Nodal Analysis- based Design for Improving Gas Lift Wells Production

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Abstract

In this work, a gas lift-based oil production wells improvement technique is presented. This technique is based on Nodal Analysis, which is applied to well head level, where the production data are available. Thus, a production model is obtained, representing the production curve. This model allows calculating the production flow and pressure drop relationship that can be found in all the components of the completion system. So, it will be possible to determine the oil or gas flow that can be produced by the well, considering the perforation and completion geometry. With this information, we can build a production optimization system in order to increase the production flow rate.

Key words: Nodal Analysis, Production Systems, Artificial Gas Lift Well, Production Control.

1 INTRODUCTION

Hydrocarbons are produced from wells that penetrate geological formations rich on oil and gas. The wells are perforated in the oil and gas bearing zones. The hydrocarbons can flow to the surface provided the reservoir pressure is high enough to overcome the back pressure from the flowing fluid column in the well and the surface facilities. Detailed information on wells and well completion can be found in (Golan et al., 1991).

Any well production is drilled and completed to move the oil or gas from its original location in the reservoir to the stock tank or sales line. Movemenet or transport of these fluids requires energy to overcome friction losses in the systems and to lift the products to the surface. The fluids must travel throught the reservoir and the piping system and ultimately flow into a separator for gas-liquid separation. The production system can be relatively simple or can include many components in which energy or pressure losses ocurr.

The production rate or deliverability of a well can often be severely restricted by the performance of only one component in the system. If the effect of each component on the total system performance can be isolated, the system performance can be optimized in the most economical way. Past experience has shown that large amounts of money have been wasted on stimulating the formation when the well's producing capacity was actually being restricted because the tubing or flowline was too small. Another example of errors in completion design is to install too large tubing.

This often happens on wells that are expected to produce at high oscillating flow. It will be shown that this practice not only wastes money on oversized equipment, but too large tubing can actually reduce rate at which a well will flow. This can cause the well to load up with liquids and die, which necessitates the early installation of artificial lift equipment or compression.

Stabilization of gas lift wells using conventional control techniques has been studied for single well systems (Dalsmo et al.,2002), (Jansen et al., 1999); and for a two-well system (Eikrem et al., 2002). In (Imsland et al., 2002), a state feedback control law was designed using Lyapunov theory and this controller was used in an output feedback setting with an extended Kalman filter in (Eikrem et al., 2004).

A requirement for casing-heading instability is pressure communication between the tubing and the casing, i.e. the pressure in both the tubing and the casing will influence the flow rate through the injection orifice. There are in principle three ways to eliminate highly oscillating well flow. First, operating conditions may change to achieve stable condition. This can be done by increasing the gas flow rate and/or by reducing the opening of the production choke downstream the well. Both remedies reduce well efficiency. Second, the injection orifice may be a valve with critical flow, meaning that the flow through the injection orifice is constant. This is a solution that has achieved industrial interest. Third, the use of control is a method to stabilize well flow.

The producing companies of oil and gas realize constant big efforts to optimize its production systems. These efforts are directed, to medium and long term, to maximize the factor of recovery (Production of oil to the minor possible cost) of the reservoir, and, in the short term, to accelerate the recovery of the recoverable reservations. The latter, though it is a subprocess of the first, constitutes the "*Core of the Business*" of the petroleum production, since it allows maximizing the total daily production of hydrocarbons with the consistent economic benefit (Brown et al., 1980).

One of the most used techniques for optimizing the oil and gas production systems, considering its verified effectiveness and world-wide level trustworthiness, is the Nodal Analysis (Beggs et al., 1991). In order to optimize the Production system using this technique, it is necessary describing the production system, making emphasis in the required energy balance between the reservoir and the installed infrastructure, for establish the production capacity of the well. For this, it is necessary to construct a well model with reservoir and production variables.

The Nodal Analysis allows to evaluate the performance of a completions of production, calculating the relation of the flow of production and the pressure drop that will happen in all his components, allowing to determine the flow of oil or gas that can produce a well bearing in mind the geometry of the perforation and increasing the rate of production to a low cost.

In order to determine the Model of the System of Production using techniques of Nodal Analysis, it is necessary to describe the system of production, making emphasis in the balance of energy needed between the reservoir and the installed infrastructure; establish the capacity of production of the well, the variables of reservoir and of production, the correlations of flow selecting; and determine the properties of the fluids multifase in the pipeline of production and the curve of gradient of pressure in the well corresponding to its real conditions of production (Beggs et al., 1991).

This paper presents the efficiency of the technique of nodal analysis for obtaining behavior stable of wells, specifically for gas lift wells. Traditionally, the technique is applied at the bottom of the well needing technology for the measurement of pressure flow and temperature, but due to the costs of the above mentioned technique it is not profitable for wells with minor production to 500 BNPD (Hernandez et al., 2001).

In this work the balance of energy is applied to level of the well surface due to the fact that, it has an instrumentation system necessary for the same (Camargo et al., 2007), allowing to identify the relationship between reservoir capability and what the system of lift can handle. In this way, we can determine the real capacity of the well, generating increase of production to a minor economic cost due to the fact that we do not require technology at the bottom of the well.

This approach was applied and executed in PDVSA (Company Oil in Venezuela) with promising preliminary results.

This paper is structured as follows: Artificial Gas Lift is described in Section 2. Statement of the Problem is described in Section 3. Production Process of well and Nodal Analysis Based Well Model are described in Section 4 and 5, while results are shown in Section 6. The paper ends with conclusions.

2 STATEMENT OF THE PROBLEM

Typical gas lifted wells have a stable behaviour at elevated gas injection rates and unstable behaviour at low gas injection rates. This means that a gas lifted well is not producing the maximum possible amount of oil at low gas injection rates in spite of the fact that these wells are operated most efficiently at these injection rates. Unstable operational conditions are the most important reason for this.

Operating a gas lifted well under unstable conditions has several disadvantages. First, the full lift potential in the gas is not properly used, resulting in a very inefficient operation. Second, surges in the production facilities may be so huge that severe operational conditions are likely to occur. Third, production control and allocation becomes very difficult.

3 ARTIFICIAL GAS LIFT

Gas lift is a technology to produce oil and gas from wells with low reservoir pressure by reducing the hydrostatic pressure in the tubing. Gas is injected into the tubing, as deep as possible, and mixes with the fluid from the reservoir, see Figure 1. The gas reduces the density of the fluid in the tubing, which reduces the downhole pressure, Pwf, and thereby increases the production from the reservoir. The lift gas is routed from the surface and into the annulus, the volume between the casing and the tubing. The gas enters the tubing through a valve, an injection orifice.

The dynamics of highly oscillatory flow in a gas lifted well can be described as follows:

(1) Gas from the casing starts to flow into the tubing. As gas enters the tubing the pressure in the tubing falls. This accelerates the inflow of gas.
(2) The gas pushes the major part of the liquid out of the tubing.
(3) Liquid in the tubing generates a blocking constraint downstream the injection orifice. Hence, the tubing gets filled with liquid and the annulus with gas.
(4) When the pressure upstream the injection orifice is able to overcome the pressure on the downstream side, a new cycle starts.

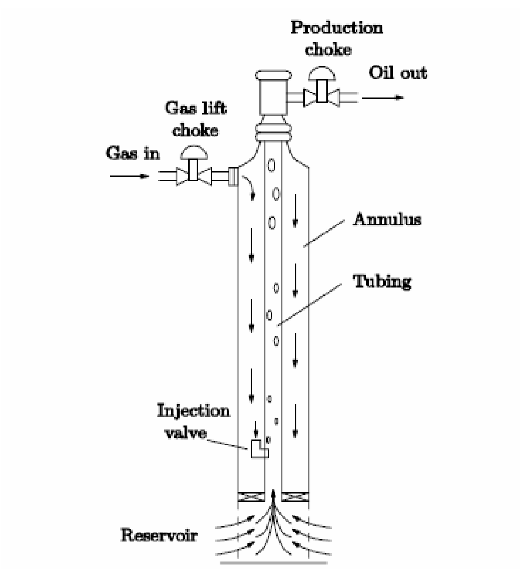

Figure 1. The Artificial Gas Lift

The Artificial Gas Lift (AGL) well behavior's model (figure 2), indicates that: when the gas injection rate increases, the production also increases until reaching its maximum value; but additional increases in the injection will cause a production diminution (Eikrem et al., 2002), (Jansen et al., 1999). The curve shows under which conditions the well exhibits stable or highly oscillatory flow. It is important to note that the average production rate may be significantly lower with unstable (see the line "open loop production"), compared to stable well flow (see the line "theoretical production").

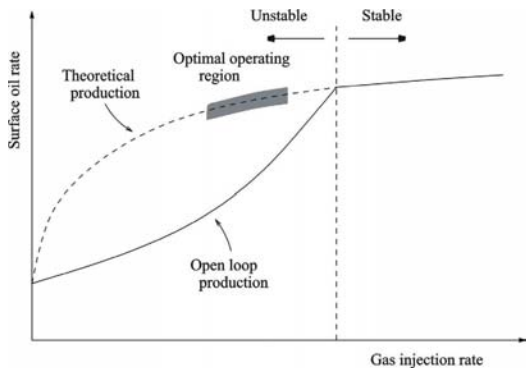

Figure 2. Artificial Gas Lift well behavior's model

Large oscillations in the flow rate from the well causes lower total production, poor downstream oil/water separation, limits the production capacity and causes flaring. A reduction of the oscillations gives increased processing capacity because of the reduced need for buffer capacity in the process equipment.

Gas lift can result in highly oscillating well flow when the pressure drop in the tubing is gravity dominated and there is a large annulus volume filled with compressible gas. In this case the pressure buildup inside the tubing under no-flow or low-flow conditions is faster than the pressure buildup in the annulus. If the pressure in the annulus is able to overcome the pressure in the tubing at a later point, the gas will flow into the tubing and the oil and gas will be lifted out of the tubing. After the fluid is removed from the tubing a new pressure buildup period starts. More information can be found in (Xu et al., 1989).

Unstable operational conditions may occur in a gas lift well because the characteristics of the systems are such that small perturbations can degenerate into huge oscillations in the flow parameters. Unstable production, often called heading, may lead to periods of reduced or even no liquid production.

At the highest gas injection rates, the pressure drop in the tubing is dominated by friction. If GOR (Gas Oil Ratio) rises, the tubing pressure will increase which will reduce the gas injection rate. This region therefore ensures stable production and explains why well stabilization by increased gas injection can be successful.

At low gas injection rates however, the hydrostatic pressure gradient dominates the pressure drop in the tubing. A small increase in

GOR results then in a lower tubing pressure, which leads to a higher gas injection rate from the annulus into the tubing through the down-hole gas lift valve. Since the gas rate is restricted by a gas injection choke at wellhead, the gas pressure in the annulus will be reduced. After a time the gas rate into the production tubing will therefore be reduced, with resulting lower oil production rates.

To further illustrate the stability problem, a stepwise description of a heading cycle is given below:

1.- Starting with an annulus pressure down-hole that is lower than the bottom-hole pressure, there is no gas flow through the down-hole gas lift valve into the tubing. Production rate and gas/liquid ratio is low. Gas is injected through the gas injection choke and annulus pressure builds up.
2.- After some time, the annulus pressure exceeds bottom-hole pressure, and gas is injected into the tubing through the down-hole gas lift valve.
3.- The injected gas lightens the tubing gradient so that bottom-hole pressure begins to decrease. Simultaneously, the production rate wellhead tubing pressure begins to increase.
4.- Gas now flows from the annulus in to the tubing at an increasing rate. Because insufficient gas can be supplied through the gas injection choke, annulus pressure decreases rapidly.
5.- Oil and gas are produced through the production choke at high rate. Wellhead tubing pressure passes through a maximum and bottom-hole pressure passes through a minimum.
6.- With decreasing annulus pressure, gas flow through down-hole gas lift valve decreases. The gradient in the tubing becomes heavier and bottom-hole pressure increases. The production rate and wellhead tubing pressure decreases again.
7.- When bottom-hole pressure exceeds annulus pressure, gas injection into the tubing stops. With continued gas injection rate at the wellhead, annulus pressure starts to build again.

Unstable production of gas lifted wells cause many drawbacks, surge is not in agreement with smooth operation and it implies safety aspects and shutdown risks. The total oil and gas productions must usually be less than the systems design capacity to allow for the peak production.

4 PRODUCTION PROCESS OF WELL

One of the most important components in the total well system is the reservoir. Unless accurate predictions can be made as to what will flow into the borehole from the reservoir, the performance of the system cannot be analyzed. The flow into the well depends on the drawdown or pressure drop in the reservoir, (Pws-Pwf). The relationship between flow rate and pressure drop occurring in the porous medium can be very complex and depends on parameters such as rock properties, fluid properties, flow regime, fluid saturations in the rock, compressibility of the flowings fluids, formation damage or stimulation, turbulence and drive mechanism. It also depends on the reservoir pressure itself and, depending on the drive mechanism, this may decrease with time or cumulative production.

The reservoir component will always be an upstream component. That is, it will hardly ever be practical to select Pr as the node pressure, although the sandface pressure Pwfs is sometimes selected. This will isolate the effects of the pressure drop across the perforations or gravel pack.

The process of production in a well of oil or gas begins from the external radius of drainage in the reservoir to the tanks where the oil is stored. The Figure 3 shows the complete system with four clearly identified components: Reservoir, Completión, Well and Flow Surface Line. There exists a pressure of reservoir of the fluids in the above mentioned process, which is the static pressure of the reservoir, Pws, and a final pressure, which is the pressure of the separator on the station of flow, Psep.

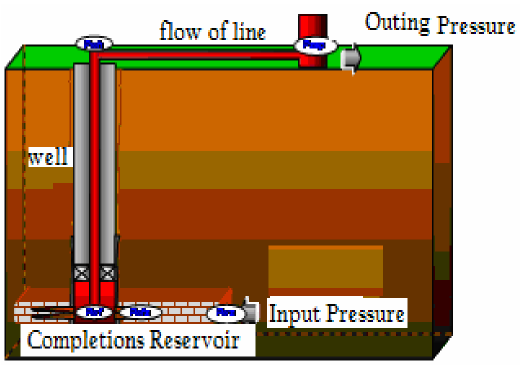

Figure 3. Productive Process of Well

The movement of the fluids begins in the reservoir to a distance “re” of the well where the pressure is Pws, travels across the porous way up to coming to the face of the sand or radius of the hole, “rw,” where the pressure is Pwfs. In this module, the fluid loses energy in the measure that the way is of low capacity of flow (Ko), presents restrictions in the environments of the hole (damage, S) and the fluid offers resistance to the flow (μo). The bigger it is the hole major will be the area of communication between the reservoir and the well, increasing the index of productivity of the well. On having crossed the completions the fluids enter to the bottom of the well with a pressure Pwf.

Inside the well, the fluids ascend across the pipeline of production conquering the force of gravity and the friction in the internal walls of the pipeline. In the well head, the resultant pressure is identified as Pwh.

The loss of energy in the shape of pressure across every component (see figure 4), depends on the characteristics of the produced fluids, and specially, the transported flow, in such a way that the capacity of production of the system answers to a balance between the capacity of energy input of the reservoir and the demand of energy of the installation to transport the fluids up to the surface.

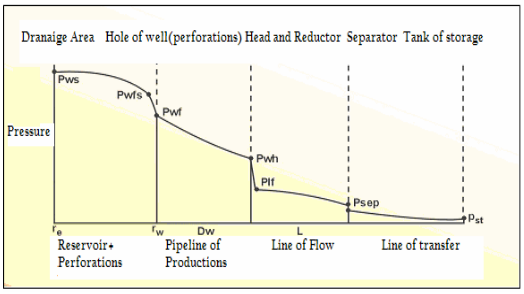

Figure 4. The loss of energy in a Systems of Production

4 NODAL ANALYSIS-BASED WELL MODEL

The analysis nodal system has been applied for many years to analyze the performance of systems composed of interacting components. Electrical circuits, complex pipeline networks and centrifugal pumping systems are all analyzed using this method.

The procedure consists of selecting a division point or node in the well and dividing the system at this point or node in the well and dividing the system at this point. All of the components upstream of the node comprise the inflow section, while the outflow section consists of all of the components downstream of the node. A relatioship between flow rate and pressure drop must be available for each component in the system.

The nodal analysis consists of finding the rate that a hydraulic system can handle, if the pressures are known at the entry and exit of the same. The Figure 5 represents a nodal analysis realized in a system constituted by two pipelines. It is known the input pressure of the pipeline 1 and the exit pressure of the pipeline 2, and the problem consists of finding the rate that can be handled by the pressures. For a pressure of entry (PE) and a pressure of exit (PS) exists only a possible rate (Beggs., 1991), the procedure consists of calculating the pressure to the exit for several rates. This pressure is called a pressure of the node. For a fixed pressure of exit of the pipeline PS, we can calculate the pressure of entry for several rates. Graphically, the pressures of the node obtained in both cases against the studied rates and the point of cut of both curves represent the point of balance where the system will operate.

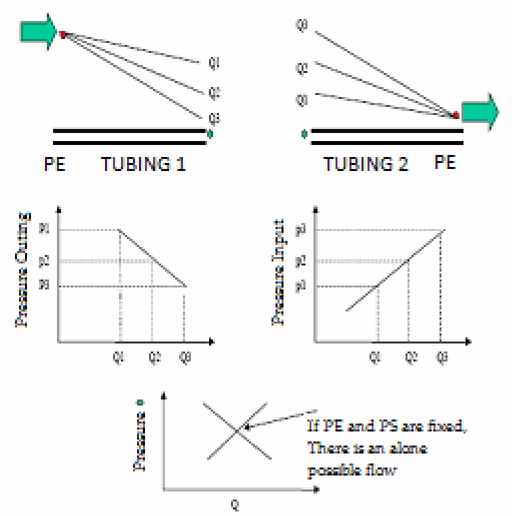

Figure 5. Nodal Analysis.

The Figure 6 shows the possible components of a nodal analysis for a well oil: the reservoir, the face of the perforations, the vertical pipeline, the well head, the line of flow and the separator. Also, it is shown in this figure the possible locations of the nodes: in the reservoir just before the perforations, at the bottom of the well (Technology of bottom) and at the head of the well (Technology of Surface).

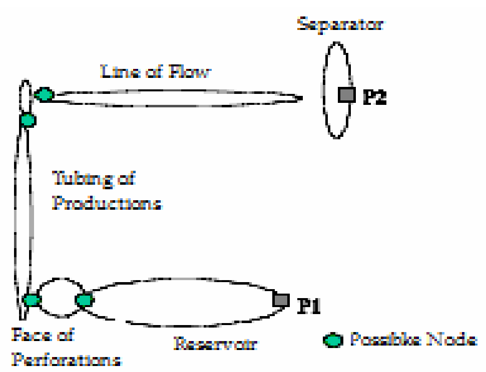

Figure 6. Nodal Analysis for Well Oil

4.1 Nodal Analysis Well Head.

The model of production of a well under the nodal analysis is obtained of the sum of the losses of energy in every component, which is equal to the total loss, that is, the difference between the pressure of begin, Pws, and the final pressure, Psep:

Pws – Psep = ΔPy + ΔPc + ΔPp + ΔPl

Where:

ΔPy = Pws – Pwfs = Pressure Drop in the Reservoir.

ΔPc = Pwfs- Pwf = Pressure Drop in the Completation.

ΔPp = Pwf-Pwh = Pressure Drop in the bottom hole pressure.

ΔPl = Pwh – Psep = Pressure Drop in the flow line.

To make the balance of energy in the node several rates of flow are assumed, and for each of them we decide the pressure with which the reservoir delivers the above mentioned rate of flow to the node, and the pressure needed in the exit of the node to transport and to deliver the above mentioned rate in the seperator with a remaining equal pressure to Psep.

The Nodal Analysis technique allows evaluating the production system performance, calculating the production flow and pressure drop relationship that will happen in all the completion system components. In the Nodal Analysis traditional, the energy balance is made at the well bottom, but in this work the energy balance was made at the well head (Figure 7), because it is available the appropriate instrumentation for that (Camargo et to., 2007). It was made in the following form:

Node Input Pressure:
Pwh (Inflow) = Pws – Δpy – Δpc - ΔPp

Node Output Pressure:
Pwh (Outflow) = Psep + ΔPl

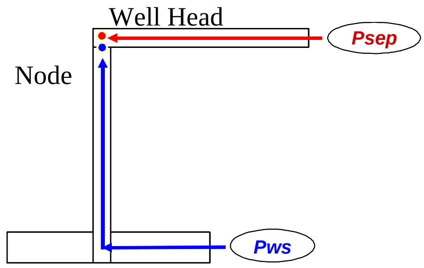

Figure 7. Well Head Node

Where Pwh is well head pressure, Pws is bottom hole pressure, Δpy is the pressure drop in the reservoir, Δpc is the pressure drop in the completion, ΔPp is the pressure drop in the well, Psep is the pressure in the separator, and ΔPl is the pressure drop in the flow line.

To make the balance of energy in the node several rates of flow are assumed suitably, and for each of them we decide the pressure with which the reservoir delivers the flow to node, and the pressure needed in the exit of the node to transport flow to Pressure Psep.

In order to graphically obtain the solution, both curves are drawn, and the production volume is obtained where the curves are intercepted, concerning different gas flow rates. Qliq is flow rate of the production (see figure 8).

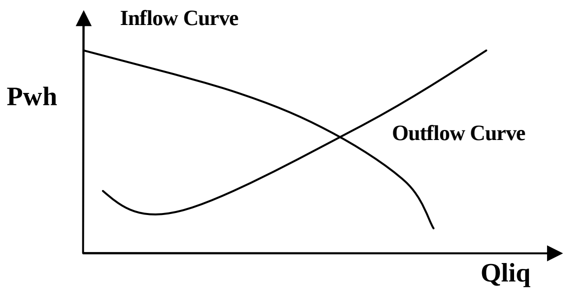

Figure 8. Inflow Curve vs Outflow Curve Intersection

The balance of energy between the “Inflow” and the “Outflow” can be obtained graphically. To make it, we assume several rates of production and calculate the pressure of inflow and outflow in the respective nodes, until both pressures are equal; of the intersection of the curve "Inflow" and the curve "Outflow", their respective rates of production are obtained.

5 RESULTS: INFLOW AND OUTFLOW CURVES FOR PRODUCTION WELLS.

The importance of obtaining reliable tests of the production of well must be born very in mind, the decisions on the operational programs and future expenses are based on the test. The falls in the production by below the potential expected from the well, they can indicate faults in the system of lift.

The behavior of many wells changes with the course of the time in the same way as the mechanical conditions of the valves do it. Therefore it becomes necessary a constant observation of the variables of the surface temperature, in order to support them operating correctly.

The well characteristics where the Nodal Analysis technique was implemented are the following: It flows without reducer towards the Flow Station located at 5360,89 ft and receives gas lift from the gas Manifold located at 508,53 ft far from it. It presents 25 API oil Gravity, 6% water Cut (see table 1).

Table 1. Physical Properties of the Flow

PVT	
Oil Gravity (API)	25°
Water Cutr (%)	6,02
Depth Perforation (ft)	3489

The completions of the producing vertical well of 3489 ft of depth, is composed by two valves of injection with an internal diameter of 2,43 in (see table 2).

Table 2 Well Completions System

Well	*Depht (ft)*	*Temperature (F)*	*DI (in)*
Tubing	3266.00	60.00	2.43
Valve 2 GL	3184.00	60.00	0
Tubing	3184.00	60.00	2.43
Valve 1 GL	1745.00	60.00	0
Tubing	1745.00	60.00	2.43
Head	0	60.00	0

The gas lift injection behaviour versus the production values in those wells was the following: initially, the well was operating at a gas injection rate from 1,1 to 2,2 MMSCFD (figure 8), where the associated well production was between 30,5 BPND and 180,1 BPND, which indicates high unstable well production.

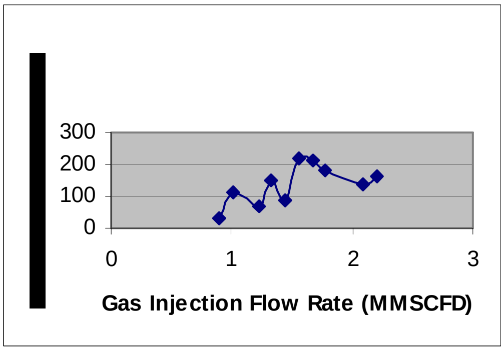

Figure 8. Initial Production curve

Using the Nodal Analysis technique, at the well head, the energy balances were made with several gas injection flow rates, and for each one of the reservoir pressures. That gives the volume of production of the well and the pressure required in the well output for transporting it to the separator. Taking as a reference the curve of initial production (see Figure 8), it determine to level of the head well (Camargo., 2007), to which rate of gas injection the pressures of bottom (Pwf) and surface (THP) are equal in a given instant. Graphically both curves and of the intersection "Inflow" and "Outflows", the rate of production was obtained (Figure 9).

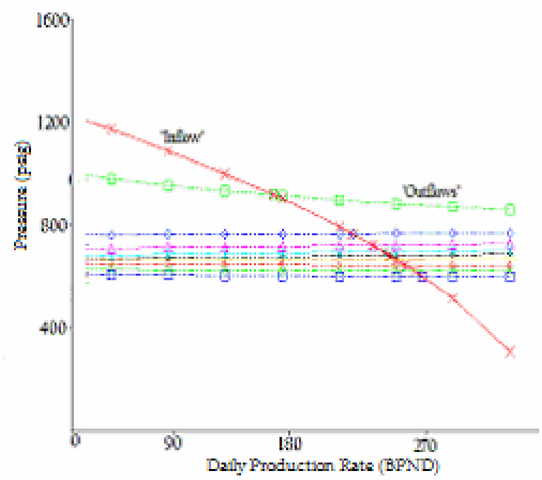

Figure 9. "Inflow" and "Outflow" Curve

With the rates of gas flow and the rate of production so obtained, the curve of production of the well is analyzed (see Table 3 and Figure 10).

Table 3. Flow of Injection vs Production

Gas Injection Flow Rate (MMSCFD)	*Daily Productions Rate (BPND)*
0	30
0,111	197
0,222	238,856
0,333	250,057
0,444	255,927
0,556	259,14
0,667	262,481
0,778	267,532
0,889	272,467
1	276,784

In agreement to the Figure 10, the rates of production of oil and gas must be in the order of (246 to 250) BPND and (0,5 to 0,7) MMSCFD. This gas injection was implanted in field founding an stable behaviour, allowing to generate greater production levels (in the order of (248±5) BPND) with a gas injection of 0,6±0,1 MMSCFD. These values were obtained at the flow station of the corresponding analyzed well.

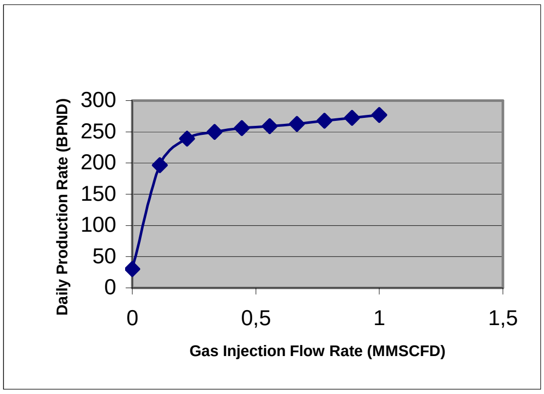

Figure 10. Obtained Production Curve

For the injection of gas lift of the well analyzed, we have used conventional control laws based on the model of the process obtained across the nodal analysis. The results are similar to the presented in the work (Dalsmo et al., 2002), (Jansen et al., 1999) and (Eikrem et al., 2002), except that they used technology of bottom for design the control law. This study describes a model for improving the artificial gas lift well production using Nodal Analysis, this model allows determining the well production rate and control at level surface.

Initial the well system has a lift rate (1,1 to 2,2 MMSCFD) which results in an oscillating system because the pressure drop is gravity dominant, while now well system is stable because one well receives all the lift gas (0,5 to 0,7 MMSCFD) and thereby the pressure drop of the flow becomes friction dominant.

However, the pressure measurement downhole in the well is not always reliable, because of the harsh conditions in a well. The control structure used the pressure in the top of the annulus as measurement, this measurement is easy available and reliable. The control structures regarding stabilization of the well systems are small. The structure which uses measurements of the pressure downhole has a shorter dynamic between the control input and output, compared to the measurement in the top of the head.

A high rate of injection gas will stabilize the well, as seen in the Initial Production curve, but not at an optimal operating point. A fixed choke opening will also stabilize the well, provided the opening of the choke is reduced until the flow from the well is stable. The reason why an increased amount of lift gas and/or a reduced choke opening gives stable flow is that the flow in the tubing changes from gravitational dominant to friction dominant flow.

The stable behavior of the well, represents the relation, between the reservoir is capable of reaching in comparison with what the system of lift can handle, identified the real capacity of the well, to maximize the factor of recovery (Production of oil to the minor possible cost) of the reservoir, and, in the short term, to accelerate the recovery of the recoverable reservations and increase of production.

To this respect, to have a system instrumentation to level of surface well, which controls the flow of gas injection and registers the pressures of the surface, allows to establish that the rate gas injection corresponds exactly with the production of the well and the functioning of the valve, indicating that the system of artificial lift this optimized (see Figure 11).

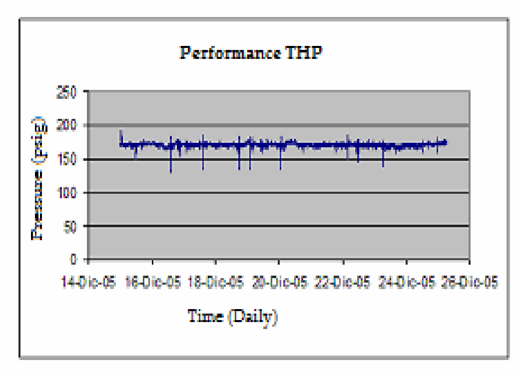

Figure 11. Performance THP

6 CONCLUSIONS

This paper shows how control can improve the performance of gas lifted wells by stabilizing the well flow. Finally, the study substantiates that there is a substantial economical benefit from controlling the pressure in the well, and thereby stabilizing production.

A model for improving the artificial gas lift well production using Nodal Analysis was presented; this model allows determining the well production rate, allowing the control of the gas injection. It was evaluated in high instability well that was generating low oil production levels. Using the inflow and outflow curves intersection, it was estimated the production curve, indicating that the gas injection rate is near 0,6 MMSCFD with a production of 250 BPND. This value of gas injection was implemented in field, presenting production values of (248±5) BPND with a gas injection of 0,6±0,1 MMSCFD, which indicates the model effectiveness obtained through the nodal analysis technique.

The use of this model obtained across nodal analysis, constitutes the first steps in the process of optimization of the production of the reservoir. This is orientated to the construction of mechanisms of observation, compilation of information and its interpretation to level of the surfaces, with the objective to provide intelligence to the process of production by means of the self-diagnosis and the auto-configuration in site.

The offer to realize the Nodal Analysis to Level of the Surface, allowing stabilizing the well, due to the unstable behavior that initially was presenting the well, the result of the Nodal Analysis allowed to optimize it to a minor rate of injection, generating a major level of production.

This paper shows how Nodal Analysis can improve the performance of gas lifted wells by stabilizing the well flow. Finally, the study substantiates that there is a substantial economical benefit from controlling the pressure in the well, and thereby stabilizing production a level surface.

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