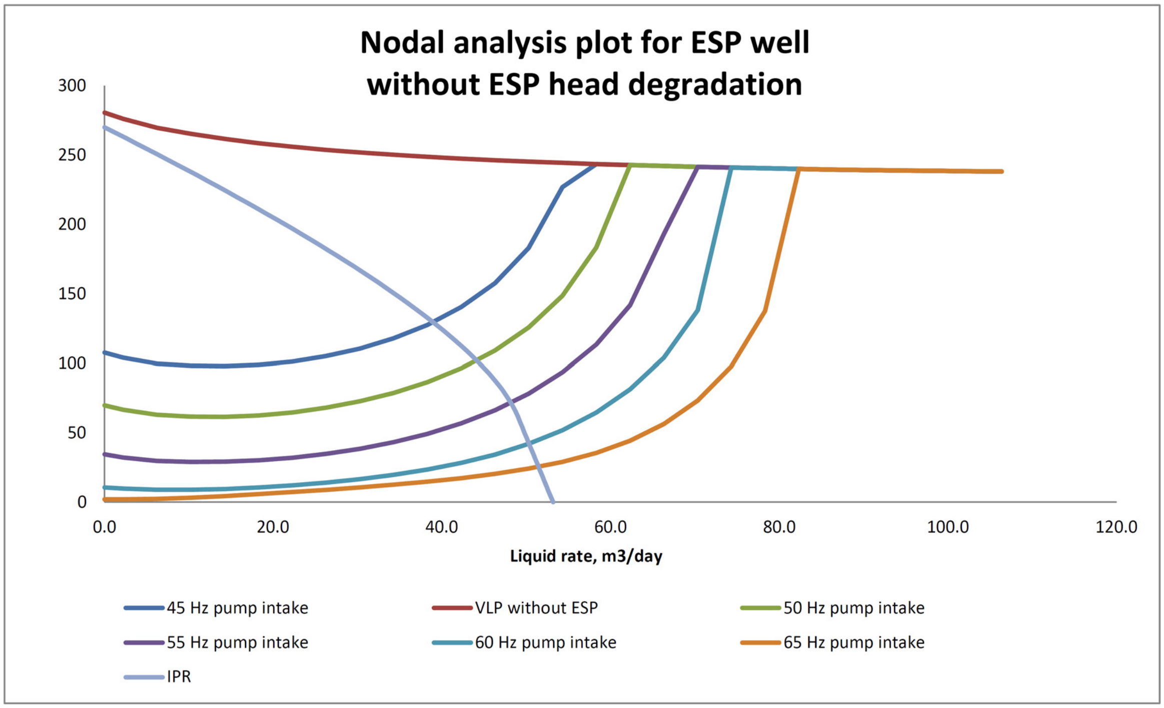

Figure 7—Nodal analysis plot without ESP head degradation

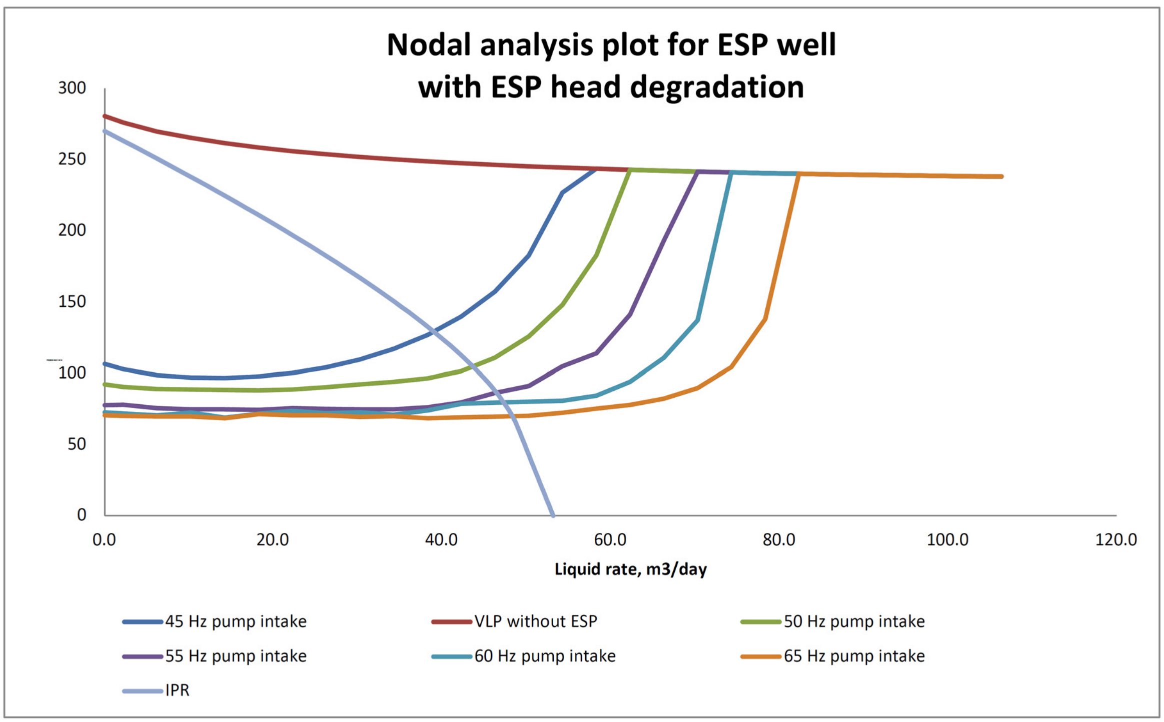

Figure 8—Nodal analysis plot with ESP head degradation

8. Calculate bottom hole pressure using multiphase flow correlation.
9. Check if more rate points need to be calculated.
10. Plot the curve.

Results of algorithm calculation are illustrated of Figure 7, Figure 8. Figure 8 show that ESP head

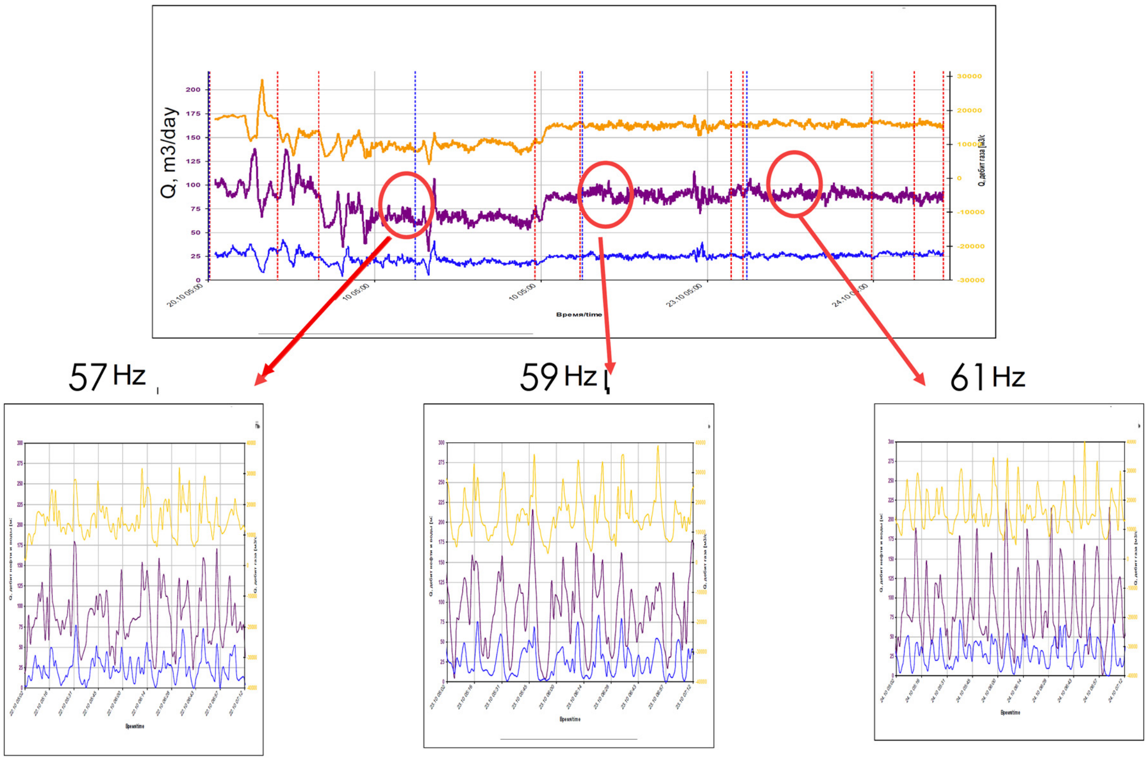

Figure 9—example of frequency change on well behavior (from [Bedrin 2008])

degradation cause that flowing bottom hole pressure for specific conditions cannot be decreased below 65 bar (approx. 1000 psi) by frequency change.

As it was mentioned at the beginning, the majority of Western Siberia well are working close to its production potential, which in most cases limited by amount of free gas ESP can handle. For example – Priobskoe field – one of the largest oil fields in Russia – average Pwf varies from 40 to 70 atm. which corresponds to 20 - 40% free gas fraction at pump intake after natural and forced separation. In addition, it is often observer for ESP equipped well that the changes in frequency do not affect Pwf and rates according to affinity law as it can be predicted from well system curve built by ESP design software (Figure 9). This behavior often confuse engineers and provoke using rule of thumbs instead of engineering calculations. Method presented allows to describe this phenomena taking into account ESP had degradation and correctly estimate target bottom hole pressure. Moreover -Figure 4 shows that ESP efficiency decreases with increasing gas fraction at pump intake. This make reasonable to estimate overall efficiency by ESP installation with different frequencies in order to improve energy efficiency of the system.

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