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# Modelling and Resolving the Low Permeability and High Capillary Pressure Effects of Tight Gas Reservoirs in Middle Indus Basin of Pakistan

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**Abstract**

The normal processes that is used for the conventional reservoir is not suitable for this unconventional reservoir we do appropriate reservoir modelling to provide the path to fluid to move easily within the reservoir which will be very helpful for producing the tight gas reservoir. And the problem statement of this research is with tight gas supplies have helpless penetrability and porosity and are considered as most trustworthy flighty vitality source. The issues looked during creation of tight gas is drained stream conduct because of less permeability (0.5mD or and >0.5mD) and high capillary pressure, which is the most well-known key issue. Subsequently, this test is the reasons why it is hard to deliver tight gas worldwide even in this serious world, and comparable is case with tight gas stores situated in center Indus bowl of Pakistan. As the light weight expands the liquid in pore spaces get caught and rock does not permit the liquid to stream. Hereafter, the relative penetrability, and small weight have substantial impact on stream conduct in tight gas reservoirs. The objectives are to investigate the influence of relative permeability and capillary pressure over gas recovery in tight bed gas reservoir with a vertical well via simulated model using eclipse, to evaluate the simulated impact of well profile (single well, multi well at short distance and multi well at long distance) on optimum productivity of gas from tight gas reserves, to conduct comparative analysis on achieved outcomes of simulated model to determine the optimistic well placement strategy in tight gas reservoirs.

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The scope of study of this research states that a diminishing chance of monetarily suitable elective wellsprings of vitality in present time, regularly broadening hole between the vitality request and gracefully and the decay of creation of ordinary petroleum product in present time, the push on whimsical sources, for example, close gas is glowingly expanding world-over.

***Keywords:*** Capillary Pressure; Low permeability; middle Indus basin; reservoir simulation; comparative analysis.

## 1. Introduction

Reservoir from unconventional formation comprises reservoirs for example skintight-sands gas, gas and oil shales, methane, thick oil and tar sands, and gas-hydrate bonds [1]. Tight gas reservoirs, also known as unconventional resources are the small permeability reservoirs which cannot be formed by conventional means of production [3]. However, they have become one of the significant sources of energy supply to all over the world and can successfully counter the energy shortage at the global level. The conventional sources of gas are found in the undeveloped tertiary basins, on the other hand the tight gas formations are almost deposited 248 million years ago [6]. Technically, tight formation gas is a natural gas that is existing in the very tight formation. This gas is confined underground in very a lesser amount of permeable solid rocks. Those rocks may be the sand stone, carbonates or the limestone. All these rocks have small permeability and porosity [18]. Admiring to the united states energy information administration [7]. Pakistan consume possibly will over 9 billion barrels ($1.4\times10^9$ cubic meters) of oil and 105 trillion cubic feet (3.0 trillion cubic meters) in natural gas (including shale bed gas) reservoirs. The technique resolve requires a bulky quantity of vertical wells. In some cases, its challenging towards make long number of cracks in tight gas reservoirs, mostly if the reservoir is go afar or lie underneath by a deprived cap or base rock. During the fracture jobs, when the pumping pressure goes above the formation pressure for an actual proppant settlement, the great pumping pressure might open the giant portion of the poor cap or base rock, follow-on in a great fracture height and fracture development in unproductive zones [18]. The flow behavior of the tight gas wells.

Three aspects are strongly effect the growth of the water behavior and gas reservoir and flow behavior. The third influence is the gas water relative permeability, which ups and downs with variation of drawdown pressure. These three influences work simultaneously and touch the gas flow and production of the tight gas reservoirs [14]. In Pakistan the tight gas resources are existing in the in the middle Indus basin region. The net pay thickness may be 16.5 m and the porosity and permeability are (≤10%) (≤0.1) md respectively. This formation having the net pay zone reaching from 25 to 250 feet original reservoir pressure is reaching on or after 1500 to 15000 psi and porosity is 3 to 10 percent. It is also considered a low permeability reservoir that mainly produces dry natural gas. In sand tight gas reservoir, we also face numbers of problems during exploration of tight sand gas reservoir [7]. In Pakistan the tight gas that confirmed to be present in the middle Indus basin Khirthar fold belt and Sulaiman fold belt. In Middle Indus there is possibility of 11 numbers in which 7 reservoir contain 7,400 bcf tight gas. In Sulaiman fold belt there is possibility of 14 with 3 reserves having 19,000 bcf of gas. In Khirtar fold belt there are 8 numbers with 2 reservoirs having 7200 bcf of tight gas. There are total 26 prospects and 8 reservoirs are known as tight gas reservoir [9]. Pakistan is facing big problem to complete their energy needs, its demands increased to 147 MTOE by 2022 with 245% increase as compared to 2008. Gas is the major source of energy supply as demand increasing day by day the resources is also declining day by day; it is expected to decline from currently available volume of 4.2 BCFD to 1.6 BCFD in 2022. Pakistan’s oil industry has to take quick step to overcome these upcoming problems by discovering and exploring large volume of oil and gas as compare to nowadays [1]. Discover new reservoirs explore it than produce it at economical rate in short period of time so we can quickly meet the needs of energy. In the 1970s the US Federal Energy Regulatory Commission (FERC) government decided to define the tight gas reservoir as the gas flow would be not as much of 0.1-0.5 md this description was lawmaking-based explanation that used to know which well expected government/ state tax [2]. Tight gas is measured as an exceptional basis of energy mainly produce dry natural gas it also contain some amount of heavy of components this formation having net pay zone 25 to above 25ft, original reservoir pressure is 1500 to 15000 psi and porosity is from 3 to 10 percentages [3]. In Pakistan it is defined in another way as per tight gas policy of 2012 by Management of Pakistan and Ministry of Petroleum and Natural assets. It is defined as tight gas is that reservoir having permeability of 1.0 md [1]. According to these both definitions it is clear that the tight gas has low permeability that makes very difficult to move the fluid from one place to another place within the reservoir. The normal processes that we used for the conventional reservoir is not suitable for this unconventional reservoir we do hydraulic fracturing to provide the path to fluid to move easily within the reservoir which will be very helpful for producing the tight gas reservoirs are less than 0.1-0.5 md this definition was political based definition that used to know which well received government/ state tax [2].

Tight gas is considered as an unconventional source of energy mainly produce dry natural gas it also contain some amount of heavy of components this formation having net pay zone 25 to above 25ft, reservoir original pressure is 1500 to 15000 psi and porosity from 3 to 10 percent [3]. In Pakistan it is defined in another way as per tight gas rule of 2012 by Government of Pakistan and Ministry of Petroleum and Natural resources. It is defined as tight gas is that reservoir having permeability of 1.0 md [1]. According to these both definitions it is clear that the tight gas has low permeability that makes very difficult to move the fluid from one place to another place within the reservoir. Tight gas is an eccentric source which is lavishly present in the Khirthar overlap belt of Pakistan so by this examination we will have the option to create tight gas holds by taking out the issues of relative penetrability slender weight and repository heterogeneity and it will be exceptionally valuable for us. We can meet the deficiency of gas in our nation and we can even create great income through this [14]. This research study provides verity of innovations in the field of reservoir engineering. Primarily, the development of simulated model to investigate the influence of capillary pressure and relative permeability over a gas recovery in tight gas reservoir, this is the unique methodological steps as tight gas reservoirs has shown complex behavior with respect to relative permeability evaluations. Moreover, the tight gas reservoirs in middle Indus basin of Pakistan are further complicated as very less of reservoir data is available from drilled wells tight gas formation in Indus basin. Secondly, the role of well design and well placement has been ignored in various simulation studies because well design is a complex to incorporate in simulation models. Henceforth, this study will present a methodological advancement in simulation technique to scrutinize the characteristics of well design in optimizing the gas recovery from tight gas reservoirs.


**Figure 1:** tight gas reserves in Pakistan.

### *1.2 Tight gas challenges in Indus basin*

In Pakistan the tight gas that affirmed to be available in the center Indus bowls Khirthar overlap belt and Sulaiman crease belt. In Middle Indus there is plausibility of 11 numbers in which 7 store contain 7,400 bcf tight gas [9]. In Sulaiman crease belt there is probability of 14 with 3 stores having 19,000 bcf of gas. In Khirthar overlay belt there are 8 numbers with 2 repositories having 7200 bcf of tight gas. There are all out 26 possibilities and 8 supplies are known as close gas repository [14]. Tight gas can likewise be found in the lower Indus bowl, Potwar bowl and seaward also these are as yet not affirming yet on the off chance that exploration will be directed and strategies will apply, at that point the quantities of tight gas repositories. Shale gas offers an elective hotspot for vitality starved Pakistan. Unpleasant appraisals demonstrate the presence of in any event 33 trillion cubic feet of unpredictable gas saves caught in close sands, as indicated by [7]. Additional report by [9]. Specialized overseer of Pakistan Petroleum Concerns sets the scale at 40 trillion cubic feet of tight gas holds in the nation. These unpredictable gas holds are in expansion to the staying customary demonstrated gas stores of more than 30 trillion cubic feet [10]. As the financial aspects of the tight gas in Pakistan are viewed as it is exceptionally hard to investigate out the tight gas due to its absence of methods and less skill in Pakistan. In Pakistan, the drilling price of a growth well swings from US$ 5 million to US$ 13 million for each well, in the result that it is situated in the South or North piece of Pakistan distinctly. The present conception of the tight gas benefit and past participation with different nation-states of the world with formation upgrade methods, from atomic outbreaks to pressure determined breaking, both show that massive gas development can be absolute, just by putting a wellbore in the nearby to region of the improvement to be conveyed. To meet the monetary necessity of wellbore positioning near the generating development, countless wells should be drilled to touch the focused on creation levels - a magnificent economic and environmental test. The fundamental sections for improvement of tight gas sand well integrate turning searching of a wellbore in the end completed with water driven break stimulation. Several innovation enhancements over previous years, while steady in environment, have merged to permit costs to be bargain whereas inquiry strategies have permitted improved well zones to be selected. Gradual improvements take joined to equal the effect of smaller quality stone being made. It is assumed that used for a huge growth in close gas creation levels, a more projecting than "steady" invention improvement must be shaped. Additional, environmental outcome can be limited by "On position Waste Management" – Nobody left the zone apart from commercial thing. Each leftover material (drill cuttings, boring liquids, and created liquids) are powerfully re-infused into appropriate areas in similar arrangements. Reprocess of things are improved [3]. Tight gas stores are portrayed by little pore throats and break like interconnection between pores. This little quality outcomes in some huge plainly visible outcome for instance high fine weight, low porosity, high unchangeable wetting stage drenching and low vulnerability. porosity, absolute porosity, viable porosity, porousness, relative penetrability and slim weight.

## 2. Modelling Technique

The modelling technique adopted in this study is deep in numerical reservoir simulation technology. Schlumberger eclipse is the most effective tool used across the world to perform such investigation. However, the numerical technique is used to achieve desired results will be based on finite difference method which will help to develop the relative permeability model. The main theme of this study to correlate the influence of relative permeability and capillary pressure effect along with optimized well placement strategy therefore, a basic model will be developed which will elaborate the relative permeability and capillary pressure effects. Furthermore, on the grounds of basic model sensitivity analysis will be performed, in which four categories of well design will be incorporated. The sensitivity models have feature of proposed well design which include.

- Single well model.
- Multiple well model with independent drainage area.
- Multiple well model with common drainage area.

Henceforth, the results from all these models will be compared and optimistic conditions will be proposed to increase the gas recovery from tight gas reservoirs.

The required materials and tools for this research are mentioned below:

**Material**

PC (Computer)

**Software**

Schlumberger Eclipse Simulation Software (E300) is accessible at IPNG MUET

### *2.1. Reservoir Description*

A 3D Cartesian model of a tight gas reservoir has been generated with obtained parameters from literatures about tight gas sand. A simple vertical single well is first used for relative permeability at Swr = 0.2 then second model is generated with a vertically at short distance and then third model is generated with a vertically at long distance and then final model is generated for comparison of both long and short distance. To model this all, data set for properties of reservoir used are given below in table 1.

### *2.2. Reservoir model input parameters*

**Table 1:** reservoir characteristics**.**

| **Parameters** | **Values** |
|---|---|
| No of layers | 4 |
| Thickness of layer | 100 ft. |
| Reservoir top depth | 9184 ft. |
| Permeability | 0.01 md |
| Porosity | 0.005 |
| Initial Water Saturation | 0.4 |
| Kz/Kr | 0.1 |
| Initial Pressure | 250 BAR (3626 Psi) |
| Well radius | 0.3 ft. |
| Zw | 150 ft. |
| Perforation length | 300 ft. |
| Temperature | 212° F |

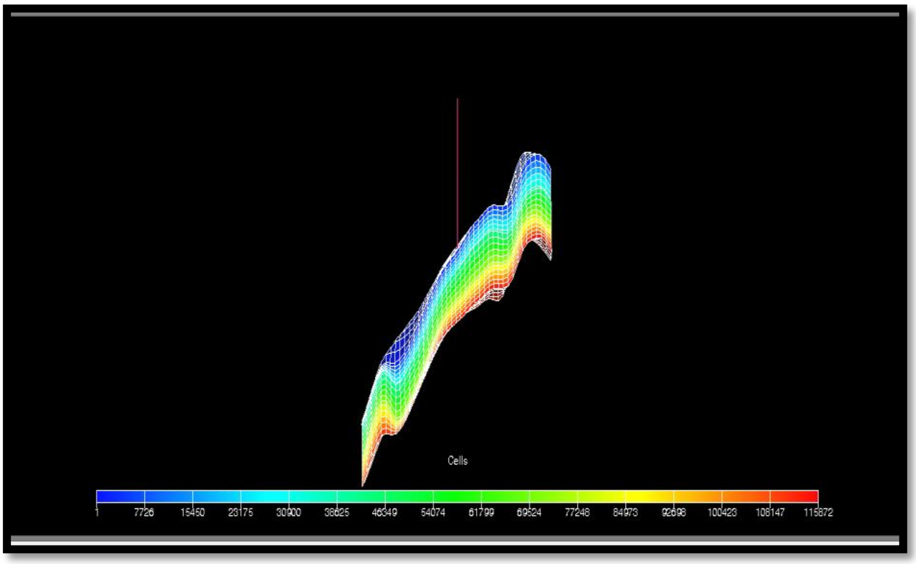


**Figure 2:** single vertical well model.

Fig 2 shows the model of single vertical well, the red line shows the single well and below the 3d grid blocks are centered in the blue zone is tight gas beds; the summary of this fig is that the single well is drilled in the tight formation.

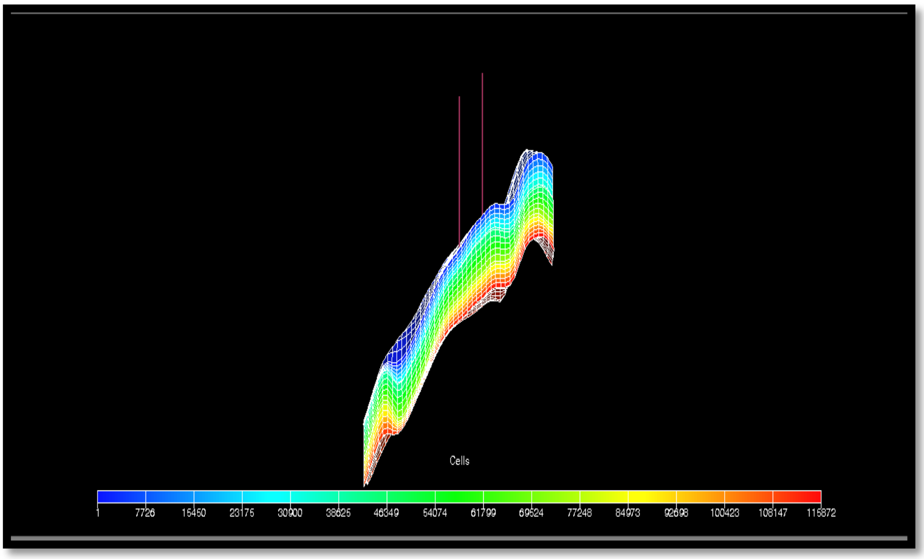


**Figure 3:** single vertical well model at short distance.

Fig 3 shows the single well model but it’s at short distance, the red lines shows the wells at short distance, the 2 wells are drilled at short distance for analysis the data of the reservoir geometry in the tight gas beds.

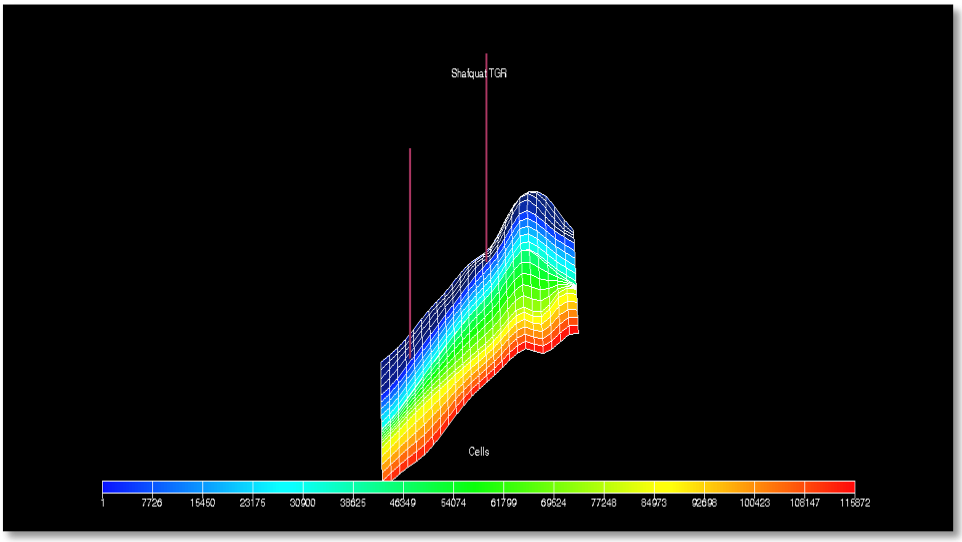


**Figure 4:** single vertical well model at long distance**.**

Fig 4 shows the single well model but it's at long distance, the red lines shows the wells at long distance, the 2 wells are drilled at long distance for analysis the data of the reservoir geometry in the tight gas beds.

### *2.3. Relative permeability*

These model evaluations are made on different data sets of relative permeability of wetting phase and non-wetting phase. The Kr graphs are generated against Sw at different values to check the effect of relative permeability on recovery factor and flow rates of tight gas sandstone reservoir. Following curves are used as the input parameters of Kr in the generated model.

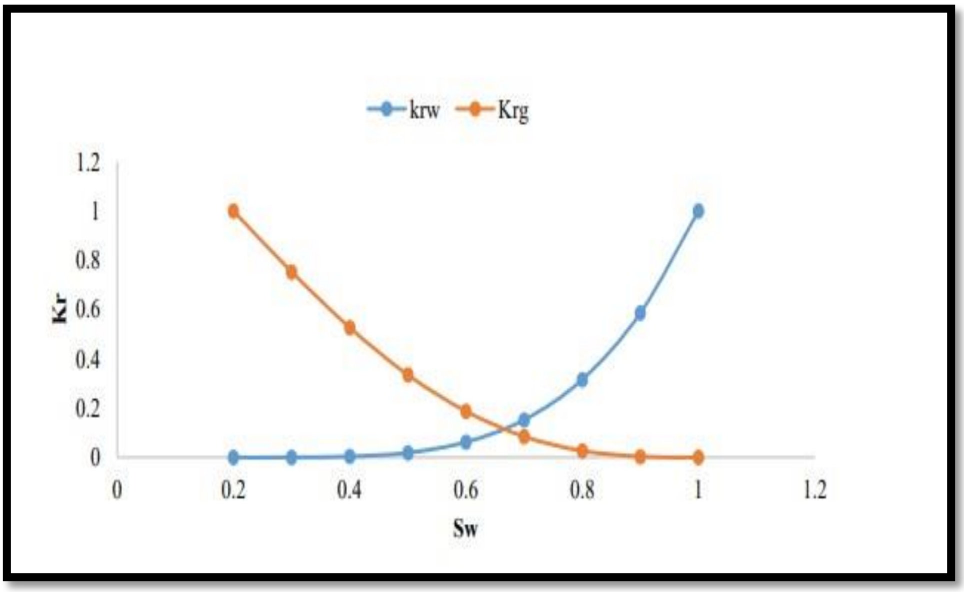


**Figure 5:** krw and krg at swr = 0.2**.**

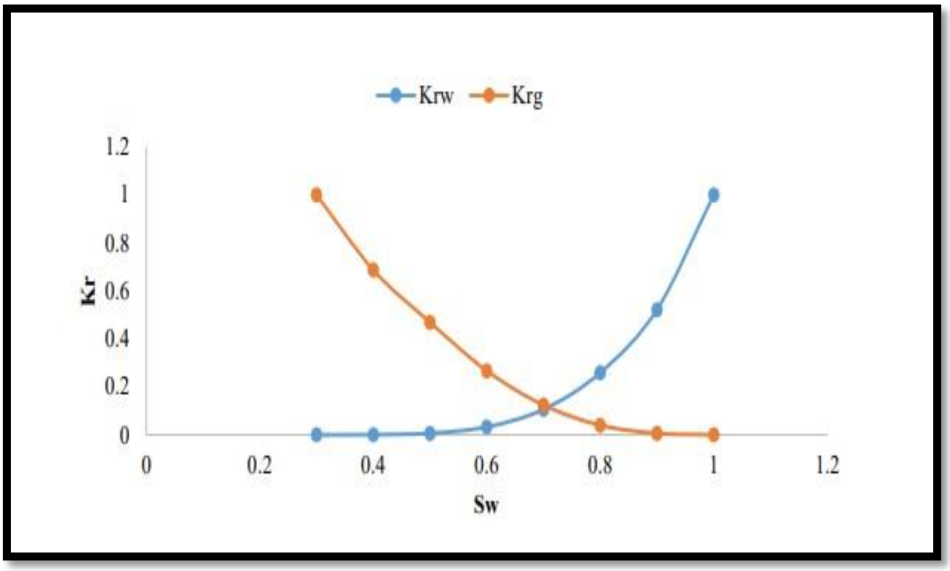


**Figure 6:** krw and krg at swr = 0.3**.**

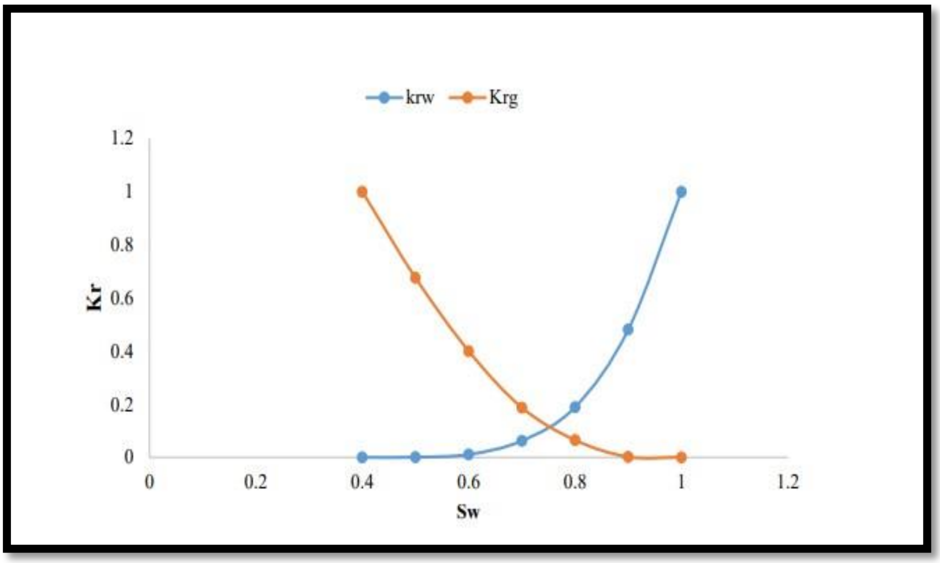


**Figure 7:** krw and krg at swr = 0.4**.**

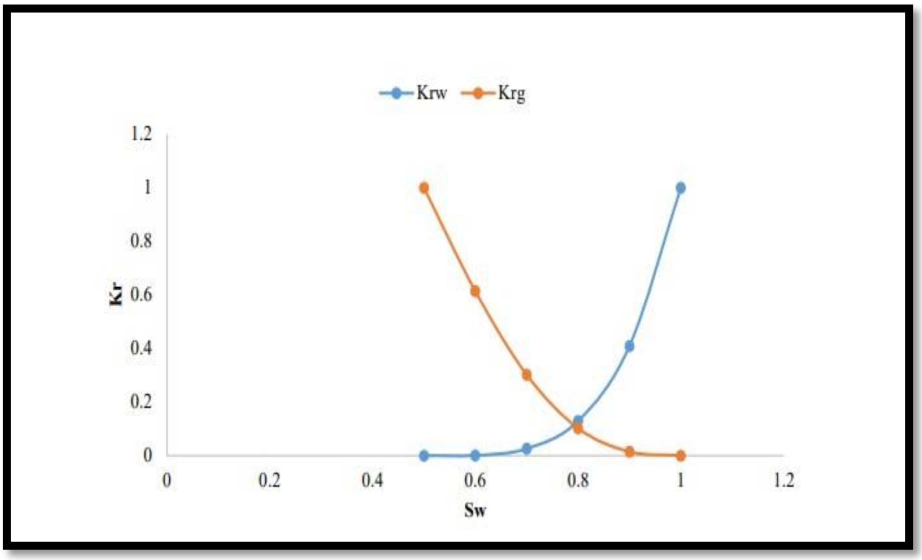


**Figure 8:** krw and krg at swr = 0.5.

### *2.4. Capillary pressure*

Model studies are made by using capillary pressures graphs by putting the virtue of gravity in the reservoir properties. The evaluations for capillary pressures have been made on different cases i.e. without capillary pressures (base case model), low capillary pressure, and high capillary pressure. All the scenarios are studied while using a vertically fractured model. These capillary pressures studies are done to check its effect on the Flow rates and the Recovery factor of tight gas sandstone reservoir. Following capillary pressure curves are used in the generated model.

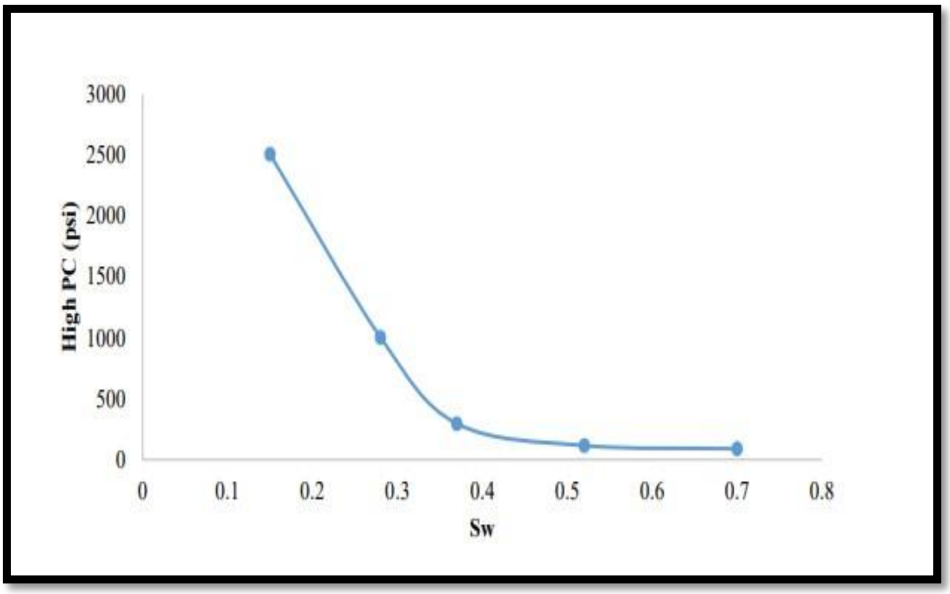


**Figure 9:** high capillary pressures.

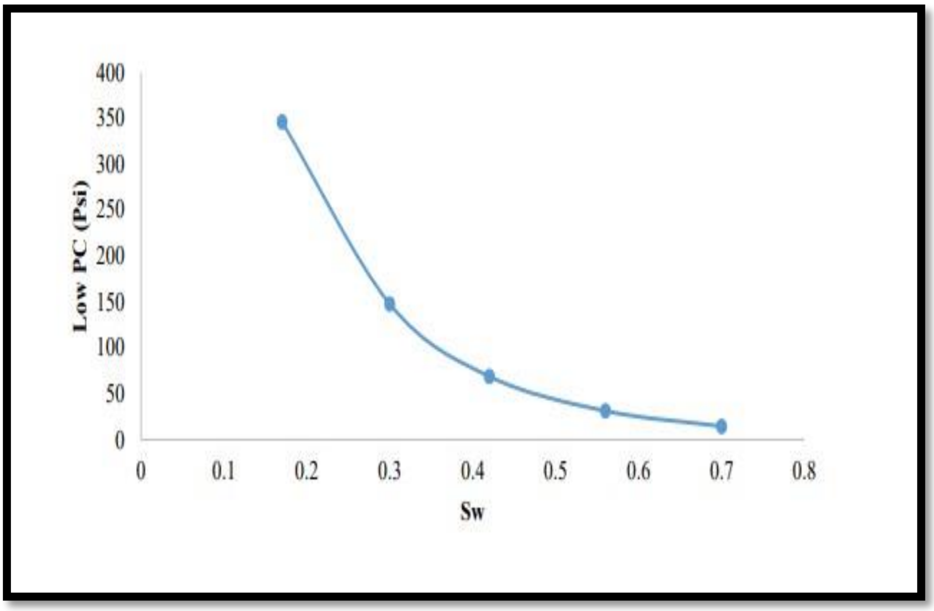


**Figure 10:** low capillary pressures.

### *2.5. Model Description*

This thesis comprises of several case studies of two reservoir properties i.e. relative permeability and capillary pressure. Following are the cases.

### *2.6. Relative Permeability Cases*

• Case 1: At Swr = 0.3

• Case 2: At Swr = 0.3

• Case 3: At Swr = 0.4

• Case 4: At Swr = 0.4

• Case 5: At Swr = 0.5

• Case 6: At Swr = 0.5

#### *2.6.1. Capillary Pressure Cases*

• Case 1: Without capillary pressure

• Case 2: With low capillary pressure

• Case 3: With high capillary pressure

Henceforth the firstly we prepared the cases relative permeability with the following Swr from beginning with 0.3,0.3,0.4,0.4,0.5,0.5 and secondly we prepared the capillary pressure cases beginning with without capillary pressure, with low capillary pressure, with high capillary pressure respectively.

## 3. Results and discussions

### *3.1. Single well Model*

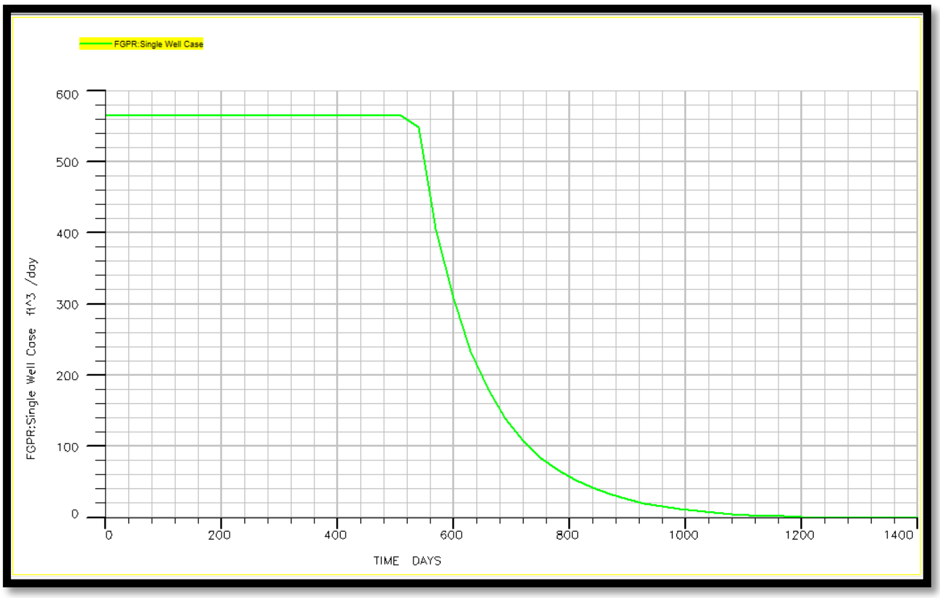


**Figure 11:** gas production rate simulated for a single well drilled in tight gas reservoir**.**

Fig 11 shows that gas produced from a reservoir by drilling just a single well so that the effect of multiple wells can be observed in tight gas reservoirs. In fact, that main focus of this study is to study the influence of relative permeability and capillary pressure effects but those effects can be analyzed on the grounds of outcomes from the reservoir. Henceforth, in single well case it is obvious that the gas production depleted within 1200 days after start of production. On the other hand, the overall production initiated at amount of 565 CFD which is however a low gas count for a field production but as only single well is drilled in whole reservoir so with respect to standard tubing sized well drilled in tight gas reservoir the amount of gas seems nominal. Further, up till 510 days from start of production the gas production remains linear and stable at the rate of 565 CFD, after 510 days the gas production showed decline transition of about 20 days and after 530 days the gas production showed rapid decline in overall production rate. Moreover, after 640 days of production the decline rate started to increase this behavior can be observed from the slope of declined curve plotted between 600 to 1000 days. Additionally, the overall production went totally unavailable within 1200 days and after 1200 days very minor production rate was observed which is technically very less amount of gas therefore gas production is considered depleted after 1200 days. Indeed, this production scenario need to be improvised therefore production optimization strategies are required to enhance the production. Moreover, ass the gas evacuates from reservoir after 500 days of production the capillary pressure within pore throats is modified and relative permeability of gas is dominated by relative permeability of water. Henceforth, effect of relative permeability and capillary pressure is clearly visible from analysis of production rate.

### *3.2. Single well short distance model*

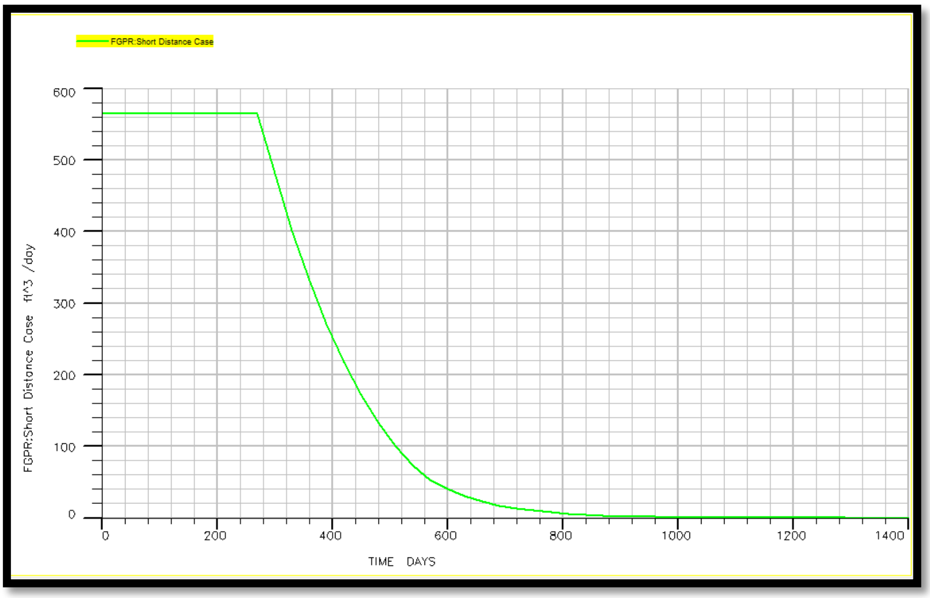


**Figure 12:** gas production rate simulated for a single well drilled at short distance in tight gas reservoir**.**

Fig 12 shows that gas produced from a reservoir by drilling just a single well at short distance so that the effect of multiple wells can be observed in tight gas reservoirs. In fact, that main focus of this study is to study the influence of relative permeability and capillary pressure effects but those effects can be analyzed on the grounds of outcomes from the reservoir. Henceforth, in single well case at short distance is obvious that the gas production depleted within 900 days after start of production. On the other hand, the overall production initiated at amount of 565 CFD which is however a low gas count for a field production but as only single well is drilled in whole reservoir so with respect to standard tubing sized well drilled in tight gas reservoir the amount of gas seems nominal. Further, up till 310 days from start of production the gas production remains linear and stable at the rate of 565 CFD, after 310 days the gas production showed decline transition of about 20 days and after 330 days the gas production showed rapid decline in overall production rate. Moreover, after 640 days of production the decline rate started to increase this behavior can be observed from the slope of declined curve plotted between 600 to 1000 days. Additionally, the overall production went totally unavailable within 900 days and after 900 days very minor production rate was observed which is technically very less amount of gas therefore gas production is considered depleted after 900 days. Indeed, this production scenario need to be improvised therefore production optimization strategies are required to enhance the production. Moreover, ass the gas evacuates from reservoir after 300 days of production the capillary pressure within pore throats is modified and relative permeability of gas is dominated by relative permeability of water. Henceforth, effect of relative permeability and capillary pressure is clearly visible from analysis of production rate.

### *3.3. Single well long distance model*

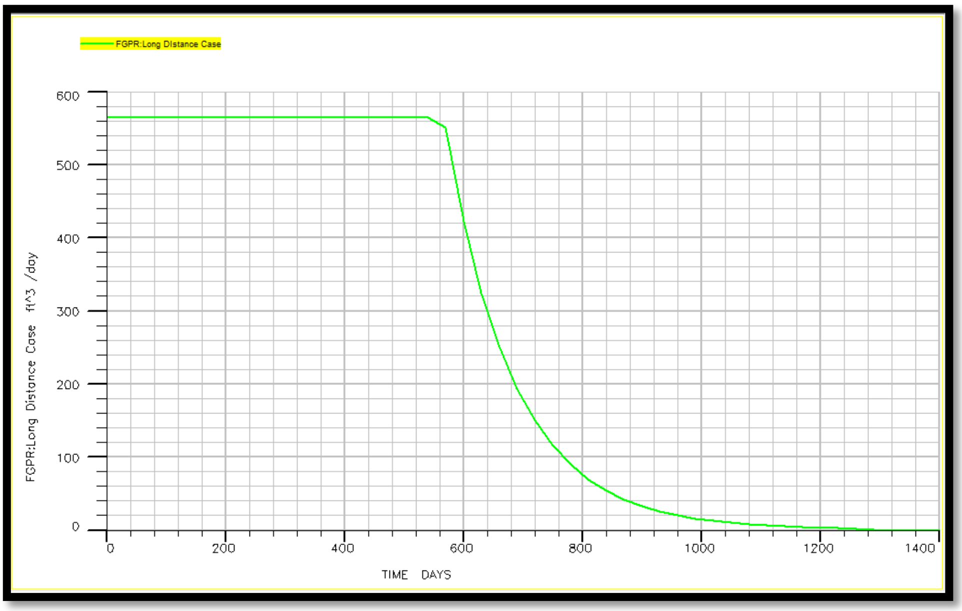


**Figure 13:** gas production rate simulated for a single well drilled at long**.**

Fig 13 shows that gas produced from a reservoir by drilling just a single well at long distance so that the effect of multiple wells can be observed in tight gas reservoirs. In fact, that main focus of this study is to study the influence of relative permeability and capillary pressure effects but those effects can be analyzed on the grounds of outcomes from the reservoir. Henceforth, in single well case at long distance is obvious that the gas production depleted within 1200 days after start of production. On the other hand, the overall production initiated at amount of 565 CFD which is however a low gas count for a field production but as only single well is drilled in whole reservoir so with respect to standard tubing sized well drilled in tight gas reservoir the amount of gas seems nominal. Further, up till 590 days from start of production the gas production remains linear and stable at the rate of 565 CFD, after 590 days the gas production showed decline transition of about 20 days and after 590 days the gas production showed rapid decline in overall production rate. Moreover, after 610 days of production the decline rate started to increase this behavior can be observed from the slope of declined curve plotted between 600 to 1000 days. Additionally, the overall production went totally unavailable within 1200 days and after 1200 days very minor production rate was observed which is technically very less amount of gas therefore gas production is considered depleted after 1200 days. Indeed, this production scenario need to be improvised therefore production optimization strategies are required to enhance the production. Moreover, ass the gas evacuates from reservoir after 590 days of production the capillary pressure within pore throats is modified and relative permeability of gas is dominated by relative permeability of water. Henceforth, effect of relative permeability and capillary pressure is clearly visible from analysis of production rate.

## 4. Comparison between long distance and short distance

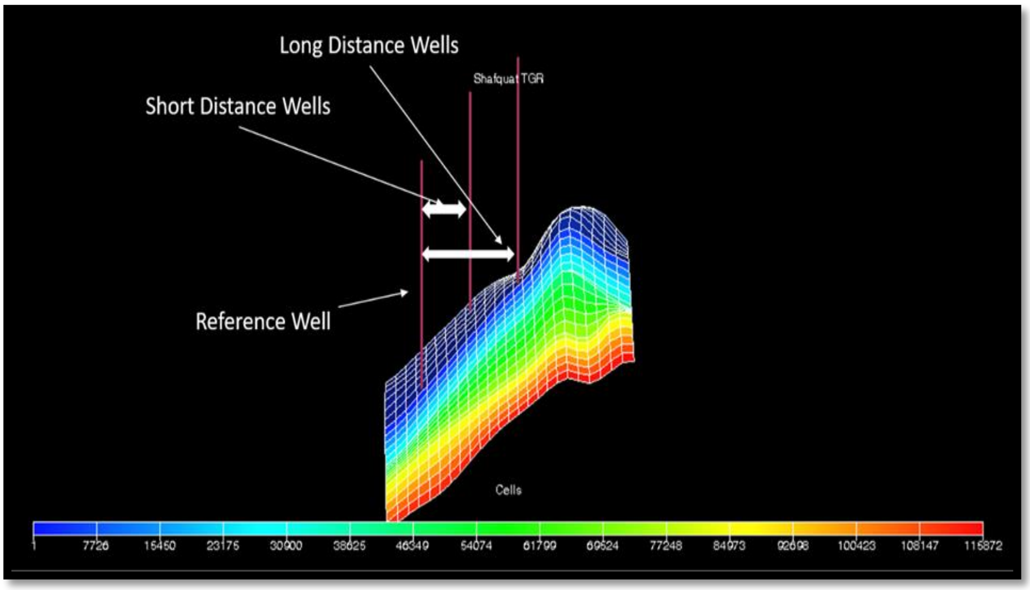


**Figure 14:** comparison model of long and short distance well**.**

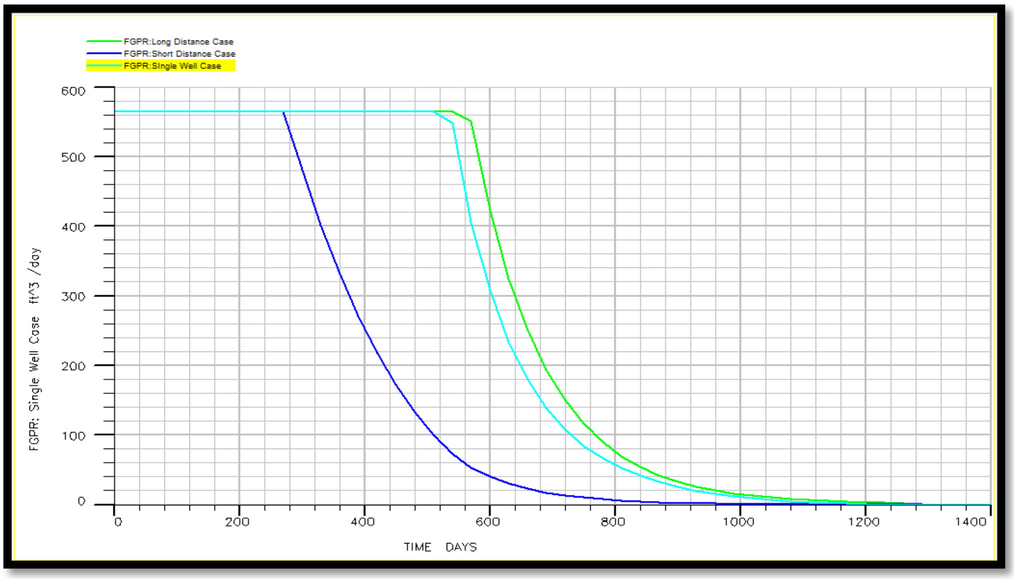


**Figure 15:** comparison between gases Production rate simulated for a single well drilled at long distance and short distance in tight gas reservoir.

Fig 14 and 14.1 shows that gas produced from a reservoir by drilling just a single well at both long distance and short distance so the blue line shows the short distance well and light green line shows the long distance well and cyan line shows the single well, that the effect of multiple wells can be observed in tight gas reservoirs. In fact, the long distance graph shows the more durability of flow of reservoir while short distance has low flow rate, that main focus of this study is to study the influence of relative permeability and capillary pressure effects but those effects can be analyzed on the grounds of outcomes from the reservoir.

### *4.1. Field pressure single well*

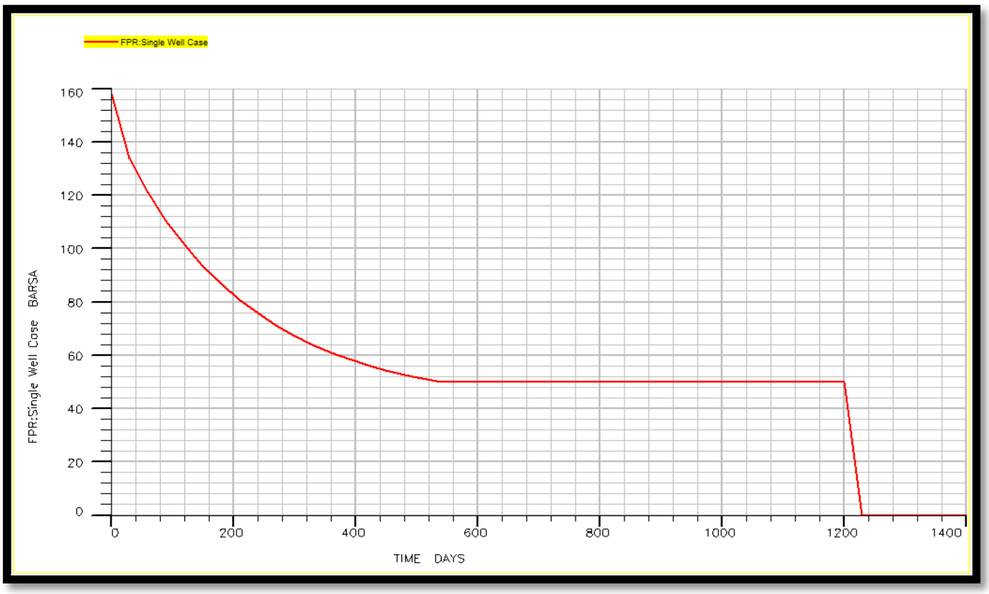


**Figure 16:** field pressure of single well model**.**

Fig 16 shows the field pressure of single well where pressure is slowly dropping from 11 BAR (160 psi) at the stage of 580 days, then the pressure is in equilibrium state at 58 psi for 1200 days then rapidly drops down on 1210 days and depleted.

### *4.2. Field pressure rate single well at short distance*

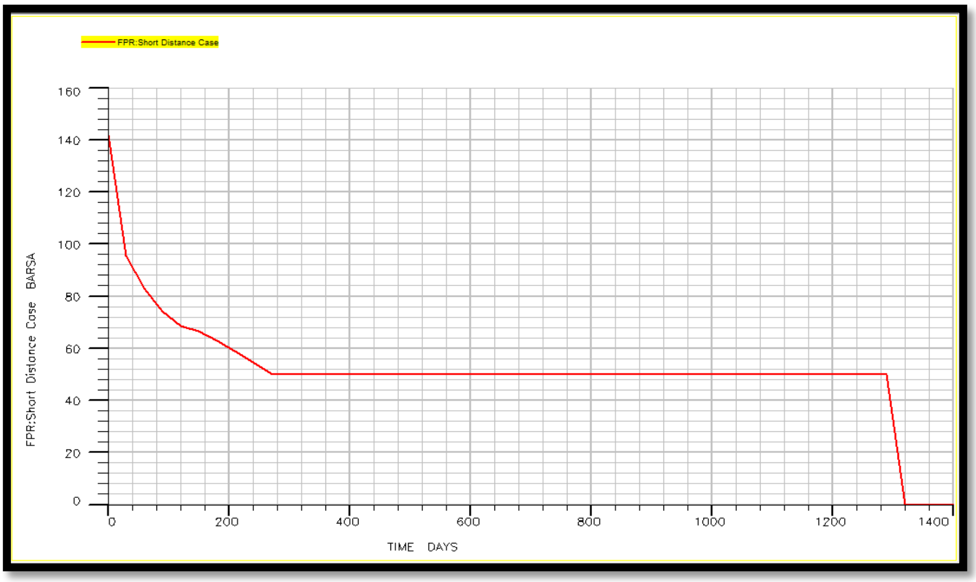


**Figure 17:** field pressure rate single well at short distance.

Fig 17 shows the field pressure of single well at short distance where pressure is slowly dropping from 140 psi at the stage of 290 days, then the pressure is in equilibrium state at 9.6 BAR (52 psi) for 1350 days then rapidly drops down on 1390 days and depleted.

### *4.3. Field pressure rate at long distance*

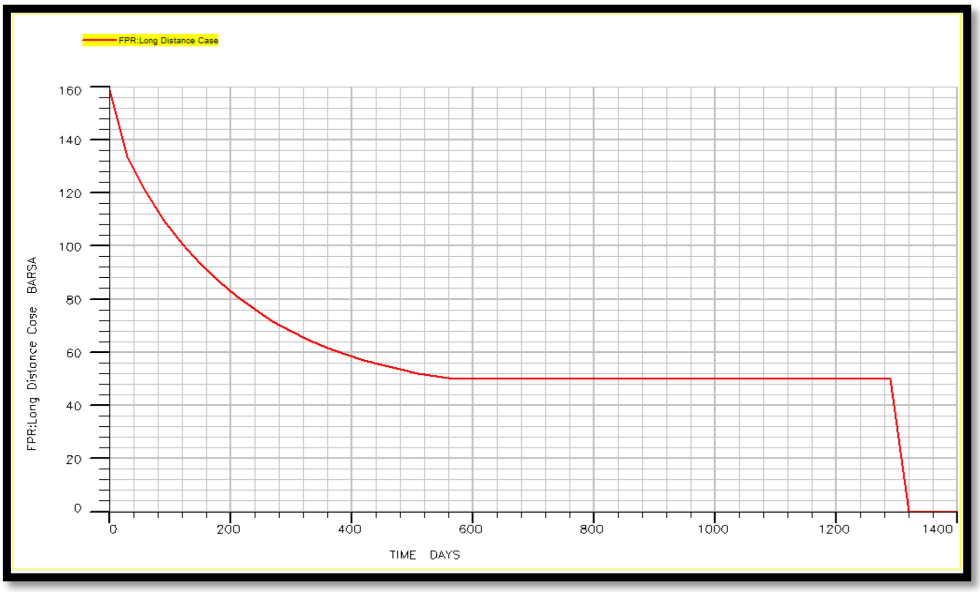


**Figure 18:** field pressure rate at long distance.

Fig 18 shows the field pressure of single well at long distance where pressure is slowly dropping from 160 psi at the stage of 590 days, then the pressure is in equilibrium state at 11 BAR for 1350 days then rapidly drops down on 1390 days and depleted.

### *4.4. Comparison between long distance and short distance*

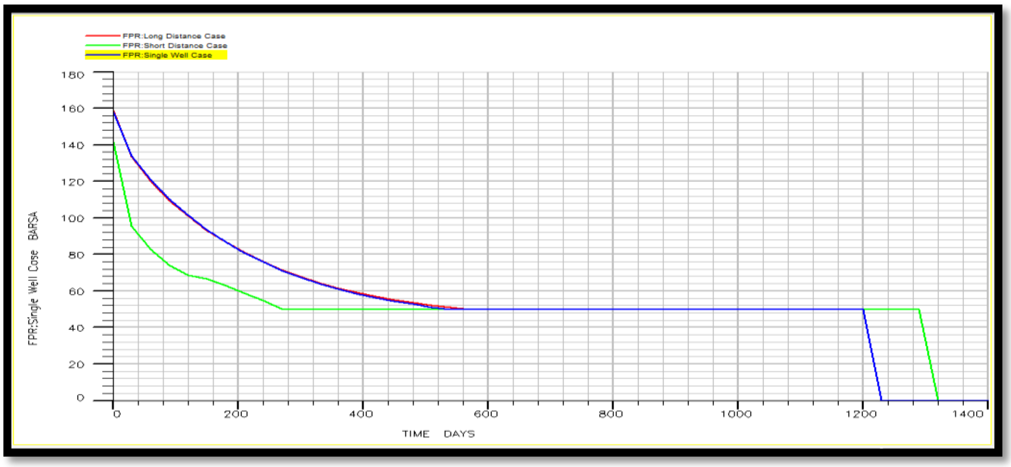


**Figure 19:** comparison of field pressure between long distance and short distance.

Fig 19 shows the field pressure produced from a reservoir by drilling just a single well at both long distance and short distance so the light green line shows the short distance well and red line shows the long distance well and blue line shows the single well, that the effect of multiple wells can be observed in tight gas reservoirs. In fact, the long distance graph shows the more pressure but the flow of reservoir decreased from 1390 days to 1210 days, while short distance has low pressure rate but the flow is increased than the long distance well, it is estimated at 1390 days of flow, that main focus of this study is to study the influence of relative permeability and capillary pressure effects but those effects can be analyzed on the grounds of outcomes from the reservoir.

## 5. Conclusions

Relative permeability and capillary pressure heavily affect the flow behavior in tight gas reservoir. In this thesis we have observed the recovery factor and flow of tight gas reservoir under the effect of relative permeability and capillary pressure cases.

At start a base case model is generated at Swr value of 0.2 in that case we have generated two models with and without fractured well. So the recovery factor without fractured well is calculated to be 2.4% and after fracturing the well recovery factor is increased to 23.4%. This result shows that when well is fractured then there is an increase of 21% in recovery factor in this case.

First of all several relative permeability models are generated at Swr=0.2, 0.3, 0.4 and 0.5. The recovery factor of these generated models is calculated. Then the above generated models are fractured to check the effect of fracture on the recovery factor. So, the calculated recovery factor without fracture models is: 2.4%, 3.1%, 4% and 4.4% respectively. While, with fracture the recovery factor is calculated 21%, 27%, 32% and 33% respectively. So this result shows that a reservoir with a fractured well has a good recovery than a reservoir without fractured well.

Recovery Factor of all the fractured well cases is compared to check the effect of changing Swr. So, we calculated the recovery factor to be 21%, 27%, 32% and 33%. This increase in the R.F with increasing Swr shows that as Swr gets increasing then it starts to act as a driving force to the fluid.

After relative permeability model, impact of capillary pressure has been analyzed by placing gravity into the model. So, in this capillary pressure model we checked the recovery factor without capillary pressure, at low capillary pressure and at high capillary pressure respectively. Recovery factor is calculated to be 21% without capillary pressure, 18.3% with low capillary pressure and 1% with high capillary pressure. The result shows a decrease in recovery factor with increasing capillary pressure. These results show that, 43% high capillary pressures in a reservoir traps the fluid within the rock and doesn’t allow fluid to move to the surface resulting the recovery factor decreases.

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