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Study on Application of Arps Decline Curves for Gas Production Forecasting in Senegal

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P A P E R I N F O

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A B S T R A C T

The purpose of this study is to evaluate the feasibility of using methods for predicting the flow rates of gas wells in fields in Senegal. Accurate forecasting of natural gas production allows you to correctly set the operating mode of wells and design onshore infrastructure. One of the gas fields of Senegal was chosen as the object of study, where deposits were discovered within the exploitation perimeters in the Campanian and Santonian sandstone horizons. Gas formations have high porosity and permeability values, as well as high formation temperatures. Gas well flow rates can be predicted using hydrodynamic models, mathematical models (hyperbolic, etc.) and other methods. This study assessed the possibility of using Arps curves for long-term forecasting of gas flow rate and comparing the forecasting results with actual data. Comparison of Arps curves and actual gas flow rates for wells made it possible to note a discrepancy in the forecast results and actual values of more than 20%. These differences arose for two reasons. Deviations at the initial stage of well operation (6 months), which is associated with the adjustment of the technological operating mode of the well and the establishment of constant parameters of rocks near the wellbore. The second reason is well repairs, which change the properties of rocks near the wellbore. In general, Arps curves of exponential type showed high convergence between predicted and actual values, which makes it possible to use them in predicting the flow rate of gas wells in Senegal.

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NOMENCLATURE

K	permeability	SW	water saturation
Φ	porosity	q (t)	gas flow rate at time t
t	time, days or month	qi	initial gas flow rate at time to
b	the Arps decline curve exponent	Di	the initial decline rate, 1/day
G_P	gas rate-cumulative production		

1. INTRODUCTION

One of the most difficult tasks of gas production engineers is to accurately predict production, which is necessary for proper investment planning [1, 2]. The largest natural gas deposits are concentrated in the Middle East, Russia and Africa. Natural gas reserves are found in sandstones and limestones. Currently, dense gas deposits are also being actively introduced into development [3, 4], for such fields, the issues of forecasting gas production are relevant [5, 6]. Natural gas production plays a major role in the global energy system. In addition to energy, natural gas is actively used as a raw material for the production of chemicals, polymers, as well as by the population for heating housing [7, 8]. Forecasting the dynamics of production plays an important role in the process of creating infrastructure and evaluating options for the development of natural gas deposits [9]. A predictive method, such as decline curve analysis, cannot be applied before the wells are put into operation because it depends heavily on historical production to estimate parameters. For this purpose, a reliable method called drop curve analysis is used to compare the flow rate related to an individual and

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a group of wells or reservoirs using a mathematical function to predict productivity by extrapolating the drop function [10, 11]. A combined method for analyzing the characteristics of the fall of a multi-barrel horizontal well in shale gas reservoirs has been developed. They came to the conclusion that the composite model developed by them can give some idea of the mechanism of fluid movement in gas reservoirs and help analyze the decrease in productivity of such wells and reservoirs. A significant part of the models used to predict the gas well performance of the dip curve analysis models is based on the Arps equation models [12].

The Arps method was not originally intended to predict gas production [13]. There are several fall curve analysis models used for gas wells, including exponential fall, hyperbolic fall, harmonic fall [14], Duong model, Fetkovich analysis [15]. Comparison of typical curves is, in fact, a graphical method of visual comparison of production data using pre-constructed curves on a logging log.

Ultimately, the choice of the model depends on the specific characteristics of the gas well. Khanamiri [10] developed a method for forecasting production for oil and gas reservoirs based on the change in time and flow rate. The results showed that the output data of the oil reservoir model is the same as the results obtained using the hyperbolic equation, and moreover, the output data of the gas reservoir model is reliable compared to the Arps method.

It is shown by Can and Kabir [16] that the Arps method provides the smallest average error among the six methods for field data. Wells in the reservoir vault that have the highest reservoir capacity and have high b-factors, while wells in the periphery have low b-factors due to a thinner productive reservoir [17].

The Arps method can take into account the stratification of the formation, the properties of fluids, etc. Cheng et al. [18] proposed a diagnosis of the contribution of other layers. Ayala [19] also proposed methods for processing gas properties depending on pressure.

The data presented in the studies allows us to conclude that the use of gas production forecasting methods should be checked and tested in specific geological conditions. The purpose of this study is to examine the applicability of standard curves that can quantify the Arps b-factor for one of the gas fields of Senegal, revealing gas reservoirs along the production perimeter in the Campanian and Santonian sandstone horizons. To achieve the objectives of the study, a comparison was made of gas production forecasts using the Arps model with various values of the b factor and natural gas production from a real well. Finally, an analysis of the reasons for the deviation of the forecast and production data from a real well was performed and the conditions for the practical application of the models were determined.

2. OVERVIEW OF THE STUDY AREA

The study of the field area is located in the western part of Senegal between the administrative regions of Dakar in the West and that of Thiès in the East. It represents Figure 1. The most explored area of Senegal and is of great interest to the country, for which it currently produces most of the hydrocarbons.

The study area is located with the deferred logging data from the fields wells, a geological model of the deposit showing the geometry and expansion of the natural gas producing horizons, which materialized by sand lenses with an average thickness of 20 m and are more pronounced in the north-east for the Santonian reservoir whereas the Campanian reservoir are more important in the west of the field with an average thickness of 6 m [20, 21]. The creation of the National Petroleum Company in 1981 led to the discovery of new natural gas and oil deposits exploited between 1986 and 2000 in the area of the southern block: approximately 218,000,000 Nm^3 were produced. In 1997, the national company discovered a new natural gas deposit with the drilling well. Since then, oil activity has experienced considerable growth, thanks in particular to the arrival of the American company which in synergy with the national company, will develop this deposit with the wells from W-1 to W-6., to this study using W-3 data to analyze the decline curve between the production flow, cumulative rate and the time. The annual cumulative production of W-3 from 2008 to 2012 is 1110 MMscf.

Using the petrophysicals characteristics represented by the model of porosity, saturation and permeability, we find that the East zone in Campanian and the West and

Figure 1. Location of the study area

South - East zone in Santonian would be the most productive areas of the sector because of their porosity (20% ≤ Φ≤ 28%) and permeability (5 mD ≤ K ≤ 10mD), and their low water saturation (30% ≤ SW≤ 50%). The characteristics of the reservoir parameters are shown in Table 1. In addition, the gas properties are stated in Table 2.

3. CURVE ANALYSIS METHODS

The possibility of using semi-analytical solutions and reduction curves to predict natural gas production on the example of a field in Senegal has been investigated.

Drop curves can be used as a direct and consistent approach to analysis. Analysis of the drop curve is much easier to perform than hydrodynamic modeling and there is no need to monitor the value of reservoir pressure, which greatly simplifies the forecasting process.

When analyzing the drop curves, I have analyzed both the accumulated gas production indicators and the flow rates of gas wells per day or month by changing the time scale in logarithmic coordinates. Based on the dynamics of the actual flow rates of gas wells, a theoretical model is selected to predict the flow rate of gas wells for the future by extrapolation.

TABLE 1. Characteristics of the Campanian production reservoir of W-3 gas well

General Formation Data	Values	
Top Gross Pay	4538.4 ft	1383.3 m
Bottom Gross pay	4564 ft	1391.1 m
Porosity	23.4 %	23.4 %
Initial Water Saturation	30 %	30 %
Initial Reservoir Pressure	196.3 psi	13534.4 KPa
Reservoir Temperature	154, °F	67.8°C
Compressibility Factor	0.8779	0.8779
Productive Area	158 acres	64 ha
Net Pay	6.9 ft	2.1 m
Initial Raw GIP	1.005, Bcf	28327, 10^6 m^3
Recovery Factor	85 %	85 %
Initial Raw Recoverable	0.855 Bcf	24078,10^6 m^3
Marketable Reserves	0.769 Bcf	21670,10^6 m^3

TABLE 2. Gas properties of W-3 well

Data	Values
Gas Gravity	0.581
N_2 Concentration	0.140 %
CO_2 Concentration	0.150 %
Critical Pressure	4638 kPa
Critical temperature	196.8 K

By using injection flows from the reservoir into the well for gas wells, the permeability or hydroconductivity of the reservoir can be obtained.

The theoretical foundations for forecasting gas well flow rates were laid at the beginning of the twentieth century. In 1921, the main results of that time were published in the Manual for the Oil and Gas Industry [22].

Further, the mathematical apparatus used to predict oil production was developed [23], and probably the most significant contribution to the development of the modern concept of the analysis of the decline curve is the classic article by Arps [11], written in 1944. In this work, a significant number of exponential and hyperbolic equations are proposed for the analysis of well production. It should be borne in mind that the functions were obtained experimentally, not mathematically. The good convergence of the predicted and actual results has led to the constant use of the "Arps equations".

The main types of gas production reduction curves are presented in the following ratios [11, 24]:

$$\frac{q(t)}{q_i} = \frac{1}{[1+bD_i t]^{\frac{1}{b}}} \quad (1)$$

For b = 0 we can get the exponential reduction equation from the Equation (1):

$$\frac{q(t)}{q_i} = \frac{1}{(D_i t)} \quad (2)$$

The rate-cumulative production relationship is:

$$G_P = \int_{t_1}^{t_2} q_t dt \quad (3)$$

Replacing the q_t flow rate in the above equation with three separate expressions describing the types of reduction curves, and integrating gives the following equation:

$$G_{P(t)} = \frac{q_i - q_t}{(D_i)} \quad (4)$$

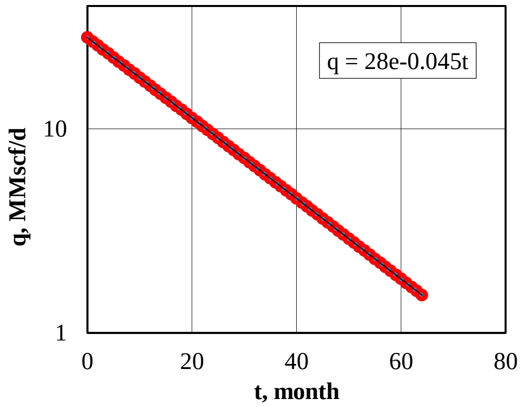
For gas wells, there is a qualitative forecasting of well flow rates for a month from time to time or from secured gas production (Figure 2).

By extrapolating the production values in a gas well, we can determine the time of its cost-effective operation and the final production values.

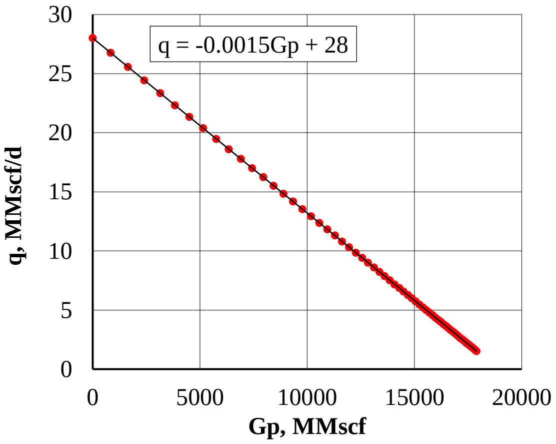
Degree b must be selected at the stage of selecting a model to predict the flow rate of the well. At 0 <b <1, we get a hyperbolic equation as in Equation (2).

As for the hyperbolic logarithm of the decline (q) as a function of time, it is no longer a straight line on the semi-logarithm, as shown in Figure 3.

For the accumulated gas production from time, we can obtain the following function based on the Equation (2):

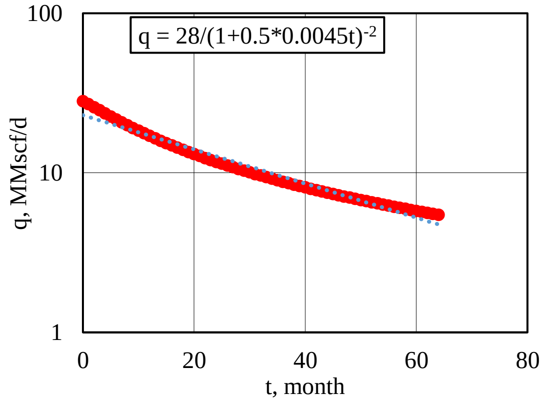


(a)

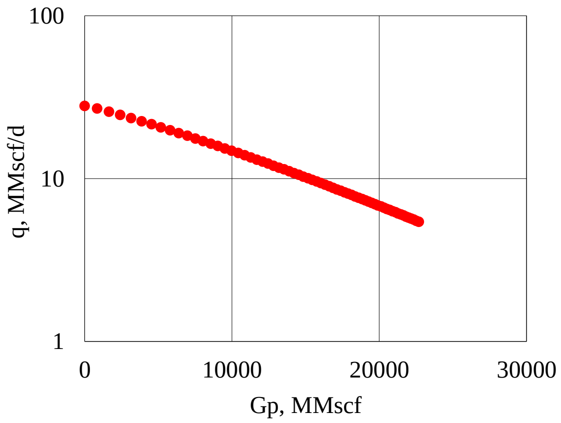


(b)

Figure 2. Exponential decline curve. (a) Rate-time curve; (b) Rate cumulative production curve



(a)



(b)

Figure 3. Hyperbolic decline curve. (a) rate-time curve; (b) Rate cumulative production

$$G_{P(t)} = \left[\frac{q_i}{D_i(1-b)}\right]\left[1-\left(\frac{q_t}{q_i}\right)^{1-b}\right] \tag{5}$$

In Equation (1), b = 1 corresponds to the harmonic decay and taking into account the following equation:

$$\frac{q(t)}{q_i} = \frac{1}{[1+bD_i t]} \tag{6}$$

If Equation (6) is integrated, the cumulative ratio of production to time over a period of time can be obtained and determined as follows:

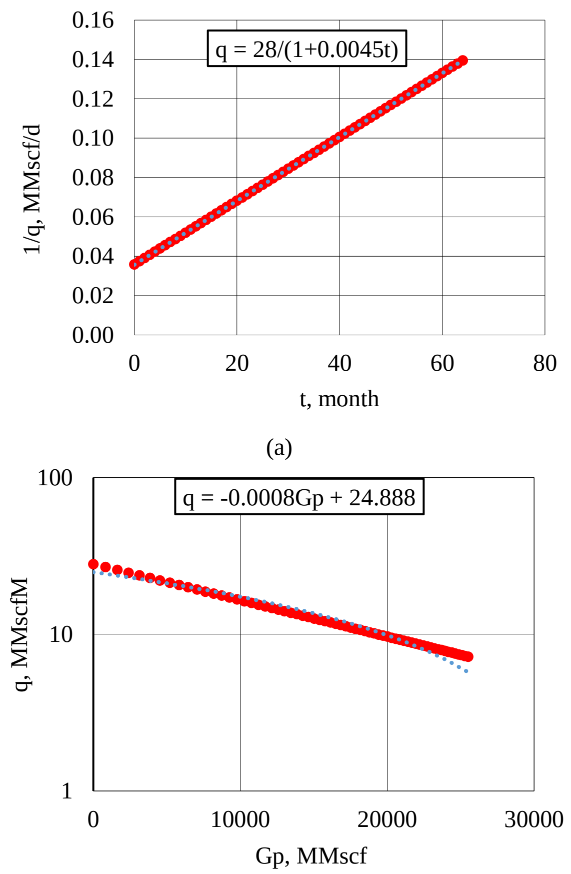
$$G_{P(t)} = \left[\frac{q_i}{D_i(1-b)}\right]\left[1-\left(\frac{q_t}{q_i}\right)^{1-b}\right] \tag{7}$$

The inverse dependence of the harmonic decay rate 1/q on time is linear, and the cumulative dependence on the log(q) (Figure 4).

4. DISCUSSION

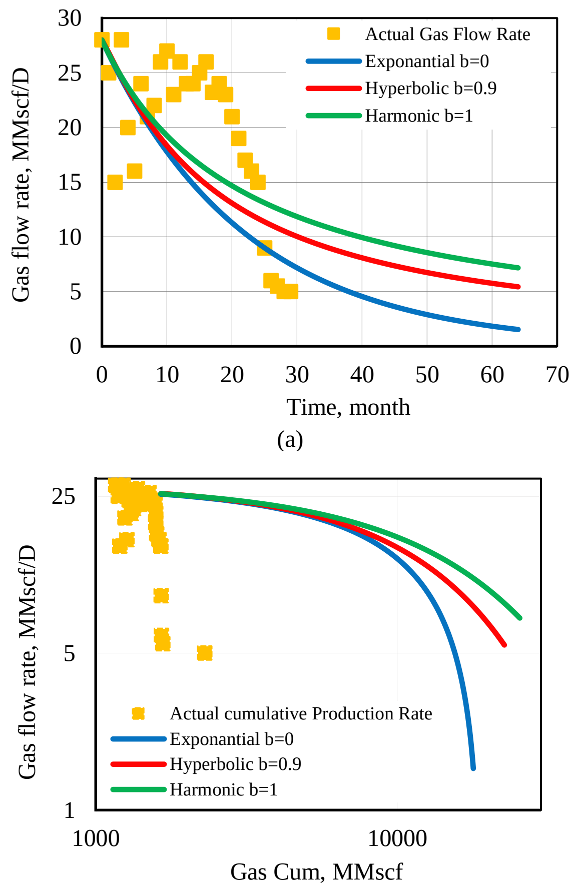
From Figure 5 it can be seen that an increase in the value of b leads to a greater decrease in the predicted flow rates of gas wells. With this, the harmonic decay is the fastest and the exponential decay is the slowest. For the considered reservoirs, the harmonic decay shows good convergence of the results. As shown in Figure 5, the deviation of the values calculated by the formula and the actual data in the first 25 months of forecasting was revealed. This is due to the establishment of the operating mode and optimization of well flow rates. Starting from the 25th month, the exponential Arps equation most accurately predicts the flow rate of a gas well in hyperbolic form. If 6 months of data is used for matching, excellent fit curves can be obtained, but there will be significant deviations in predicting the cumulative production trend. These phenomena are associated with well workovers and frequent shutdowns. Therefore, when the Arps method is used for analysis, the natural gas production time must be significant and must be sufficiently long. Using similar models by Guzev et al. [25], the error did not exceed 5%.

The studied equations take into account the state of rocks near the borehole wall in the initial state. During the operation of a well, various phenomena can occur in the reservoir that change the permeability [26-28].



(b)

Figure 4. Harmonic decline curves. (a) Rate-time curve; (b) Rate-cumulative production curve



(b)

Figure 5. Arps decline curve shapes for a Cartesian rate-time (a) and cumulative-time (b) plot

The change in permeability in the initial period is associated with a decrease in pressure in the reservoir and rock deformations [29, 30]. If the field is large in area and has large reserves, then changes in permeability can lead to a significant deterioration in production [31] For more accurate forecasting of the natural gas flow rate, it is necessary to introduce refinements with the dependence of permeability on effective stresses. We state that there are significant changes in well operation and workovers associated with abrupt changes in gas production and the impossibility of using the Arps equation for wells W-3.

For wells without workovers, the equations make it possible to predict gas production with high accuracy (Figure 6). The greatest deviations occur in the first months of well operation, associated with the setting of the operating mode and the establishment of equilibrium conditions in the wellbore formation zone.

It was identifying some potential problems with Arps models: Arps models require accurate, reliable and sufficient input data to be effective. In some cases, the data may be incomplete, inaccurate or not adequately representative of the system. This can result in inaccurate projections and predictions. Arps models tend to be rigid and inflexible, meaning they may not be able to account for changes or new variables in the system. Arps models are based on certain assumptions and simplifications about the system being modeled. Assumptions about market behavior, for example, may not hold true in reality, or may change over time. Simplifications, such as aggregating data or assuming linear relationships, can also lead to inaccurate results. Inability to capture all factors: Arps models can only capture the factors that are included in the model. This means that some external factors or variables that may impact the system may not be accounted for, leading to incomplete or inaccurate predictions. But in gas wells, as a rule, the flow rate of wells monotony decreases and these models can show a good result. Deviations from the design parameters may occur during emergency situations at wells and well repairs. The results of a single well analysis can be combined to characterize the performance of the field. Future natural gas production can be predicted using a hyperbolic type curve. The operation of wells with a very short production history can be modeled using well data and similar geological parameters.

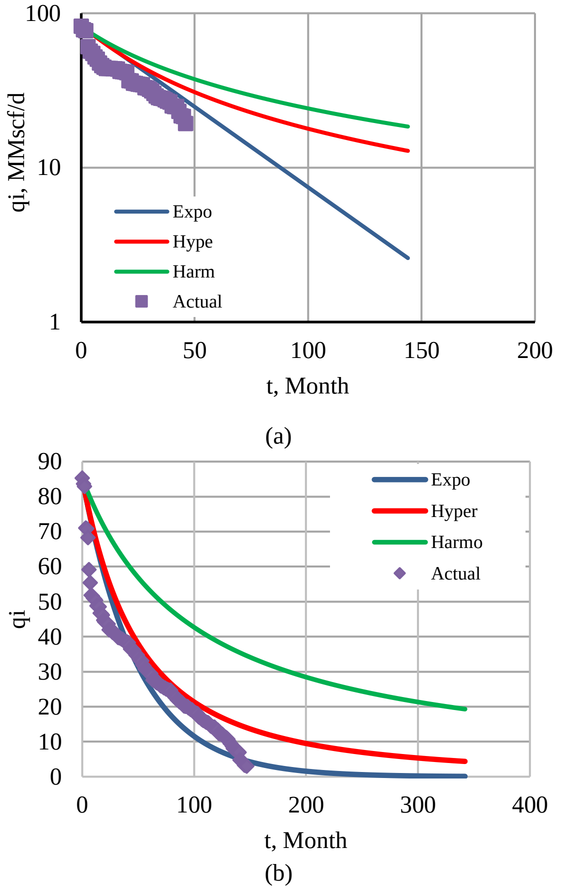


Figure 6. Arps decline curve shapes for a Cartesian rate-time (a) – well SA-2; (b) – well GD2)

4. CONCLUSIONS

This study tested the feasibility of using Arps curves to predict gas well production rates in a field in Senegal. Comparison of Arps models and actual well flow rates made it possible to note the presence of deviations. There were 2 types of deviations. The first type of deviation is associated with a change in the filtration parameters of the formation due to a change in the stress state when putting wells into operation. Deviations of this type can be observed in the first 6 months from the start of well operation. The second reason for deviations is well repair. During repairs, the filtration parameters of rocks near the well wall change. When excluding the above factors, exponential Arps curves can predict gas production in Senegal quite accurately.

5. FUNDING STATEMENT

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Persian Abstract

چکیده

هدف از این مطالعه ارزیابی امکان سنجی استفاده از روش‌هایی برای پیش‌بینی نرخ جریان چاه‌های گاز در میادین سنگال است .پیش بینی دقیق تولید گاز طبیعی به شما امکان می دهد تا به درستی حالت عملیات چاه ها را تنظیم کنید و زیرساخت های خشکی را طراحی کنید .یکی از میادین گازی سنگال به عنوان هدف مطالعه انتخاب شد که در آن ذخایر در محدوده بهره برداری در افق های ماسه سنگی کامپانین و سانتونین کشف شد .سازندهای گازی دارای مقادیر تخلخل و نفوذپذیری بالا و همچنین دمای سازند بالا هستند .نرخ جریان چاه گاز را می توان با استفاده از مدل های هیدرودینامیکی، مدل های ریاضی) هذلولی و غیره (و روش های دیگر پیش بینی کرد .این مطالعه امکان استفاده از منحنی‌های آرپس را برای پیش‌بینی بلندمدت نرخ جریان گاز و مقایسه نتایج پیش‌بینی با داده‌های واقعی ارزیابی کرد .مقایسه منحنی‌های Arps و نرخ جریان گاز واقعی برای چاه‌ها، نشان دادن اختلاف در نتایج پیش‌بینی‌شده و مقادیر واقعی بیش از 20 درصد را ممکن کرد .این اختلافات به دو دلیل به وجود آمد .انحراف در مرحله اولیه بهره برداری چاه 6) ماه (که با تنظیم حالت عملیات فن آوری چاه و ایجاد پارامترهای ثابت سنگ ها در نزدیکی چاه همراه است .دلیل دوم تعمیرات چاه است که خواص سنگ های نزدیک چاه را تغییر می دهد .به طور کلی، منحنی‌های آرپس از نوع نمایی همگرایی بالایی بین مقادیر پیش‌بینی‌شده و واقعی نشان دادند که استفاده از آن‌ها را در پیش‌بینی نرخ جریان چاه‌های گاز در سنگال ممکن می‌سازد.