Improving the Shale Gas Production Data Analysis Using the Quarterly Decline Rate: Comparison Study

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Abstract

Production data analysis is the main core for the petroleum industry. It is used in calculating the recoverable reserve by using DCA methods. Accurate calculation of the reserve is one of the most important criteria in order to know the future of any petroleum company.

Shale gas has become an increasingly important source of natural gas in the last two decades. Due to its behavior with the ultra-low matrix permeability, horizontal wells with transverse hydraulic fracture are necessary in order to produce from the shale reservoirs. These reservoirs stimulation produce long-term transient flow regime that may last for long time until the flow reaches the boundary.

Different methods were introduced in order to simulate the shale gas production performance. However, none of them was able to give an accurate way to know the transition time at which the flow reaches the boundary; they give unrealistic value for both daily and monthly decline rate.

In this paper, a quarterly decline rate was introduced in order to differentiate the time at which the flow behavior changes from transient to boundary dominated flow (BDF). The quarterly decline rate is used to smoothen the operating condition of any field. It is equal to 20 %, where a transient flow exists above this value and a BDF exists below this value.

Production data from four different wells in four different field with different reservoirs were used. The results show that using the quarterly decline rate instead of daily and monthly decline gives an easier and accurate way to estimate the transition time to BDF.

1. Introduction

The energy demand has been increasing in recent years, which makes the fossil fuel one of the most important sources of energy in the world. Conventional reservoir was used in order to produce the oil and gas, as it is easy to drill, to access and to produce. However, it becomes rare to be found and harder to meet the demand.

The world decided to turn to the term of unconventional reservoir to describe the hydrocarbon resources that are in huge volume but required lots of innovation technology in order to be produced.

Coal Bed Methane (CBM), shale gas, gas hydrates, natural bitumen, and oil shale deposits are examples of the unconventional hydrocarbon reservoirs. Their large volume of hydrocarbon reserves characterizes them. However, they have low effective porosity and low permeability (less than 0.1 md) as shown in **Figure 1.1.** They required special technology to be produced (e.g., dewatering of CBM, massive fracturing programs for shale gas, steam and/or solvents to mobilize bitumen for in-situ recovery, and, in some cases, mining activities).

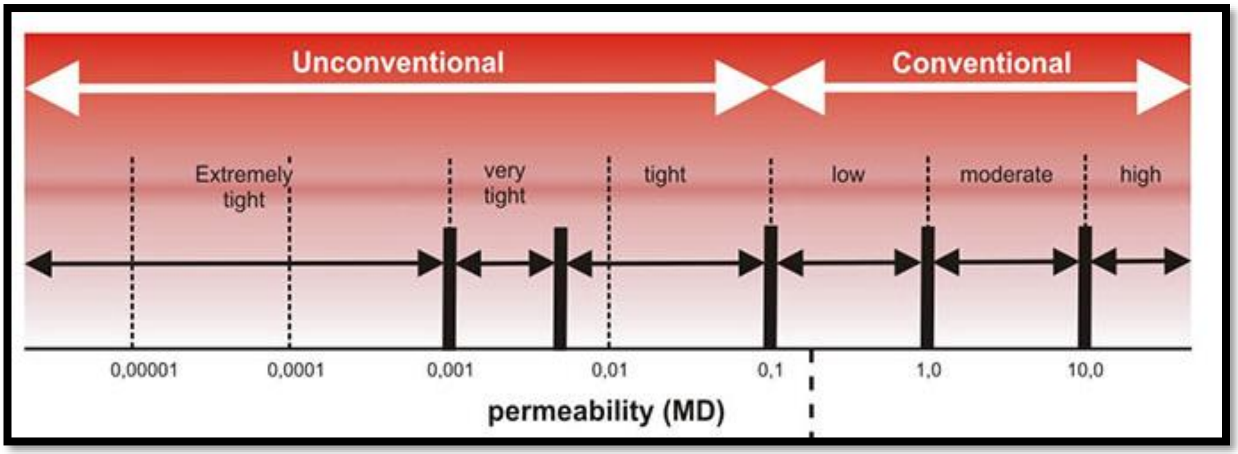

Figure 1.1. Different ranges of permeability for conventional and unconventional reservoirs.

In order to produce from these unconventional reservoirs, horizontal drilling and advanced hydraulic fracture technology is required as shown in **Figure 1.2.**

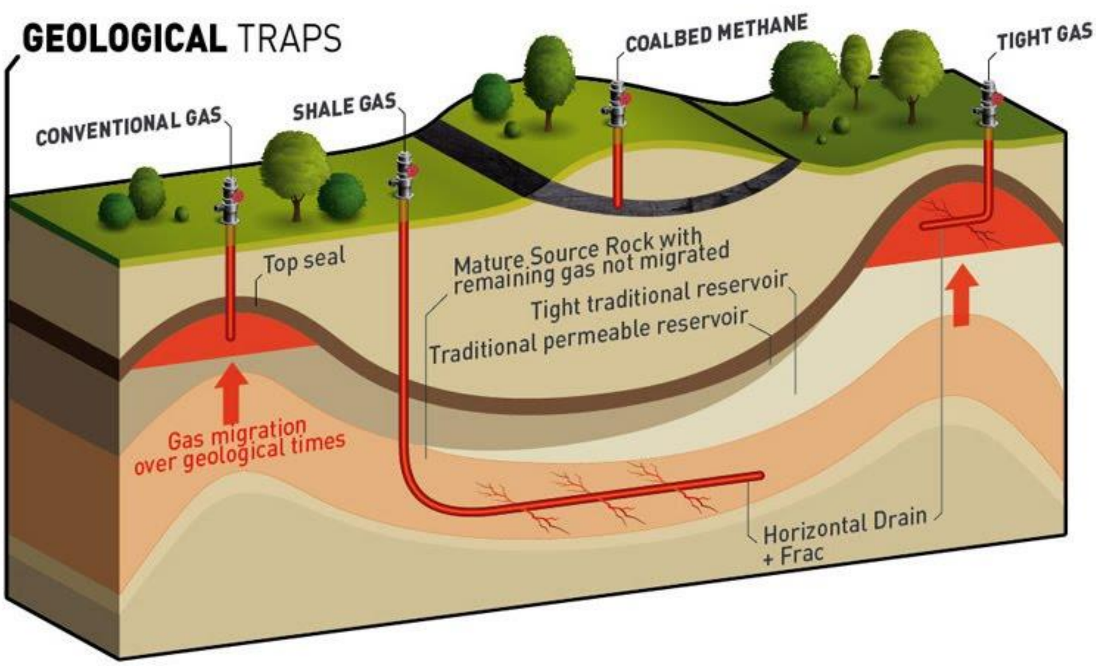

Figure 1.2. Different types of wells of conventional and unconventional reservoirs.

1.1. Egypt with the unconventional reservoirs

Unconventional reservoirs occur in four basins in Egypt: Alamein, Shoushan-Matruh, Abu Gharadig, and Natrun as shown in **Figure 1.1.1.**

Obaiyed field is an example of a tight gas condensate field in the Western Desert; where tight gas is characterized by a permeability less than 0.1 md.

Coal-Bed Methane (CBM) gas reserves are yet unconfirmed in Egypt. However, Halliburton reports the occurrence of CBM in the southern parts of Egypt (after Egypt Oil and Gas Newspaper).

Natural gas hydrates occur in the gas-rich eastern basin and are stable throughout the Mediterranean deep-water basins (>1,000 m).

As per Energy Informative Administrator (EIA, 2015), Egypt contains 535 tcf of shale gas in place, with recoverable of 100 tcf comparing to the other countries.

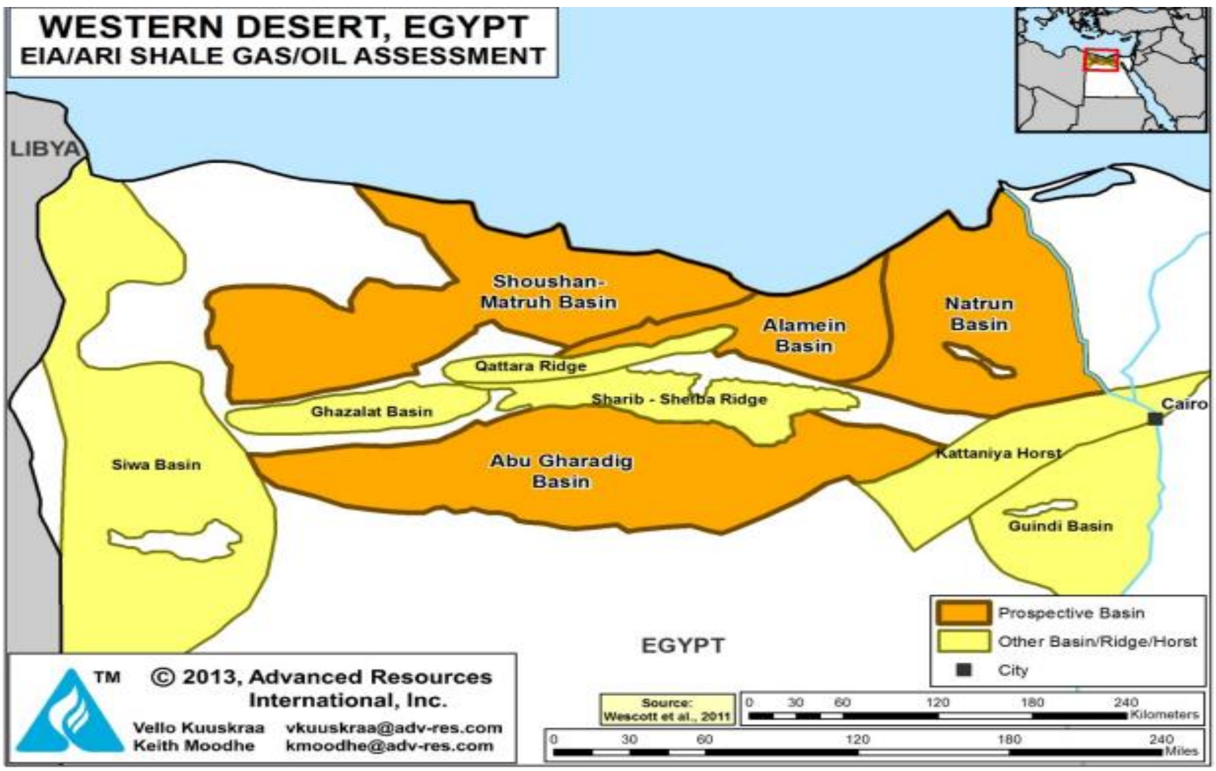

Figure 1.1.1. The Hydrocarbon basin with shale potential in Egypt's Western Desert region (after IEA, 2015)

Accurate estimation of the reserve is the most challenging thing as it affects the value and the assets of any company. They are required to take decisions in oil and gas industries, to make long-term plan for the internal business and to secure project finance from investor based on economic study.

In this paper, we will work on one of the unconventional reservoirs. Shale gas reservoir is challenging reservoir due to the difficulties encountered when estimating reserves and choosing of production data analysis methods. It is characterizing by its complex reservoir and flow behavior (complex wellbore/hydraulic fracture geometry).

1.2. Why shale gas reservoirs?

Shale reservoirs have become an important source of energy and received commercial and research focus due to the advances in drilling and fracturing techniques. Shale reservoir refers to fine-grained sedimentary rocks that contain self-sourced hydrocarbons. Mudstone (shale) is highly heterogeneous rock in both composition and pore structures, which comprises two distinct media: organic matter (kerogen) and nonorganic minerals (clay, quartz, etc.).

Unlike conventional reservoir, shale gas reservoir is complex. It has a dual porosity nature as it stored the hydrocarbon in rock matrix and natural fracture with a very low permeability. The permeability is usually in the order of hundreds of nano-darcies. That is why the reservoir stimulation with horizontal drilling are necessary to produce the hydrocarbon. Thus, the hydraulic fracture is necessary to re-connect the natural fracture matrix.

1.3. Challenges Related to Analyzing the Producing Shale Gas wells

Under natural conditions, producing from shale gas reservoirs with economic value is difficult. Drilling horizontal wells with several stages of hydraulic fracturing (SRV) is the best way to produce from shale gas reservoirs. This SRV may results in different flow regimes as shown in **Figure1.3.1.**

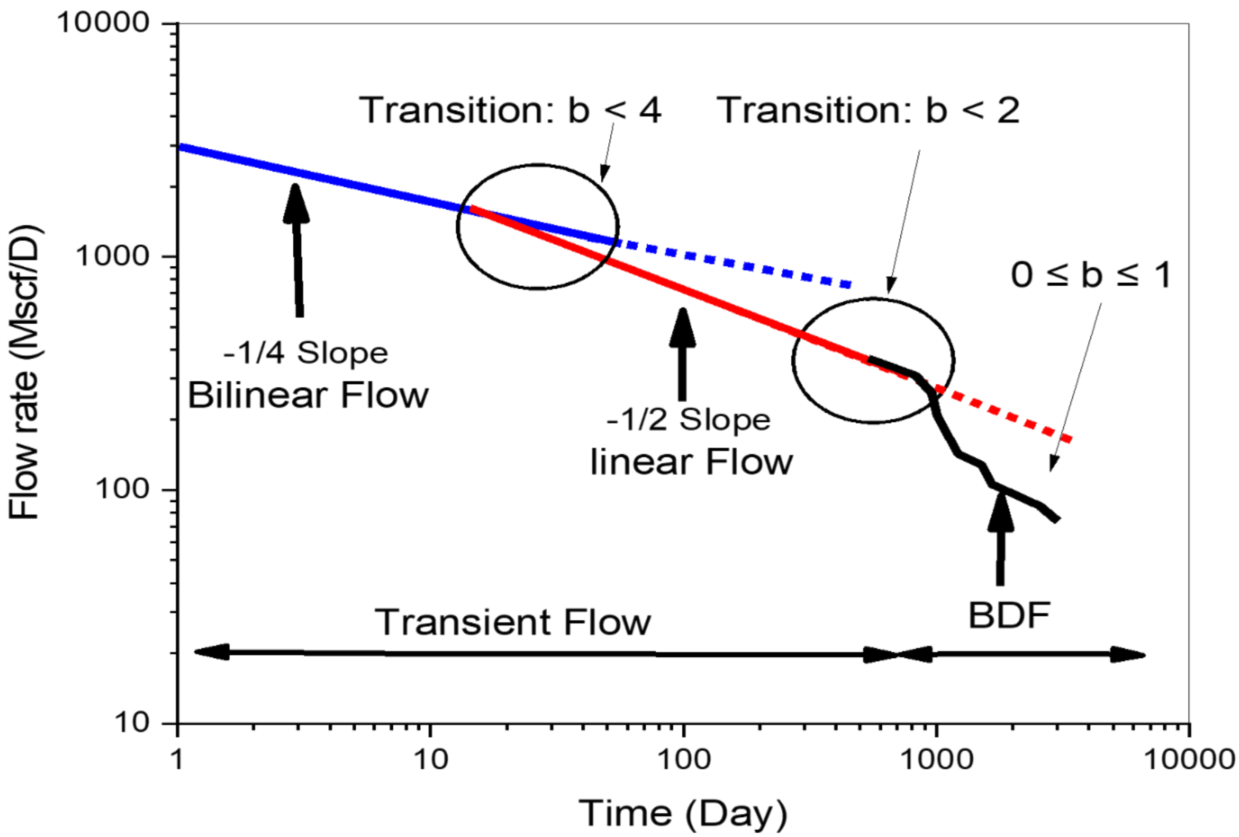

Figure 1.3.1. Identifying the different flow regimes based on the slope value on the log-log plots.

The following flow regimes may exist while developing shale gas wells and have an effect on the DCA trends:

- **Linear Flow:** this can be the primary flow throughout the lifetime of the well. The fluid flow perpendicular from the matrix to the hydraulic fractures. This is called as transient linear flow and can be known by plotting the flow rate vs time with a -1/2 slope on a Log-Log plot.
- **Linear–Boundary Dominated Flow (BDF)**: This is a combined flow; it starts after the transient linear flow and is called the BDF. It can be seen on a log-log plot as the slope deviate from the -1/2.
- **Bilinear–Linear:** the bilinear flow is the starting flow regime (linear followed by another linear). It usually occurs in the beginning and lasts for a relatively short time; it is typically related to natural fractures. In this case, the flow starts by linear flow from the matrix to the fractures followed by another linear flow from the fractures to the well. Thus, a plot of -1/4 slope on Log-Log plot indicates a bilinear flow; while a -1/2 slope indicates a linear flow.
- **Bilinear-linear-BDF:** this is a combination flow where all type of the above-mentioned flow exists together.

These flow regimes can lead to long-term transient flow that may lead to over or under estimate to the reserves. Some of the empirical decline methods took the effect of the transient flow only, some others took the effect of the BDF only and others combined between different methods in order to simulate the exact case of shale gas. However, they did not succeed in giving the right way to know the time at which the flow changes from transient to BDF. They consider that when the daily rate reaches a threshold value of 5 %, the flow changes to BDF. However, this is not the real case, as there is a fluctuation of the daily decline rate either above or below this threshold value during the lifetime of the well.

Using daily decline or even monthly decline to describe the time when the flow reaches the boundary can lead to misunderstanding. It is so hard to use that threshold number to get the exact time.

The following wells will illustrate the important of using the quarterly decline rate instead of the daily and the monthly rate as it smoothens the operating condition of any wells. It will also be seen that at quarterly decline rate of 20%, it is easy to describe the time of BDF.

2. Data

This study is based on actual data that was released in 2021 on the SPE official website. The data consists of more than forty wells of dry gas in shale gas reservoirs. Four wells were selected. The selection was based on choosing wells from different field and different reservoirs. The characteristics of each well is shown in **Table (2.1) and Table (2.2**). Knowing that each table contains two wells.

Table 2.1. Well_12&Well_27

The Specifications of Well_12. [21]		**The Specifications of Well_27.** [22]	
State	LA	**State**	PA
Formation/Reservoir	HAYNESVILLE SHALE	**Formation/Reservoir**	MARCELLUS
Initial Pressure Estimate (psi)	9939	**Initial Pressure Estimate (psi)**	3486
Reservoir Temperature (deg F)	285.21375	**Reservoir Temperature (deg F)**	115
Net Pay (ft)	268.39703	**Net Pay (ft)**	101.6
Wellbore Diameter (ft)	0.7	**Wellbore Diameter (ft)**	0.7
Porosity	0.088000059	**Porosity**	0.070015
Water Saturation	0.183792612	**Water Saturation**	0.3297
Oil Saturation	0	**Oil Saturation**	0
Gas Saturation	0.816207388	**Gas Saturation**	0.668996
Gas Specific Gravity	0.58	**Gas Specific Gravity**	0.57
TVD (ft)	11258.854	**TVD (ft)**	5707.639

Table 2.2 Well_29&Well_40

The Specifications of Well_29. [23]		**The Specifications of Well_40.** [24]	
State	PA	**State**	PA
Formation/Reservoir	BOSSIER SHALE	**Formation/Reservoir**	MARCELLUS - UPPER
Initial Pressure (psi)	3900	**Initial Pressure Estimate (psi)**	3150
Reservoir Temperature (deg F)	137	**Reservoir Temperature (deg F)**	124.56
Net Pay (ft)	133.958	**Net Pay (ft)**	230.5
Wellbore Diameter (ft)	0.7	**Wellbore Diameter (ft)**	0.7
Porosity	0.06944	**Porosity**	0.0675
Water Saturation	0.3159	**Water Saturation**	0.27
Oil Saturation	0	**Oil Saturation**	0
Gas Saturation	0.6841	**Gas Saturation**	0.73
Gas Specific Gravity	0.57	**Gas Specific Gravity**	0.57
TVD (ft)	7543.37	**TVD (ft)**	6936.15

3. Analysis

In this paper, the impact of using the quarterly decline rate on the monthly production data is shown using Cartesian plots.

For each well, the daily production rate was converted into monthly production rate in order to smoothen the variation in data due to the variation in the operating condition. Also, a log-log plot of daily rate versus time is presented in order to know the -1/2 slope that present the transient flow .Then, daily , monthly and quarterly decline rate will be presented on Cartesian plot and will be validated using the plot of different flow regimes.

3.1 WELL_12

Figures 3.1.1 and 3.1.2 show the actual production data of the daily rate versus time and the average monthly daily rate versus time respectively

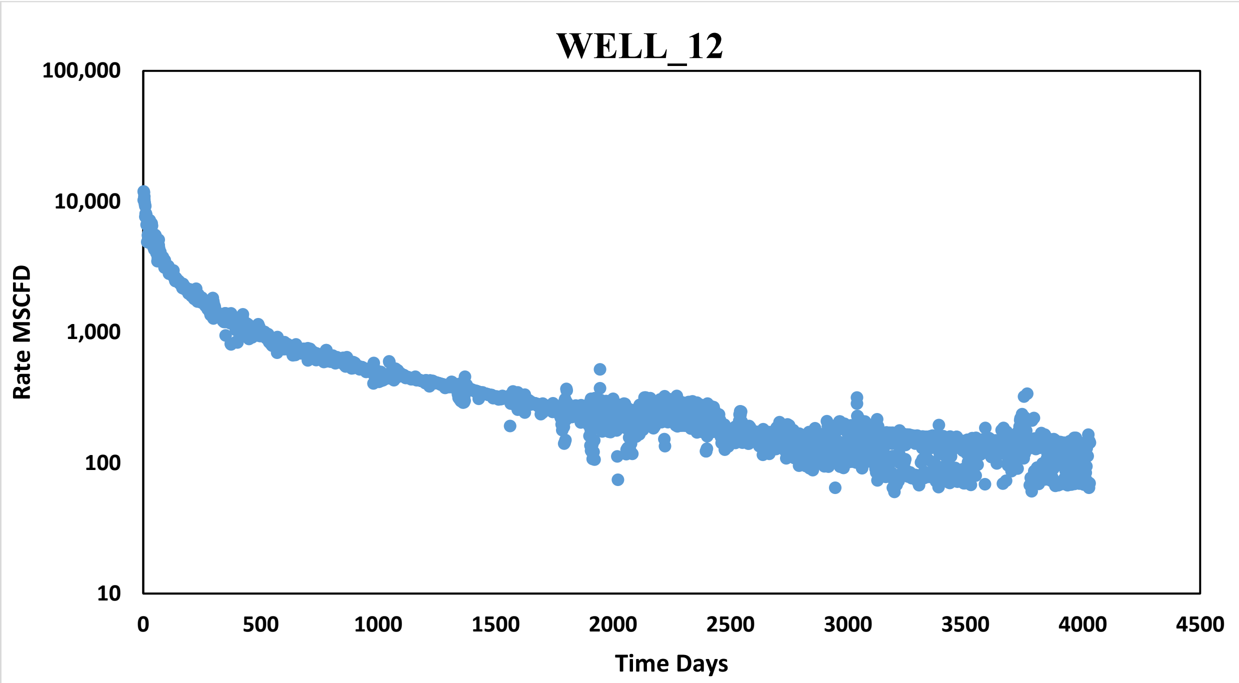

Figure 3.1.1. The production data daily rate versus time.

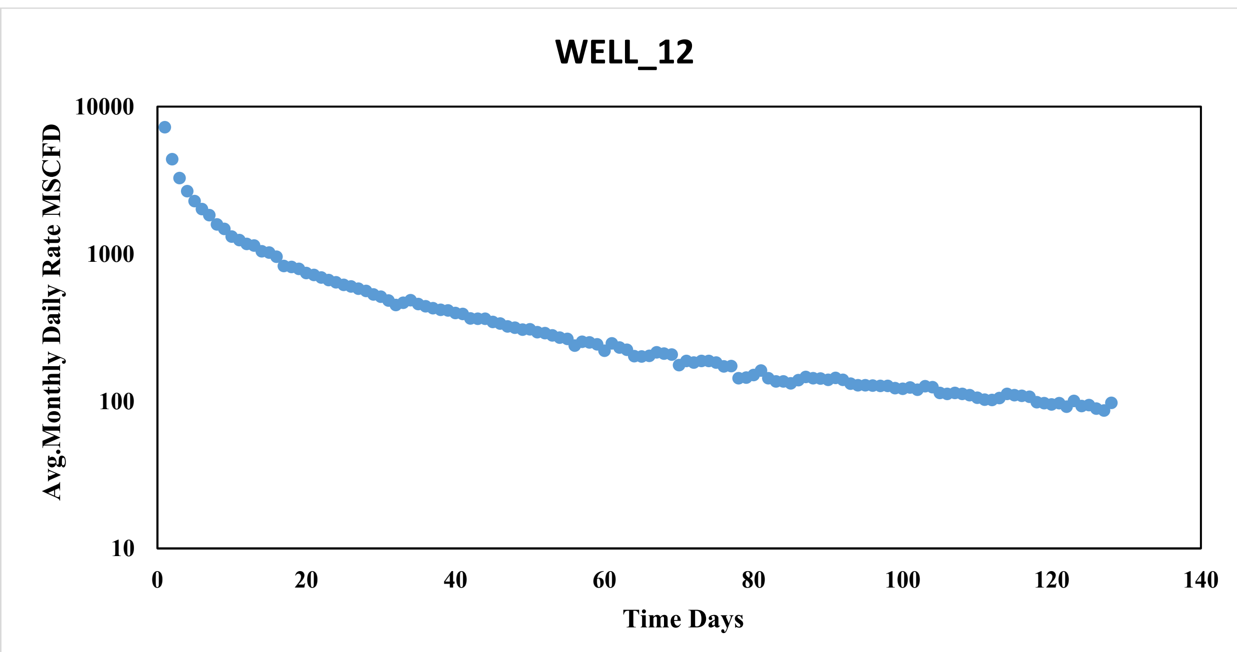

Figure 3.1.2. The production data of the average monthly daily rate versus time.

Figures 3.1.3 shows how the different flow regimes are identified from the log-log plot of the flow rate versus time by detecting the trend line with the characteristic slope of each one. This chart is also used to validate that the quarterly decline rate gave the same results as that from the log-log plot. However, the quarterly decline rate is more accurate as it gives the exact time at which the flow reaches the boundary.

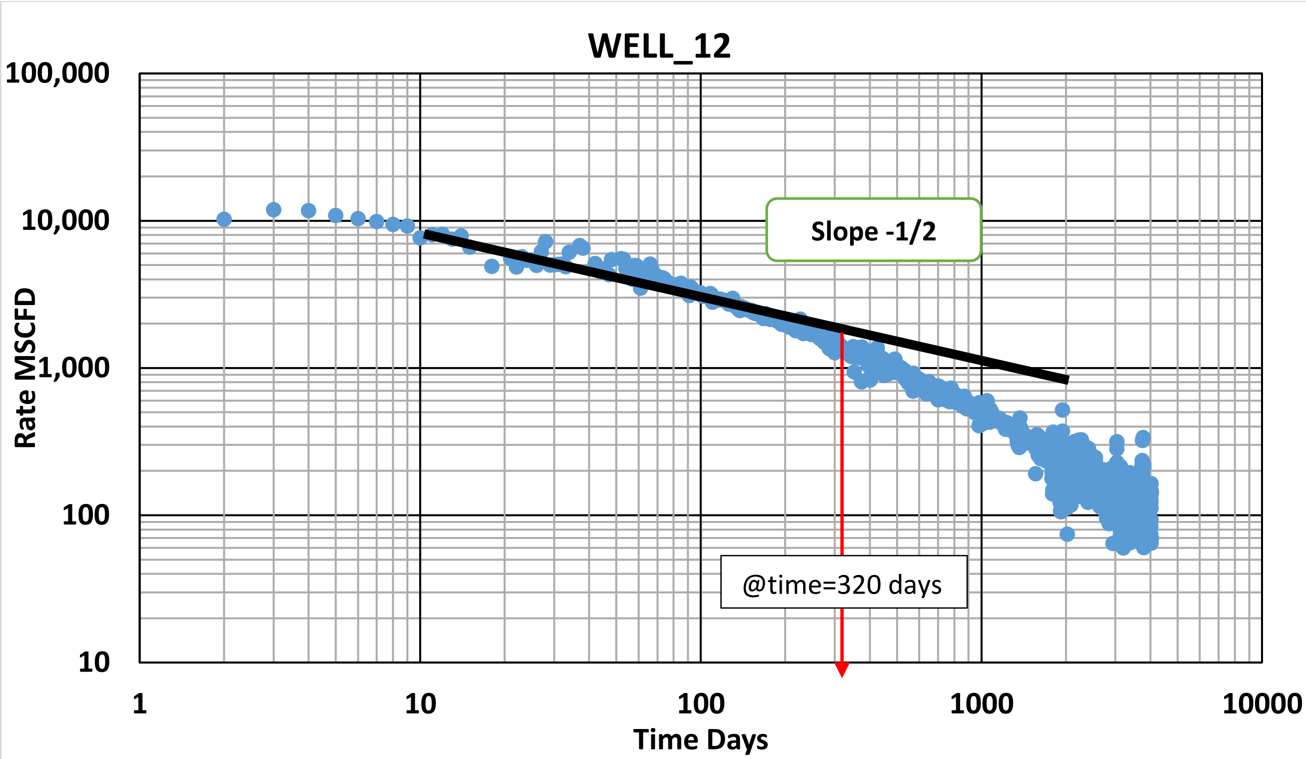

Figure 3.1.3. Identify the different flow regimes.

Figure 3.1.4 to Figure 3.1.6 show the different types of decline rate (daily, monthly and quarterly respectively) on cartesian plot of decline rate on y-axis versus time on x-axis. Using **Figure 3.1.3**, it can be seen that at time 320 days, the flow reaches the boundary. Knowing that, it is impossible to know the exact time at which flow reaches the boundary using the daily decline rate as there are lots of fluctuations in its value during the life of the well as shown in **Figure 3.1.4**. In addition, it can be seen that using the monthly decline rate at time equal 11 months that is equivalent to 320 days, there is no realistic or specific decline rate value to describe this. However, it can be seen in **Figure 3.1.6** that at time equal to 320 days which is equivalent to the quarter 4 at which quarterly decline rate is equal to 20% or less.

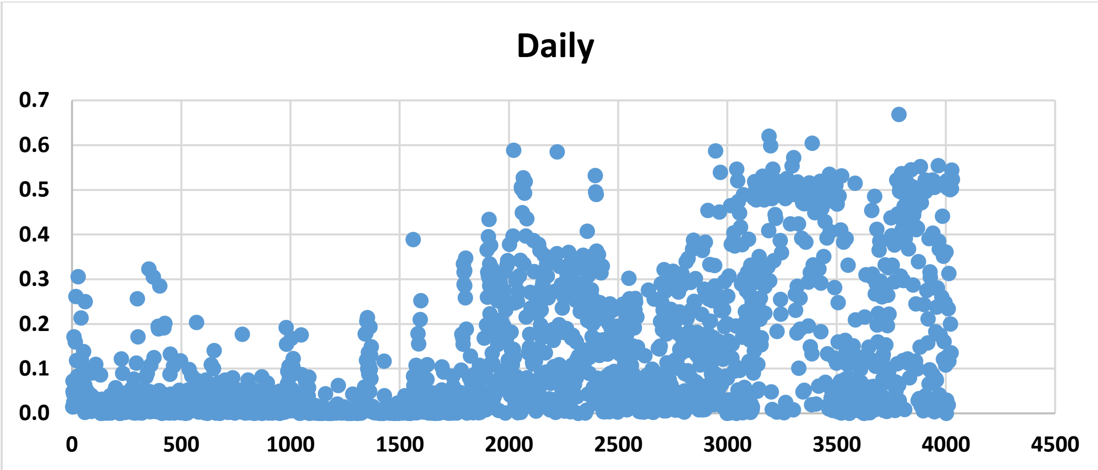

Figure 3.1.4. Daily decline rate versus time.

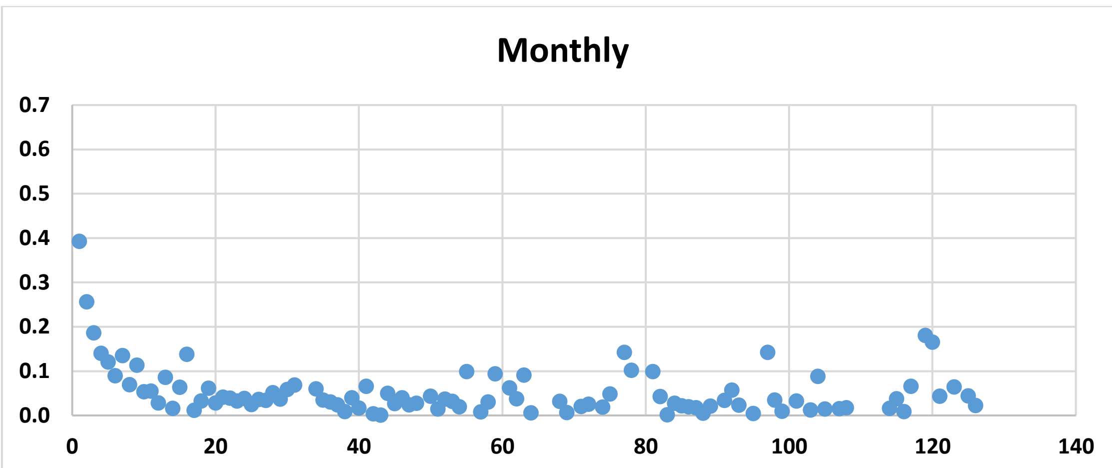

Figure 3.1.5. Monthly decline rate versus time.

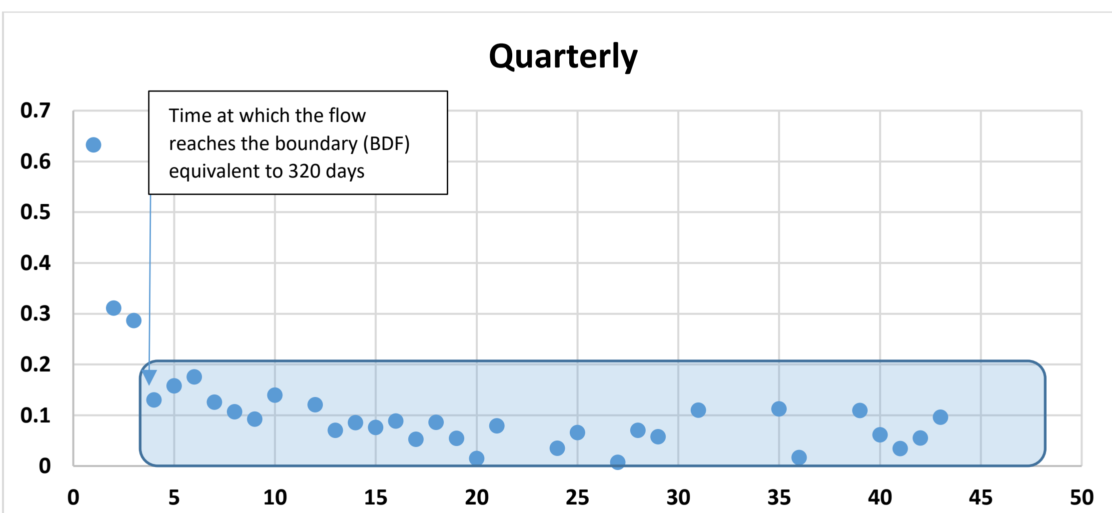

Figure 3.1.6. Quarterly decline rate versus time.

3.2 WELL_27

Figures 3.2.1 and 3.2.2 show the actual production data of the daily rate versus time and the average monthly daily rate versus time respectively

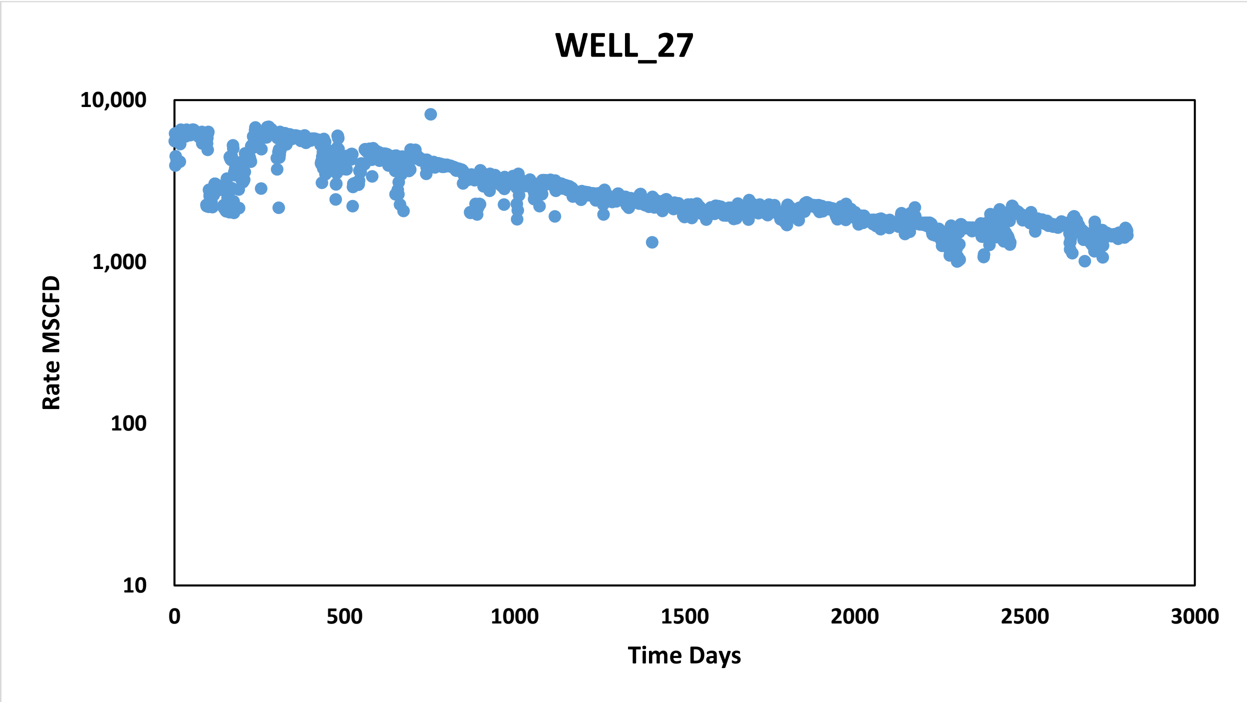

Figure 3.2.1. The production data daily rate Versus time.

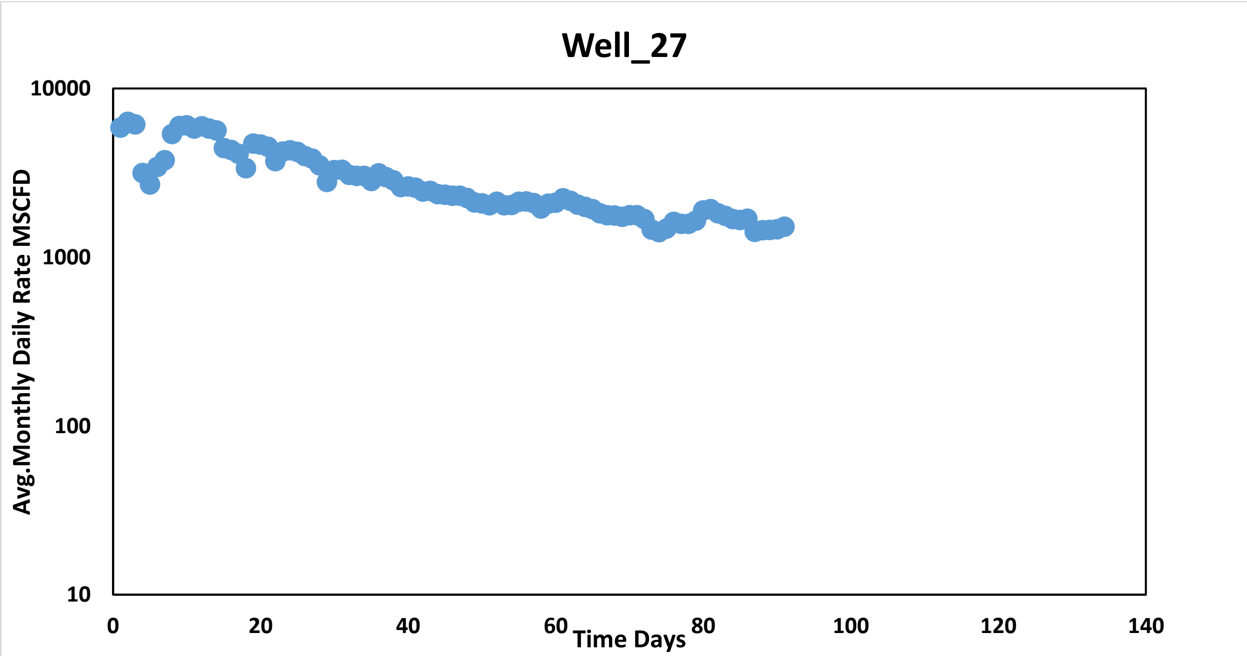

Figure 3.2.2. The production data of the average monthly daily rate versus time.

Figures 3.2.3 shows how the different flow regimes are identified from the log-log plot of the flow rate versus time by detecting the trend line with the characteristic slope of each one. This chart is also used to validate that the quarterly decline rate gives the same results as that from the flow regime plot. However, the quarterly decline rate is more accurate as it gives the exact time at which the flow reaches the boundary.

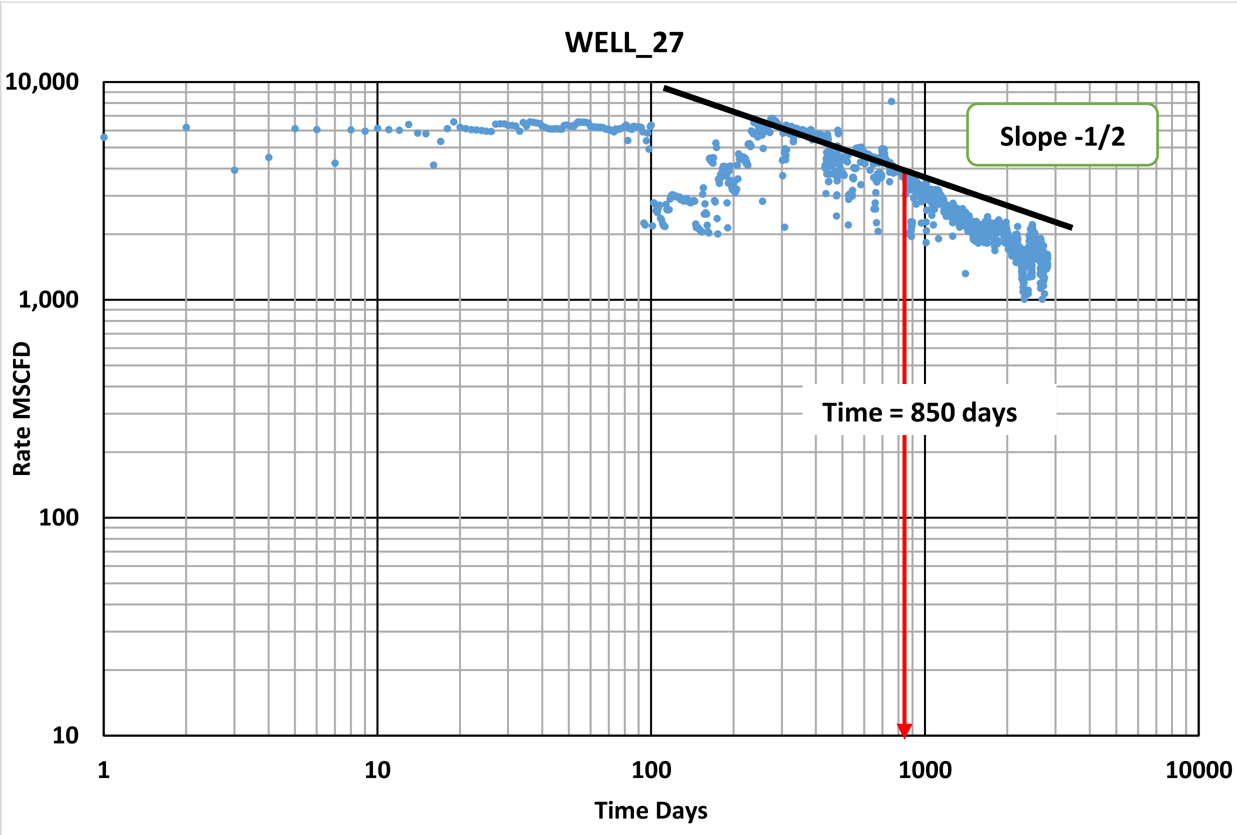

Figure 3.2.3. the daily production rate with transient flow regime.

Figure 3.2.4 to Figure 3.2.6 show the different types of decline rate (daily, monthly and quarterly respectively) on cartesian plot of decline rate on y-axis versus time on x-axis. Using **Figure 3.2.3**, it can be seen that at time 850 days where the slope deviates from the -1/2, the flow reaches the boundary. Knowing that, it’s impossible to know the exact time at which flow reaches the boundary using the daily decline rate as there are lots of fluctuations in its value during the lifetime of the well as shown in **Figure 3.2.4**. Also, it can be seen that using the monthly decline rate at time equal 29 months which is equivalent to 850 days, there is no realistic or specific decline rate value to describe this. However, it can be seen in **Figure 3.2.6** that at time equal to 850 days which is equivalent to the quarter 9 at which quarterly decline rate is equal to 20% or less.

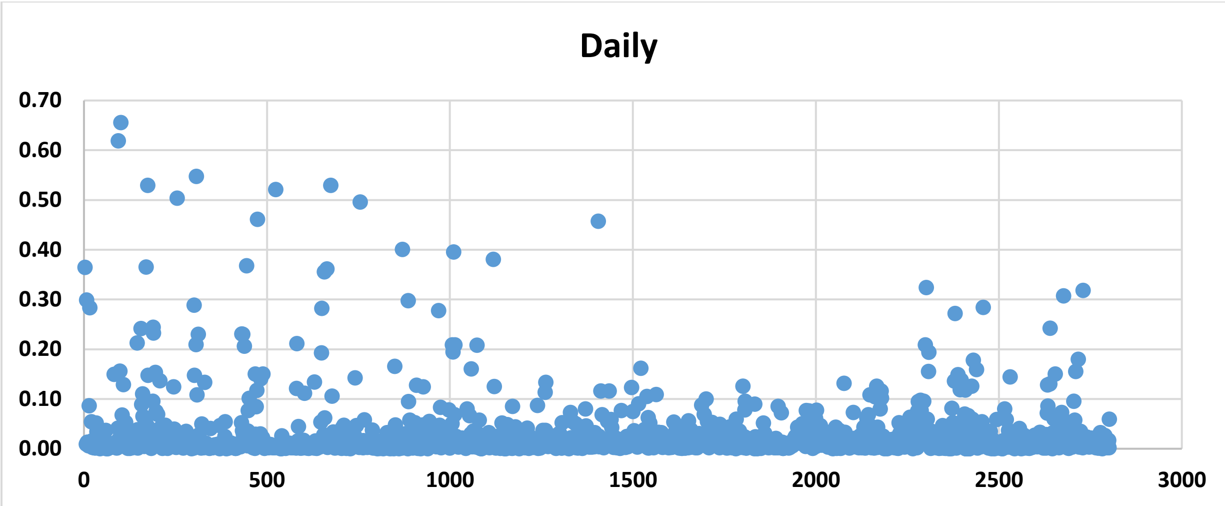

Figure 3.2.4. Shows Daily decline rate versus time.

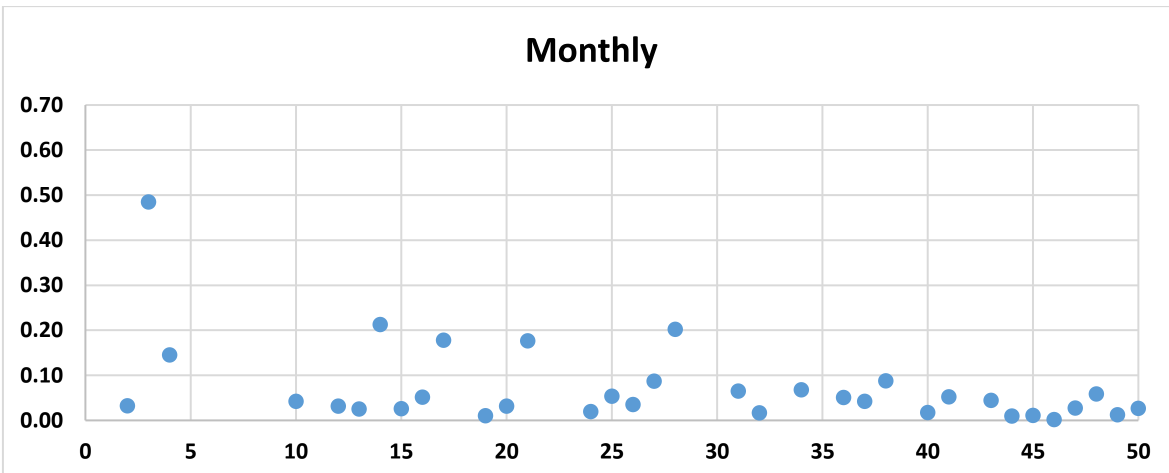

Figure 3.2.5. Shows monthly decline rate versus time.

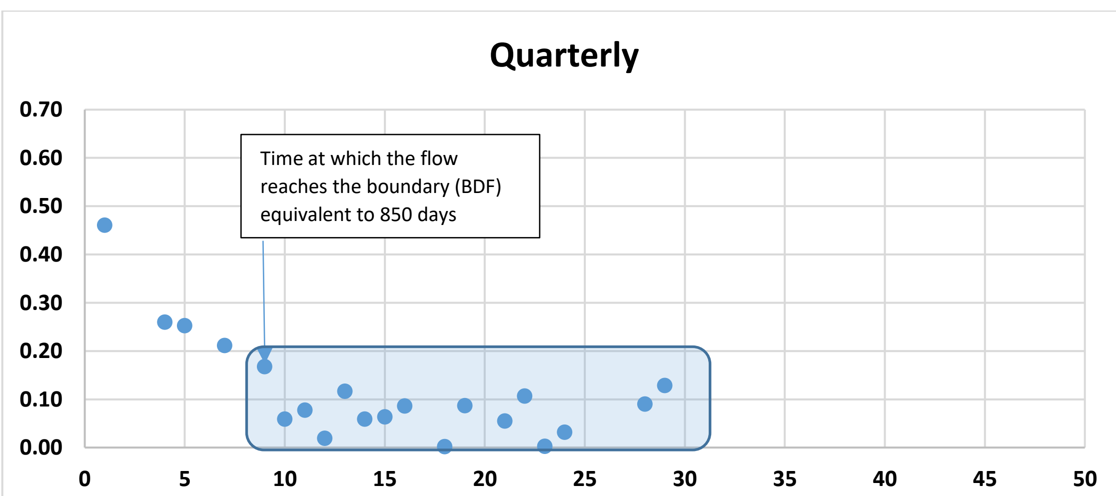

Figure 3.2.6. Shows quarterly decline rate versus time.

3.3 WELL_29

Figures 3.3.1 and 3.3.2 show the actual production data of the daily rate versus time and the average monthly daily rate versus time respectively

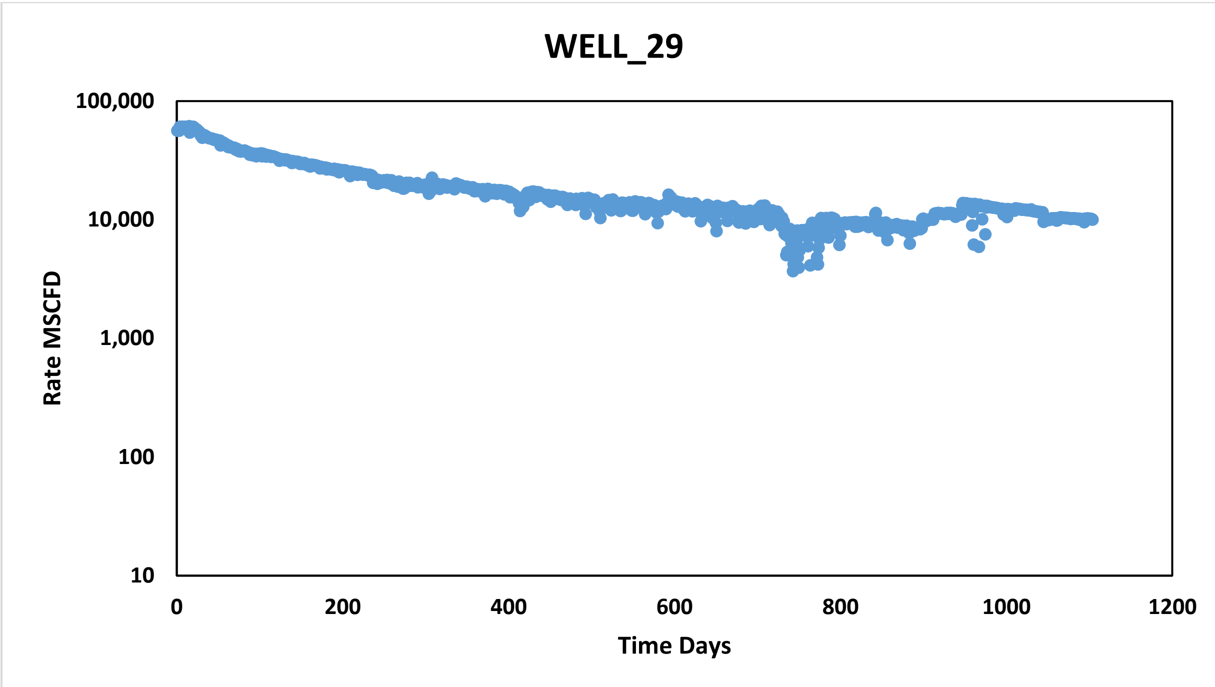

Figure 3.3.1. The production data daily rate Versus time.

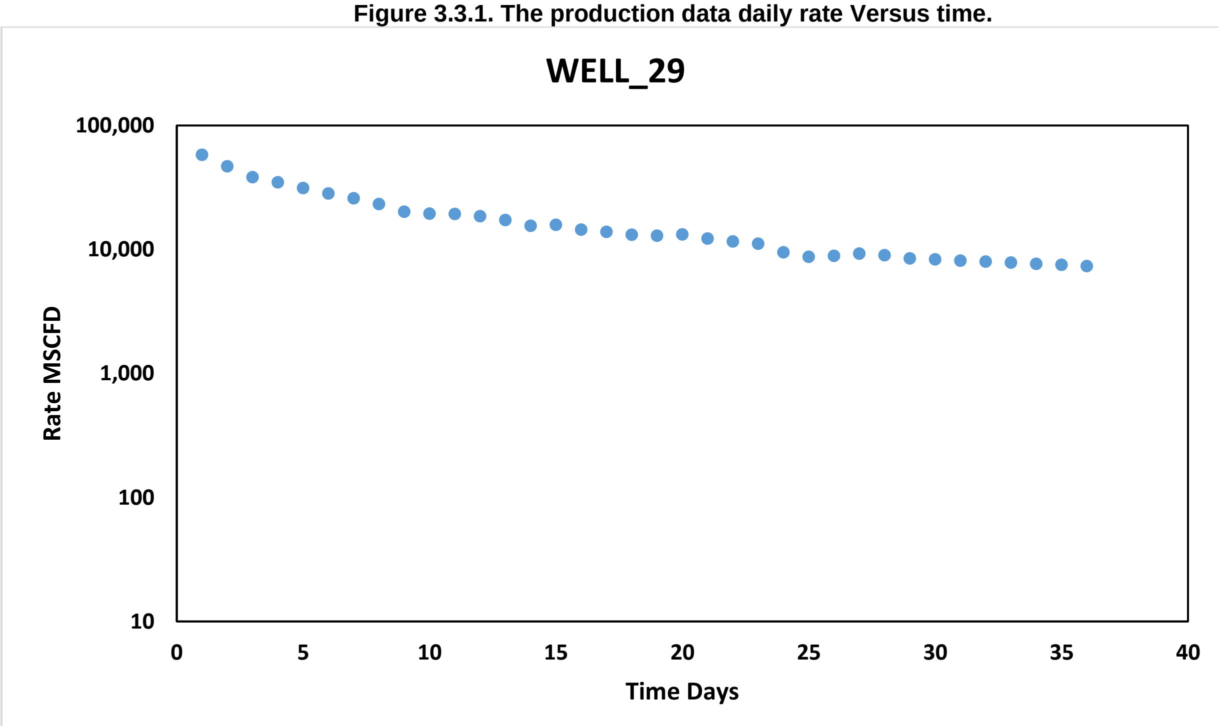

Figure 3.3.2. The production data of the average monthly daily rate versus time.

Figures 3.3.3 shows how the different flow regimes are identified from the log-log plot of the flow rate versus time by detecting the trend line with the characteristic slope of each one. This chart is also used to validate that the quarterly decline rate gives the same results as that from the log-log plot. However, the quarterly decline rate is more accurate as it gives the exact time at which the flow reaches the boundary.

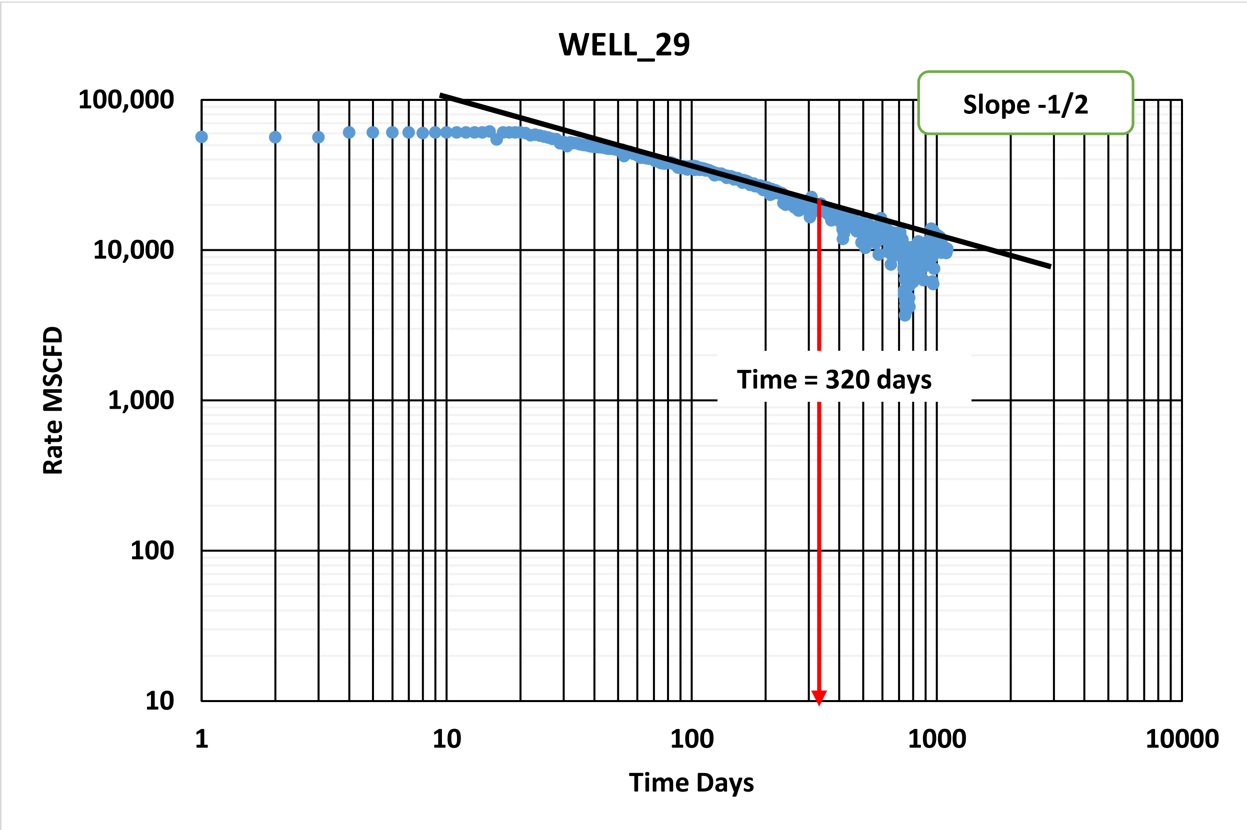

Figure 3.3.3. Shows identifying the different flow regimes.

Figure 3.3.4 to Figure 3.3.6 show the different types of decline rate (daily, monthly and quarterly respectively) on cartesian plot of decline rate on y-axis versus time on x-axis. Using **Figure 3.3.3**, it can be seen that at time 320 days where the slope deviates from the -1/2 , the flow reaches the boundary. Knowing that, it's impossible to know the exact time at which flow reaches the boundary using the daily decline rate as there are lots of fluctuations in its value during the lifetime of the well as shown in **Figure 3.3.4**. Also, it can be seen that using the monthly decline rate at time equal 11 months which is equivalent to 320 days, there is no realistic or specific decline rate value to describe this. However, it can be seen in **Figure 3.3.6** that at time equal to 320 days which is equivalent to the quarter 4 at which quarterly decline rate is equal to 20% or less.

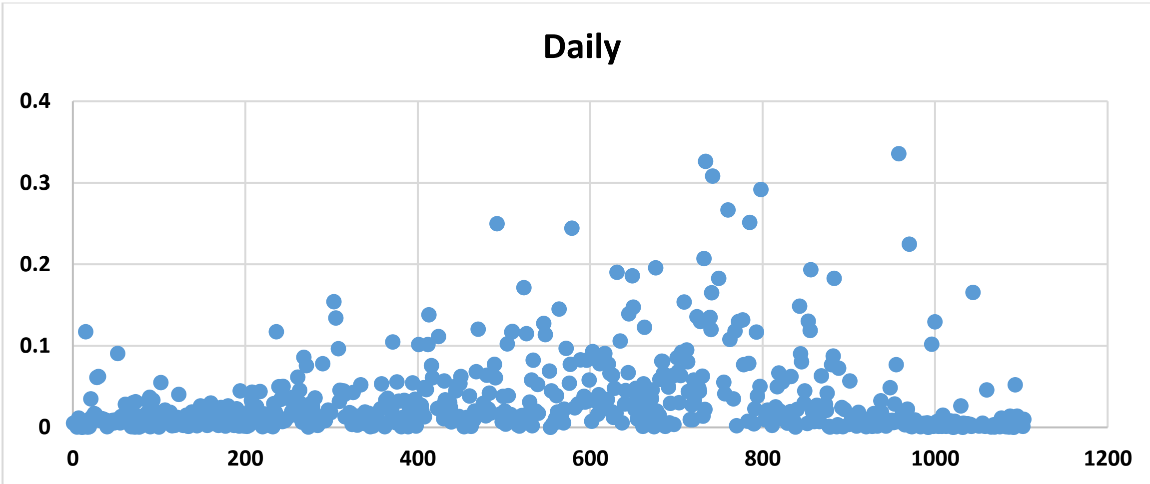

Figure 3.3.4. Shows Daily decline rate versus time.

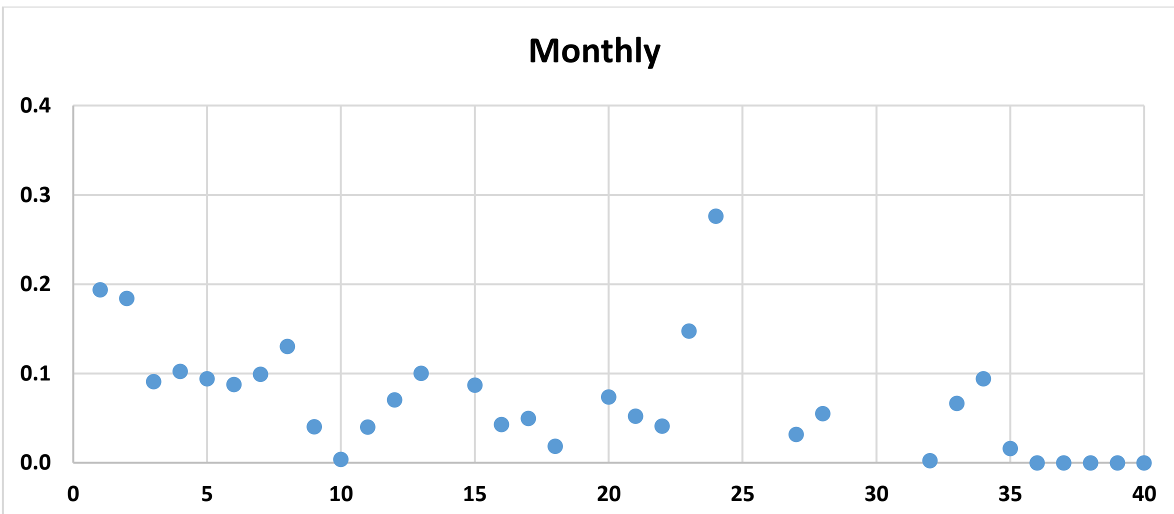

Figure 3.3.5. Shows monthly decline rate versus time.

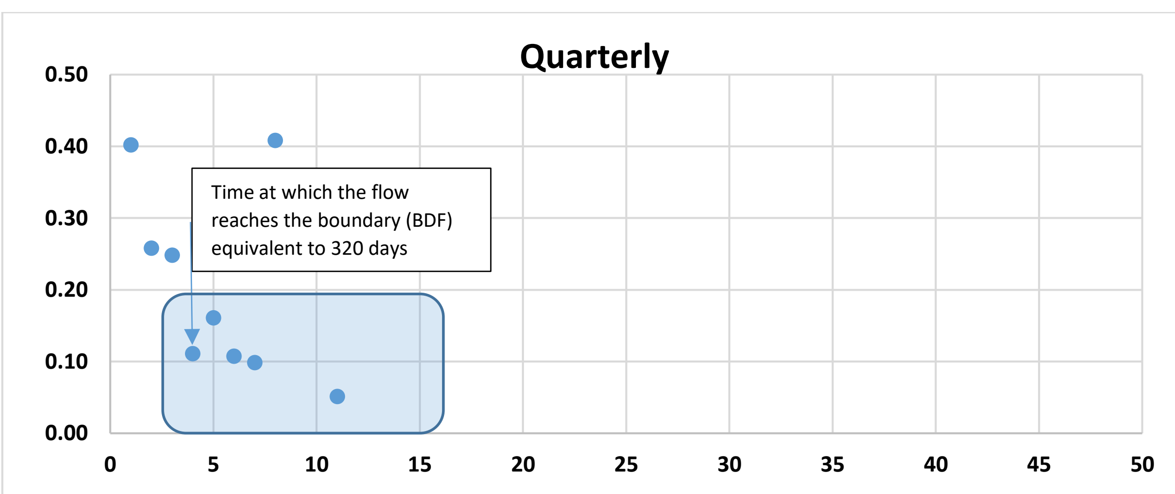

Figure 3.3.6. Shows quarterly decline rate versus time.

3.4 WELL_40

Figures 3.4.1 and 3.4.2 show the actual production data of the daily rate versus time and the average monthly daily rate versus time respectively

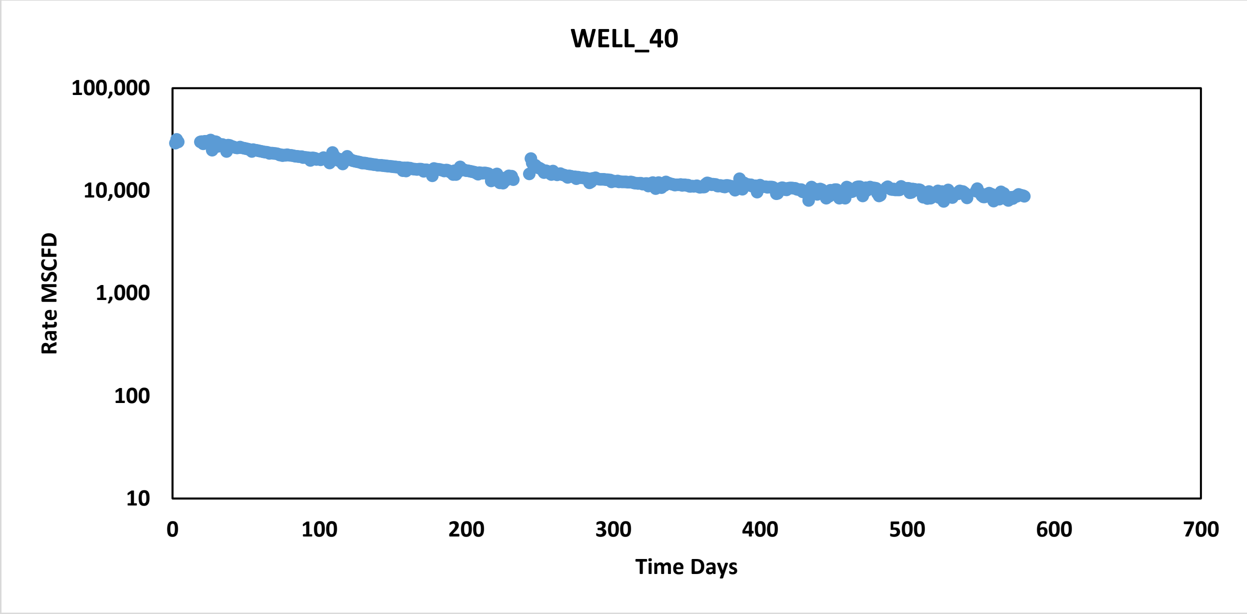

Figure 3.4.1. The production data daily rate Versus time.

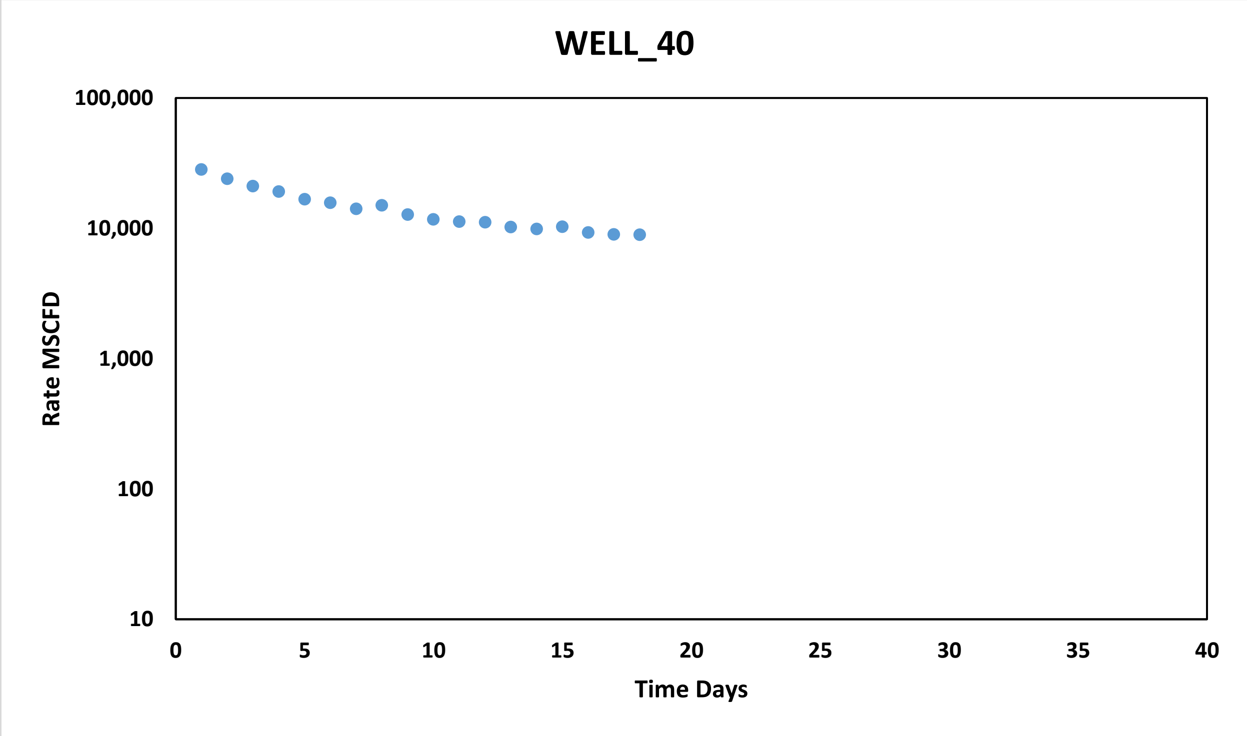

Figure 3.4.2. The production data of the average monthly daily rate versus time.

Figures 3.4.3 shows how the different flow regimes are identified from the log-log plot of the flow rate versus time by detecting the trend line with the characteristic slope of each one. This chart is also used to validate that the quarterly decline rate gives the same results as that from the log-log plot. However, the quarterly decline rate is more accurate as it gives the exact time at which the flow reaches the boundary.

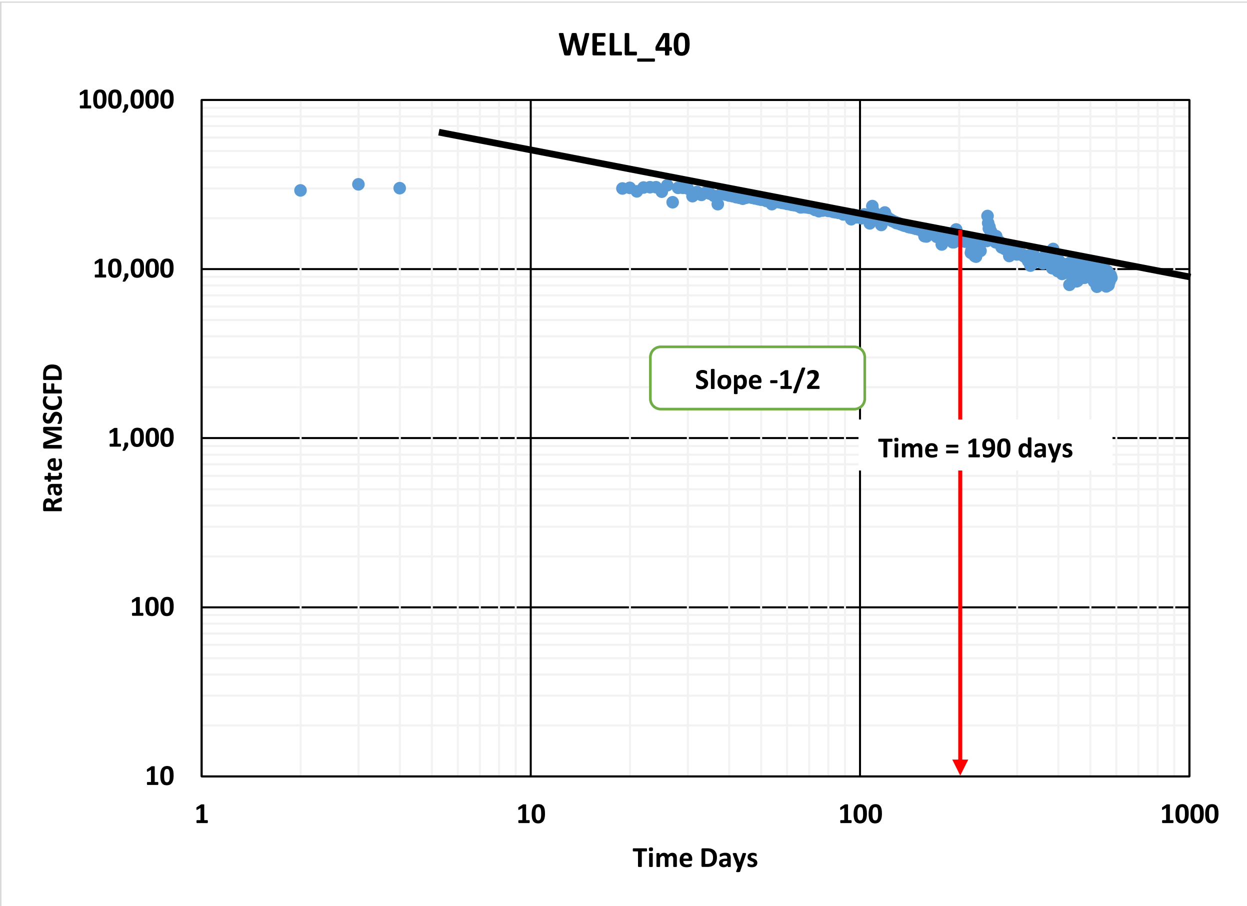

Figure 3.4.3. Shows identifying the different flow regimes.

Figure 3.4.4 to Figure 3.4.6 show the different types of decline rate (daily, monthly and quarterly respectively) on cartesian plot of decline rate on y-axis versus time on x-axis. Using **Figure 3.4.3**, it can be seen that at time 190 days where the slope deviates from the -1/2 , the flow reaches the boundary. Knowing that, it's impossible to know the exact time at which flow reaches the boundary using the daily decline rate as there are lots of fluctuations in its value during the lifetime of the well as shown in **Figure 3.4.4**. Also, it can be seen that using the monthly decline rate at time equal 8 months which is equivalent to 190 days, there is no realistic or specific decline rate value to describe this. However, it can be seen in **Figure 3.3.6** that at time equal to 190 days which is equivalent to the quarter 3 at which quarterly decline rate is equal to 20% or less.

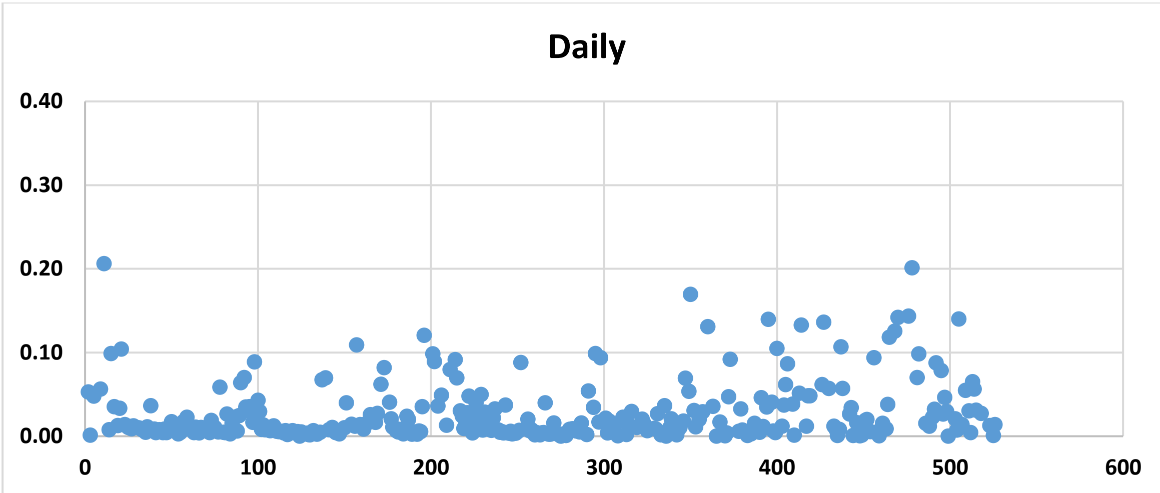

Figure 3.4.4. Shows Daily decline rate versus time.

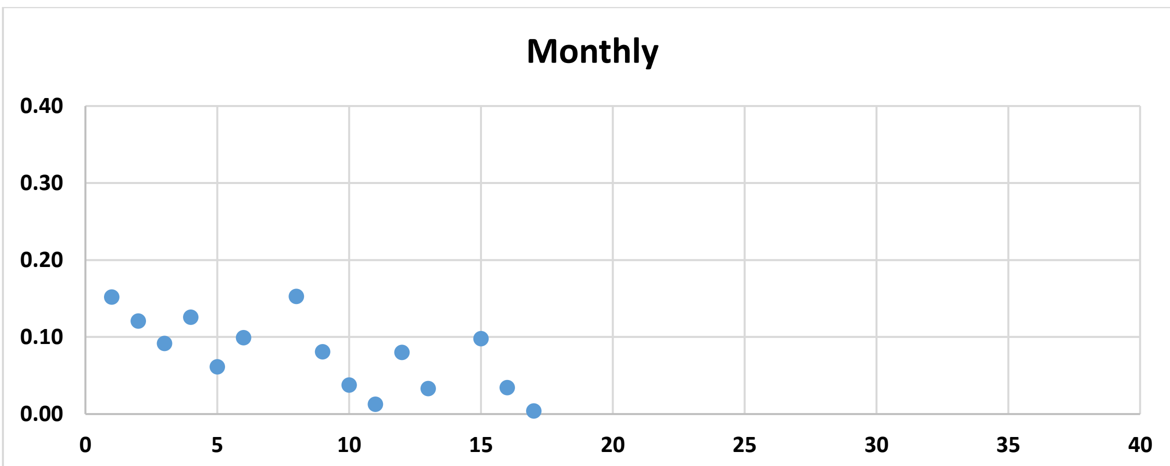

Figure 3.4.5. Shows monthly decline rate versus time.

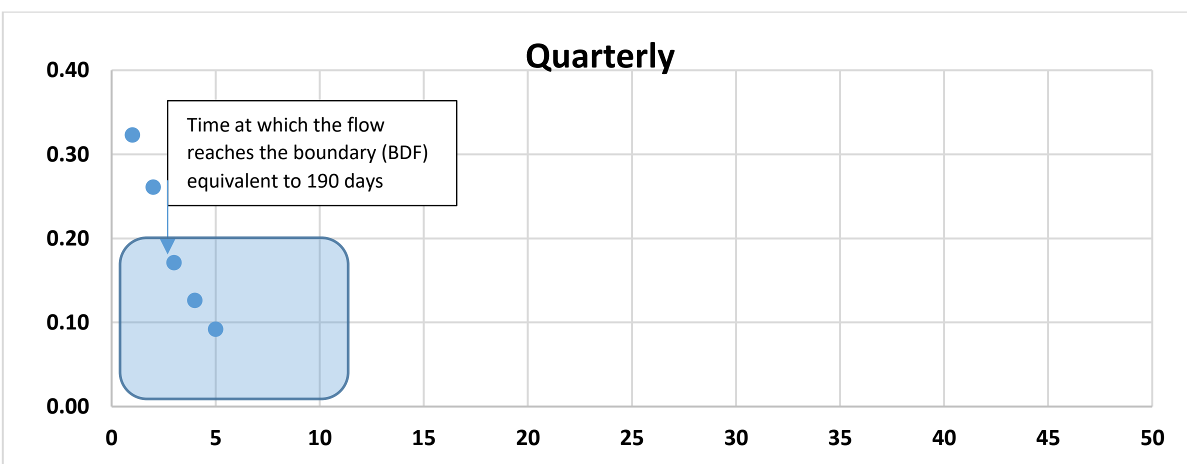

Figure 3.4.6. Shows quarterly decline rate versus time.

4. Conclusions and Recommendations

In this paper, Quarterly decline rate was used to improve the production data analysis of the shale gas wells. This decline proved its efficiency comparing to the daily and monthly decline rate. Using the quarterly decline rate helped in knowing the exact time at which the flow reaches the boundary. Determining the different flow regimes related to the shale gas using the log-log plot was effective in validating the idea of the quarterly decline rate. After verifying the idea on four different wells with different reservoir, a threshold value of 20% can be used in order to know the exact time at which the flow reaches the boundary.

Acronyms

BDF	=	Boundary Dominated Flow
CBM	=	Coal Bed Methane
DCA	=	Decline Curve Analysis
SRV	=	Stimulated Reservoir Volume

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