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ABSTRACT

Shale gas is one of the most rapidly growing forms of natural gas. Unconventional natural gas deposits are difficult to characterize overall, but in general are often lower in resource concentration and more dispersed over large areas. Moreover, gas is densely packed into the matrix which account for large volume of gas reserves. Gas production from this tight shale deposits are made possible by extensive and deep well fracturing which contacts large fractions of the formation. Production of gas takes place by diffusion of adhered gas in the matrix and by Darcy type flow in the fractures.

This thesis aims at detailed modeling of gas desorption, diffusion and flow in combination with statistical representation of the two processes. The representation of the model involves a cube as a porous media and a sphere inside it where gas is adsorbed. Gas is considered to be densely packed into the sphere which desorbs and then diffuses to the pore space and fractures in the cube on variation in concentration of gas and pressure decline. Many of these representative but general cells of the reservoir are put together and linked to a well or well fracture. The thesis quantitatively describes these processes as well as clarifies the geological conditions under which a successful shale gas production could be expected.

A mathematical model has been derived which is then compiled on FORTRAN to develop a simulator for the production of shale gas by considering sphere as a source term in each of the grid block. The obtained production plot explains the unique characteristics of gas production from tight shale formations.

This thesis also includes an analytical fracture model for a linear inflow and linear flow in the vertical fracture. The analytical model has been used to compare the pressure in fracture with that of numerical solution. The obtained results highlight the stability and applicability of the numerical model.

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Special thanks are due to my parents, brother and sister-in-law for supporting and encouraging my education since the beginning. Without your support, I wouldn't have made it so far.

Finally, I would like to express my sincere gratitude to University of Stavanger for letting me a part of this impressive organization.

Chapter 1
Introduction

This chapter gives an introduction to producing shale reservoirs worldwide and highlights geological and physical properties of shale gas and its comparison with the conventional reservoirs. The use of shale gas is seen in context of other unconventional gas resources, and a review of today's level of shale gas production is included. In the latter half of the chapter, the theory of pores in shale plays and how the gas is considered to be stored is highlighted. And towards the end, the objective followed by an outline of this thesis is mentioned.

1.1 Background

From the advert of the modern oil and gas industry, petroleum geologists and engineers have followed a conventional route for exploration; look for hydrocarbon source rocks, find reservoir quality rocks where hydrocarbons can accumulate, identify a trapping mechanism and then drill a well. But a revolution is taking place in the E&P industry. Rocks that in the past were of little interest, other than as potential source rocks, are today being actively pursued as potential reservoirs. When considering unconventional resource plays, the focus is on finding organic shale's (Alexander, et al., 2011, p. 40).

The Barnett Shale of central Texas, USA, is recognized as the play that initiated the recent interest in developing shale as producing reservoirs. This development represents a fundamental shift in the way exploration companies consider resource plays. Engineers and geologists studying shale gas resources find that reservoir can lead to process adaptation and refinement of techniques. It is important to integrate data from many sources and at many scales to optimally drill, complete and stimulate wells to produce hydrocarbons from their source rocks (Alexander, et al., 2011, p. 40).

The two other type of existing unconventional gas resources are coal-bed methane and tight gas. As per World Energy Outlook 2014, there has been substantial increase in production of shale gas in the United States since year 2000 due to recent advancements in fracking technology.

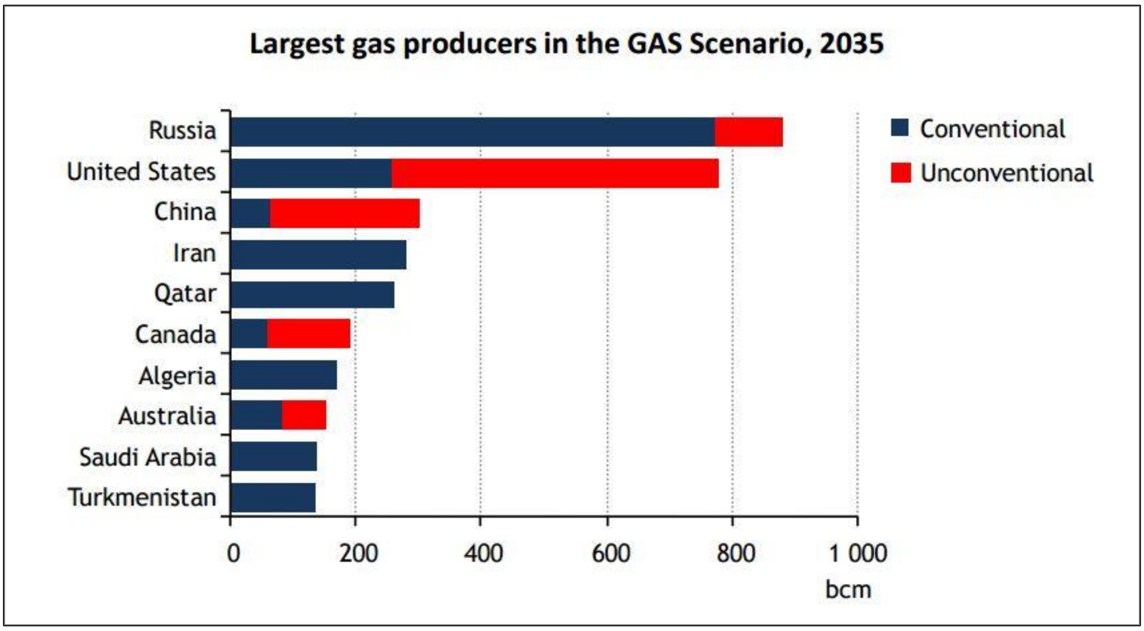


Figure 1.1 Largest Gas producers in the Gas scenario, 2035 *(World Energy Outlook , 2011)*.

The report by World Energy Outlook, 2011 describes that unconventional gas supplies 40% of the 1.8 tcm increase in gas demand to 2035, taking up nearly one quarter of total production. Natural gas can enhance security of supply: global resources exceed 250 years of current production; while in each region, resources exceed 75 years of current consumption. Shale production is projected to increase from 23% of total US gas production in 2010 to 49% by 2035 (Annual Energy Outlook, 2012, p. 93).

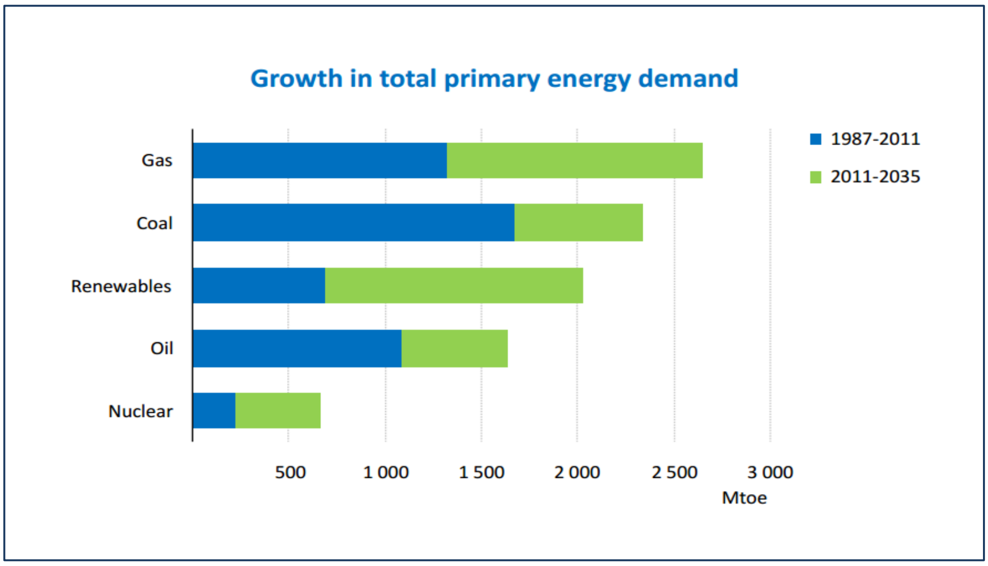


Figure 1.2 Growth in total primary energy demand *(World Energy Outlook, 2013)*.

In-spite of growing demand of gas and recent technological advancements, the modelling techniques of the shale gas production is not well understood. The conventional production forecasting methods have proved to be very pessimistic and inaccurate. This thesis provides a new approach to model the shale gas production to accurately express the characteristics and depict long term shale gas production behaviour.

The model and the presentation of the shale gas characteristics and developments used in this thesis is based on the shale gas production in the United States, as this shale gas industry is by far the most developed and well documented. The most famous and developed shale formations are the Barnett Shale in Texas and the Devonian Shale in eastern U.S. Other famous shale gas locations include Haynesville, Fayetteville, Marcellous and Woodford. Only considering the shale gas resources in the U.S., these are estimated to be between 500 and 1000 trillion cubic feet (Arthur, Bohm, & Layne, 2008).

1.2 Shale Gas Characteristics

Shale formations are sedimentary rocks that fall under the category of mudstones. These are usually composed of clay minerals such as illite, smectite and kaolinite. Shale is distinguished from other mudstones because they are fissile and laminated.

Laminated because the rock is made up of many thin layers whereas it is fissile due to easiness with which the rock splits into thin pieces along laminations. Some shale's have special properties that make them important resources. Black shale's contain organic material that sometimes breaks down to form natural gas or oil.

There are different definitions for shale gas; Boggs (2001) states that shales are siliciclastic sedimentary rocks composed of mud-sized particles but uses term shale for all sedimentary rocks composed dominantly of mud size (<0.6 mm) particles. Potter (2003) classifies shale as a type of "mudrock". According to this classification "mudrock" are sediments with >50% terrigenous material of which >50% is less than 63 microns. Potter further requires the rock to be lithified and fissile. In this classification scheme rock with >67% silt are "siltshale"; those with >67% clay are "clayshale" and between these are mudshale (Moghanloo, Javadpour, & Davudov, 2013, pp. 1-2).

There are two important characteristics by which shale gas reservoirs differ from the conventional gas reservoirs. Firstly, they have very low matrix permeability. Secondly, in some instances they contain organic-rick rocks where gas can also be adsorbed. For shale gas reservoirs, the effective permeability may often be in the range of 10^{-3} to 10^{-6} mD as shown in figure 1.3. Production from these reservoirs requires long horizontal wells with multiple staged hydraulic fracture treatments to create extensive artificial fracture networks near the wellbore. The effective conductivity of fractures and the actual permeability of the shale rock are also crucial for the productivity.

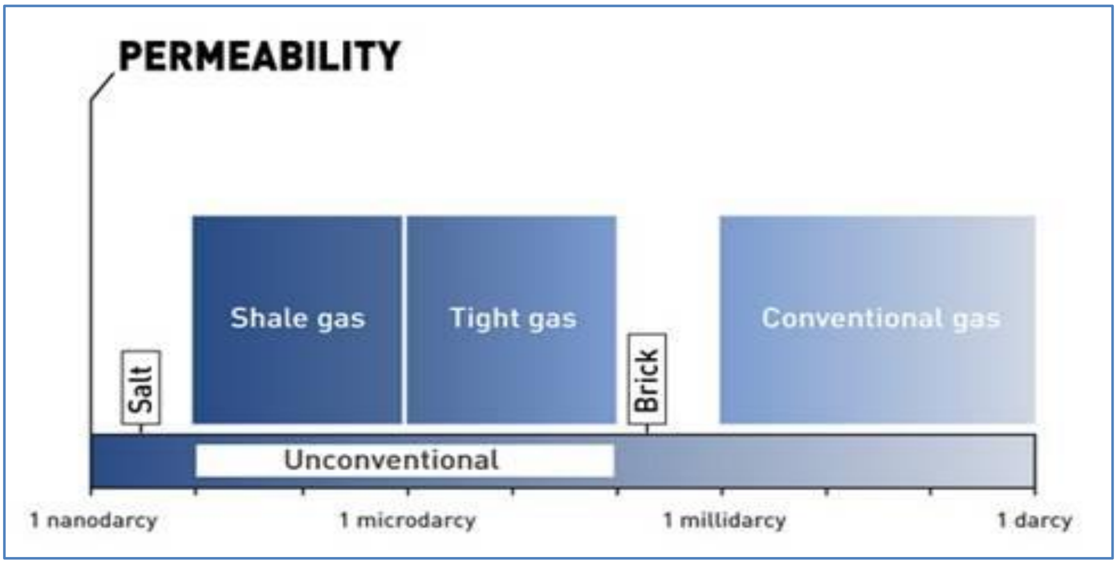


Figure 1.3 Permeability comparison between conventional and unconventional gas reservoirs (Total S.A, 2015).

Estimation of original gas-in-place in shale gas reservoirs requires:

- For free gas – a conventional volumetric method using porosity, bulk rock volume, porosity, fluid saturations, and pressures.
- For adsorbed gas – use of Langmuir Isotherms.

Typically, all water in a tight/shale gas reservoir is not moveable and so reported water production is almost always attributable to production of load fluids (completion/fracture treatment fluid) (Fekete Associates Inc., 2012).

A comparison of conventional and tight/shale gas reservoirs are shown below (tab. 1.1):

Characteristics	**Conventional**	**Shale**
Gas Generation	Gas is generated in the source rock and then migrates into the reservoir.	Gas is generated and trapped within the source rock.
Gas Storage Mechanism	Compression.	Compression and adsorption.
Gas Produced	Free gas only.	Free and adsorbed gas.
Production Performance	Minimal transient period followed by a long boundary-dominated flow	Very long transient (linear) flow period that can extend many years. In

	period. Production rates are mainly relatable to permeability and declining reservoir pressure. From a traditional decline perspective, 'b' values typically range from 0 to 0.5 but can be somewhat larger if there are commingled layers. Recovery factor = 50% – 90%	some cases, it is debatable if boundary-dominated flow will ever be fully realized. Production rates are mainly relatable to the success of creating a large fracture network around a long horizontal wellbore and to the matrix permeability. From a traditional decline perspective, 'b' values initially equal 2.0 (indicating linear flow), and then transition to <1.0 as boundary-dominated flow becomes prevalent. Recovery factor = 5% – 20%

Table 1.1 Comparison between conventional and shale gas reservoirs (Fekete Associates Inc., 2012)

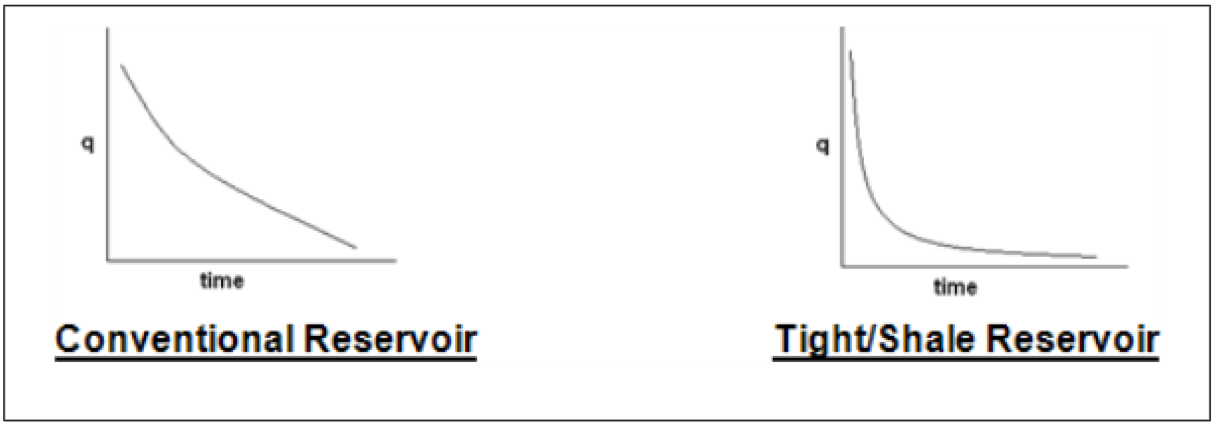


Figure 1.4 Comparison of conventional vs. tight/shale gas rate-time plots (Fekete Associates Inc., 2012)

The shale formations act as both the source rock and reservoir rocks; in other words, the shale gas lacks the presence of a trapping mechanism as opposed to the conventional reservoirs. Javadpour et al. (2007) suggested different gas storage processes in gas shale namely; compressed free gas in nanoscale pores in the organic matter, and dissolved gas in the kerogenic material. Gas shale consists of a solid matrix and fractures that contribute to the natural permeability pathway for gas flow. Matrix constituents are lithified clays, detrital minerals, and organic material where the latter is an essential constituent of a productive shale gas reservoir (Moghanloo, Javadpour, & Davudov, 2013, p. 2).

The gas in shale reservoirs is stored in 3 ways:

- Free gas in pores and fractures
- Adsorbed gas onto organic matter & clay minerals in the matrix
- Dissolved gas in oil & water

Shale gas reservoir show high gamma ray value, low P-impedance, lower V_p/V_s ratio and higher resistivity value. V_p/V_s ratio and P-impedance can be used to differentiate between shale and other lithology and also to separate between reservoir shale and non-reservoir shale. For shale gas, V_p/V_s is lower as V_p reduces when gas is present.

1.3 Pores and Microfractures

This section is based on Linkedin post "Pores in Shale Plays" by Emanuel Martin, 2015.

The gas inside the shale is found stored in pores and natural microfractures. The pores we can classify in two groups: pores inside the non-organic matter and pores inside the organic matter.

1.3.1 Pores within Organic Matter

These type of pores generally are the most abundant in the shale and are associated to the generation of hydrocarbons in-situ from kerogen, their sizes ranging from 1 nm to 10 μm and may arrive to have to 1000 pores in a small portion of organic matter.

Reed estimated that the porosity within the organic matter ranges from 0 to 25% in weight, it can become even 5 times bigger than the porosity of the matrix and is dependent of the pore pressure and stress. In the Barnett play for example more than 70% of the pore volume comes from the pores present in the organic matter.

The Kerogen has the feature to be able to store a large amount of gas due to its volume pore, inside which the gas is found like free gas, and their ability to adsorb molecules of gas in the pore walls. In the majority of the shale has been found a directly proportional relationship between increasing of matter organic contents (TOC) and the gas storage capacity. In the majority of the shale has been found a directly proportional relationship between increasing of matter organic contents (TOC) and the gas storage capacity.

1.3.2 Pores with Matrix

The pores within the matrix may be classified as intercrystalline, intraparticle, intergranular and pores formed by mineral dissolution.

Intercrystalline pores are among clay flakes and other particles of the matrix. Their sizes range from 0.1 nm to 2 μm. These types of pores are more abundant in compacted shale and highly pressurized (Fayteville) or shale rich in clays (New Albany).

Intraparticle pores are found within nano-fossil fragments, calcareous mudstone or within framboidal pyrite. They have a pore size ranging from 0.1 nm to μm.

Intergranular pores are associated with grain-supported silty laminae or beds within shale. (Montney and Colorado Shale's); these pores are larger than the pores found in organic matter, with sizes ranging from the 10μm the 200μm.

Pores formed by dissolution: they are produced by the dissolution of carbonate, dolomite and/or pyrite. They are generally present in smaller quantities (Milner et al., 2010) associated with secondary porosity with sizes of pores ranging from the 2 μm the 200 μm.

1.3.3 Natural Micro-fractures

The natural microfracture can harbour relatively large quantities of gas and generate important flow networks to connect among themselves and with pores present in the kerogen and matrix. These microfracture and microfissures were generated during the transformation of organic matter into hydrocarbons when these reached the thermal maturity needed they cracked.

1.4 Objective

Gas is densely packed into the matrix which account for large volume of gas reserves which cannot be neglected. Gas production from this tight shale deposits occur by connecting the formations to the well through multiple fractures. Production of gas takes place by desorption and diffusion of gas into the pores space in the matrix and then by Darcy type flow in the fractures.

This thesis aims at proposing a model that can be used to simulate the gas desorption and diffusion processes in combination with Darcy flow in the formation. It aims at creating a mathematical expression that explains the long term well performance characteristics of the shale gas production. The representation of the model involves a cube as a porous media and a sphere inside it where gas is adsorbed. Gas is considered to be densely packed into the sphere which desorbs and diffuses to the pore space and fractures in the cube on variation in concentration of gas and pressure decline. Many of these representative but general cells of the reservoir are put together and linked to a horizontal well through a vertical fracture.

The thesis also aims at developing a simulator on FORTRAN compiler that describes the detailed modelling of gas adsorption/desorption and linear flow in combination with statistical representation of the two processes. The simulator developed is named as FSGP (FORTRAN code for Shale Gas Production) and it uses single phase flow of gas in two dimensional reservoir. Moreover, it also aims at analysing how the production profile would behave when a heterogeneous inputs are given to the simulator, i.e., the sensitivity analysis of the simulator. Towards the later part of the thesis, an analytical fracture model is also presented which aims at verifying the stability and applicability of the numerical model by comparing the fracture pressures.

1.5 Outline of the thesis

This thesis proposes a flow model for the production of shale gas taking into account processes such as Diffusion and Desorption of adhered gas. The scope includes development of a simulator FSGP on FORTRAN compiler to simulate the flow model and depict the long term shale gas well performance characteristics.

The objective of chapter 2 is to present the flow model and look into the theoretical aspects of various processes involved in the flow model. It also gives brief introduction to FSGP simulator and shows the advantage of flow model in calculating original gas in place efficiently.

Chapter 3 presents the numerical and mathematical model involved in the flow of shale gas in two dimensional reservoirs. It explores the simulation techniques used and gives an overview of the way programming is done on FORTRAN.

An analytical fracture model for a rectangular shaped fracture is presented in chapter 4. The model considers linear inflow of gas from the formation followed by linear Darcy flow into the fracture. The model has been used to compare the results with numerical solution.

Chapter 5 presents the results generated through FSGP simulator. Brief comments have been made on each results. Moreover, the stability of simulator has been highlighted by testing it for different and heterogeneous reservoir properties. Towards the end of chapter, a comparison has been done between fracture pressures obtained analytically and numerically.

Conclusions of the thesis and future work that needs to carried out are listed in chapter 6. This has been followed by the list of references involved in the making of this thesis. Appendix A, B and C presents FORTRAN code, input data file and generated output data file in FSGP simulator, respectively.

Chapter 2
Shale Gas Flow Model

In this chapter, a model for the flow of shale gas is being proposed to efficiently model the production. It describes the model in detail by treating it in a step-wise process. In the next section, an introduction to FSGP simulator is given which defines the assumptions and geological conditions under which the simulator works. Later on, we highlight the theoretical aspects of diffusion, adsorption and desorption of gas in shale reservoirs and how it is being used in this model. In the end, we discuss about the modelling approach of fracture that has been used in this thesis for the production of shale gas.

2.1 Description of Flow Model

Shale gas is one of the most rapidly growing forms of natural gas. It will make a major contribution to future world gas production. These are the complex rocks characterized by heterogeneity in structure and composition in all scales. However, understandings and technologies needed for effective development of these resources are still lacking and as a result, we have low gas recovery. There have been numerous approaches to model the gas production from the reservoirs from advanced simulators to analytical solutions.

Moreover, long term shale gas well performance characteristics are generally not well understood. The extremely low permeability of shale reservoirs gives steady and continuous presence of pressure transient effects during well production. This makes production forecasting a difficult and non-unique exercise. In this thesis, we present a straight forward methodology to explain the characteristics of well performance by modelling gas production in a new innovative way.

Gas in shale reservoirs is present both in the naturally occurring micro fractures and adsorbed onto the surface of the shale grains. By storing gas in a dense, liquid-like adsorbed phase, the overall storage capacity of the rock is increased relative to if there were a free gas phase alone. Moreover, the release of this adsorbed phase is pressure dependent. As a reservoir is depleted, the adsorbed phase is freed, providing not just additional gas for production but helping to maintain pressure (and perhaps open pore throats for fluid flow) as well. While adsorption allows for larger quantities of gas to be in place and possibly produced, factors such as desorption pressure, kinetics, and alteration of effective stresses makes it difficult to know if desorbed gas will contribute significantly to production.

Gas production from this tight shale deposits are made possible by extensive and deep well fracturing which contacts large fractions of the formation. Production of gas takes place by diffusion of adhered gas in the matrix and by Darcy type flow in the fractures.

The model presented here can be divided into three stages:

1. Firstly, we look into the model of one cell of the reservoir . In this work, we develop a flow model with a cell in the shape of a cube and a sphere inside it. The gas in stored in natural fractures, pores and adsorbed onto kerogen/organic matter. When the production starts, free gas from the natural fractures is produced first and then the matrix feed the fracture network and matrix is in turn fed by adsorbed gas on kerogen or organic matter exposed inside the nanopores. Matrix here means both the organic matter or kerogen and the inorganic matter. However, the inorganic matter have much bigger pores and they can be classified as micro-fractures. These micro-fractures becomes active

after hydraulically fracturing the formation. Thus, it is convenient to define pore space inside the organic matter as matrix and that of in the inorganic matter as micro-fractures.

In this thesis for the ease of modelling, we assume all the kerogen bulk or organic matter to be located at one place, i.e., inside the sphere. Thus, the amount of adsorbed gas is present only inside the sphere as shown in figure 2.1. Whereas, the space outside of sphere and inside the cube consists of inorganic matter with micro-fractures where free gas is stored. In actual reservoir, the organic matter is much more dispersed throughout the inorganic matter but this assumption is to efficiently model the gas production.

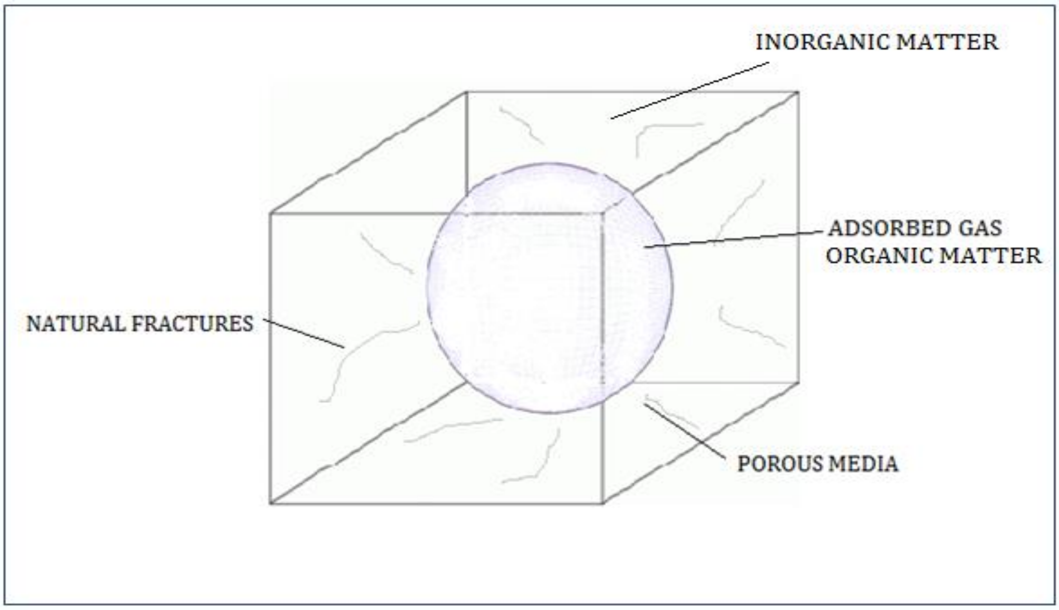


Figure 2.1 3D representation of single cell used in FSGP model.

As the gas is produced first from the micro-fractures, the decrease in pressure in the cell will trigger desorption of gas from the organic matter or the surface of kerogen. After desorption, surface area are available for gas to diffuse from kerogen. This diffused gas gets adsorbed onto the available surface of kerogen. When the adsorbed gas is released, it will firstly act as free gas within the kerogen pores within the sphere. This free gas will act like a gas source and feed gas to the micro-fractures in the cube. The flow in network is considered to be linear Darcy's flow. This shows the extent of gas transport in shale gas reservoirs.

The sphere can be considered consisting of many layers of adsorbed gas. With pressure decline, the gas will be desorbed first from the outer most layer of sphere which will cause decrease in molecular concentration of gas. The available surface area and change in concentration will trigger the diffusion of gas from kerogen. The process will continue to all the layers present internally until all the gas diffuses out of the kerogen, absorbed onto available surface area and is desorbed into the micro-fractures in the cube.

Figure 2.2 illustrates schematic of the outward gas flow from the surface of the organic matter towards the network of fractures where gas flow occurs. The direction of diffusion here is in the direction of increasing radius, r. Assuming that the outer surface of the organic matter or sphere remains constant during the flow due to the gas desorption that takes place internally. The concentration in the outer layer will only change when all the gas is desorbed from the inner layers. Also, we assume that the concentration of gas in the micro-fracture remains constant once desorption of gas starts from the sphere. The amount of gas adsorbed in the sphere is given by Langmuir's Isotherm which is discussed in detail later. Figure 2.3 gives 2D representation of cell defined in figure 2.1.

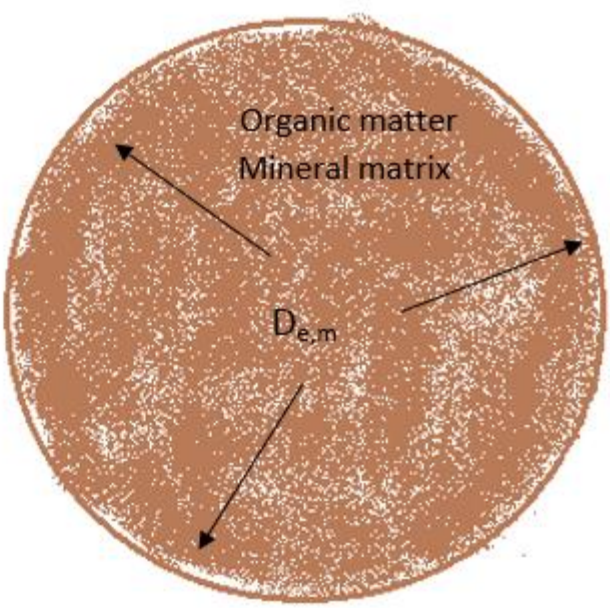


Figure 2.2 2D representation of sphere with organic matter.

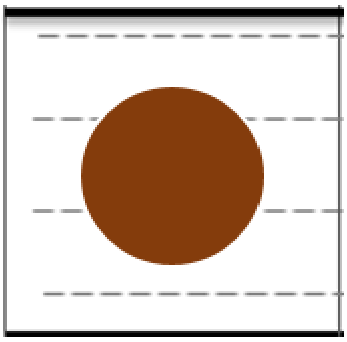


Figure 2.3 2D representation of a Cell used in FSGP model.

2. Many of these representative but general cells are put together forming a layer of reservoir and linked to a well or well fracture. The thesis quantitatively describes these processes as well as clarifies the geological conditions under which a successful shale gas production could be expected in chapter 3. The arrangement of cells is in the same way as for conventional reservoir for the numerical solution.

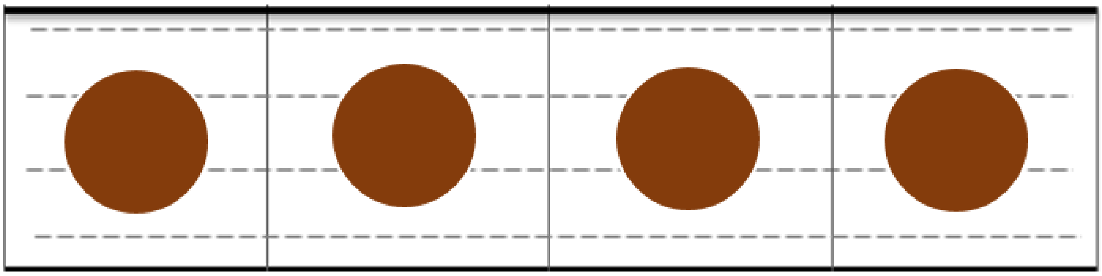


Figure 2.4 Cells linked together forming a layer of reservoir.

3. Multiple layers of cells are then linked to a horizontal well through a hydraulic fracture vertical fracture. The flow of gas is from one cell to another and then to the well through the induced fracture. However, the model is based on number of assumptions. Desorption of gas from the organic matter feed the matrix only and do not contact the fractures directly. The matrix then feeds the gas to the micro-fracture. Finally, it is assumed that gas flows out only through the fractures and no gas flows out from the matrix directly. Figure 1.7 shows the complete representation of the model proposed.

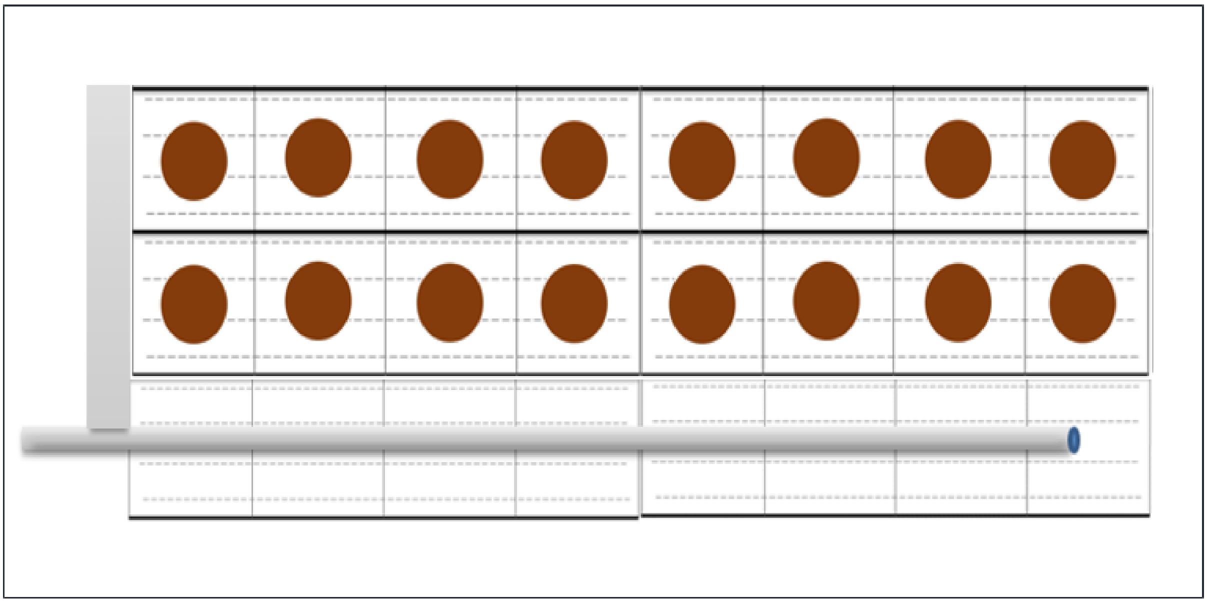


Figure 2.5 Shale formation is connected to a well through hydraulic fracture.

Chapter 3 describes the mathematical model derived for single phase flow of gas in 2D reservoir.

When the well is opened for production, the free gas will start flowing from the micro-fractures to the vertical fracture and then to the horizontal well due to pressure depletion. After certain amount of time, when the pressure in the cell depletes below the critical desorption pressure, desorption of gas will start and feed gas to the micro-fractures.

2.2 Diffusion in sphere

Diffusion is a process where molecules in random motion move from higher to lower concentration. Fick described diffusion in a mathematical equation derived from Fourier's equation of heat conduction which is given as:

$$F = -D \frac{\delta C}{\delta x} \qquad 2.1$$

This is known as Fick's first law of diffusion in isotropic medium. F is the rate of transfer of diffusing substance per unit area of section, D is the diffusion coefficient, C is the concentration of the diffusing substance and x is the space coordinate.

Solute diffusion into porous soil aggregates and into lithofragments in sediments and aquifer materials in the sorptive uptake and desorption mode may be described with Fick's second law in spherical coordinates (figure 2.6):

$$\frac{\partial C}{\partial t} = D_a \left[\frac{\partial^2 C}{\partial r^2} + \frac{2}{r}\frac{\partial C}{\partial r}\right] \qquad 2.2$$

Where *C, t* and *r* denote concentration, time and the radial distance from the centre of the sphere (Grathwohl, 2006).

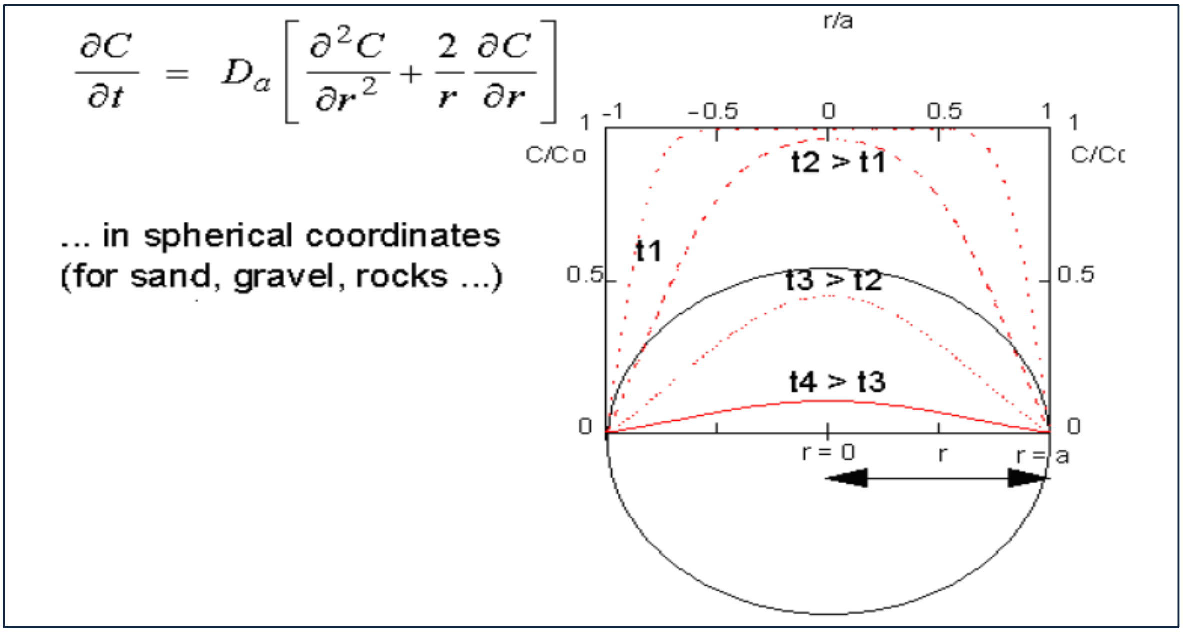


Figure 2.6 Diffusion out of sphere. Concentration profiles after times t1- t4. a is the radius of the sphere and r is the radial distance (coordinated from the centre) (Grathwohl, 2006)

However, the equation for 1D diffusive flow through mineral matrix for a spherical shape can be expressed as (Moghanloo, Javadpour, & Davudov, 2013):

$$\frac{\partial(\phi_m C_{i,m})}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D_{e,m}\frac{\partial C_{i,m}}{\partial r}\right), \qquad 2.3$$

Where ϕ_m is the porosity of the matrix, $C_{i,m}$ is the concentration within matrix, and $D_{e,m}$ is the effective diffusion coefficient of the matrix.

Initially, both the kerogen bulk and matrix (nanopores) are at initial reservoir pressure and thus gas diffusion rate will be zero.

However, in the mathematical model which is also used for developing the FSGP simulator, we assume that desorption of gas is only pressure dependent and we neglect the gas transport process of desorbed gas through diffusion. This indicates that with pressure changes, the adsorbed gas will reach balance with free gas in the micro-fractures immediately. This assumption is acceptable because of two considerations:

i. Firstly, the rate of molecular diffusion and mass transport differ a large amount from each other. In fact, the rate of molecular diffusion is much higher than that of mass transport.
ii. Secondly, the pressure in shale gas reservoirs changes very slowly due to low matrix permeability or low flow rate. So as the pressure changes, the time needed to reach a new balance between gases adsorbed and free gas is so short that it can be neglected (Wang, 2013, p. 27).

The mathematical model and FSGP simulator neglects the diffusion process and assumes the gas to be adsorbed onto the available surface of kerogen which feeds the gas to micro-fractures. The sphere is thus treated as a source term in the model.

2.3 Adsorption/Desorption in Shale Gas Reservoirs

Natural gas in shale reservoirs is present both as a free gas phase and as an adsorbed gas phase on the solid. In shale gas reservoirs, gas or methane molecules are adsorbed to the carbon-rick components called Kerogen (Mengal and Wattenbarger, 2011; EIA, 2011; Wu et al. 2012). The adsorbed gas represents significant quantities of total gas reserves (20-80%) as well as recovery rates, which cannot be ignored in any model or modelling analysis. Experiments performed on organic-rich shale samples from different basins in U.S. showed a directly proportionality between the amount of adsorbed gas and total organic content (TOC) (Wang, 2013, p. 9). As the pressure decreases with continuous gas production from reservoirs, more adsorbed gas is released from solid to free gas phase, contributing to the flow or production. By using core samples one can, with the right instruments, determine a lot of information about the amount of gas adsorbed in the reservoirs. The examination of samples exposed to different pressures at a constant temperature, creates the basis for adsorption isotherm. Adsorption isotherm describes the amount of adsorbed gas in the sample.

In order to measure the amount of adsorbed gas, gas content (scf/ton) and sorption isotherm are measured in lab using core samples. Gas content is the amount of total gas adsorbed on the surface of the reservoir rock. In this research, Langmuir's isotherm (1918) is used to define the relationship of pressure and gas storage capacity of the reservoir rock.

Langmuir's isotherm is given as:-

$$V_E = V_L \frac{P}{P + P_L} \qquad 2.4$$

Where,

V_E - Gas content or Langmuir's volume in scf/ton (standard volume adsorbed per unit rock mass)

P - Reservoir gas pressure

P_L - Langmuir's pressure, the pressure at which 50% of the gas is desorbed

V_L – Maximum amount of adsorbed gas, function of the organic richness (or TOC)

After studying data from various literature, we decided to use approximate values of V_L (218.57 scf/ton), P_L (2695.57 psi) from Barnett shale. Langmuir isotherm can be constructed using this values which is shown in figure 2.7.

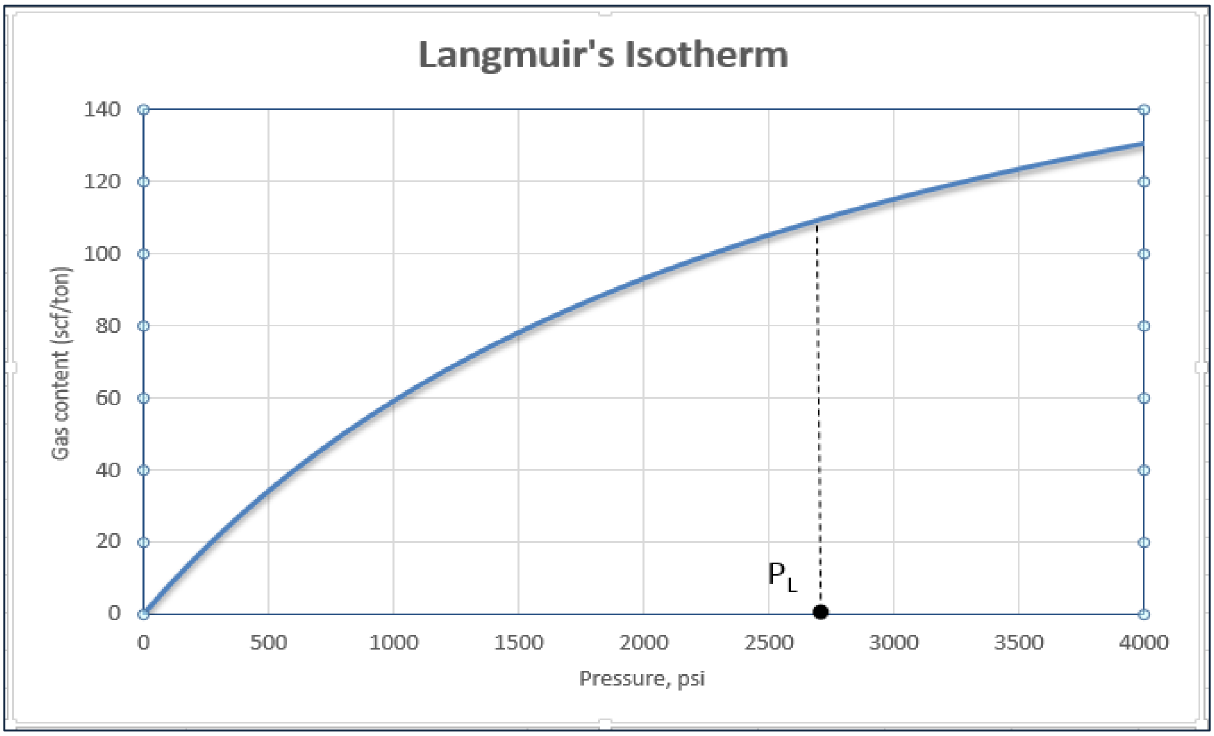


Figure 2.7 Adsorbed Gas content vs pressure for Barnett Shale

Gas adsorption capacity is affected by several factors, such as organic matter, micro-pore structure and mineral composition. Organic matter in the shale is the most important factor because it affects both the size and the structure of pores in the matrix and thereby affects the amount of surface area that is available for adsorption. Organic matter features includes type of organic matter, total organic carbon (TOC) content and thermal maturity. In general, Langmuir's volume, V_L, is a function of the organic richness (or TOC) and thermal maturity of the shale. Figure 2.8 illustrates the effect of TOC on the adsorbed gas content for the Marcellus Shale (EIA, 2011).

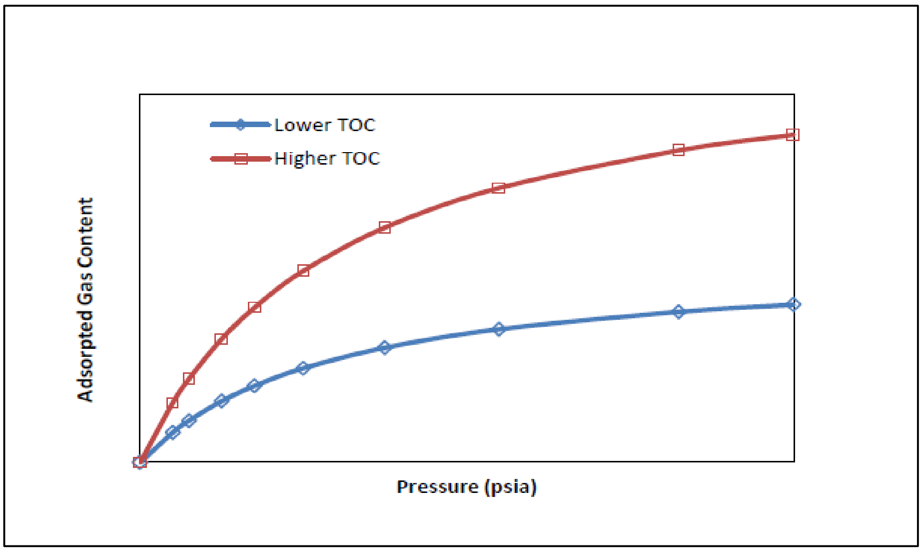


Figure 2.8 Marcellus Shale Adsorbed Gas Content (EIA, 2011).

We can safely deduce that at low reservoir pressures most of the gas production comes from desorbed gas. In this respect ignoring desorbed gas when doing decline curve or material balance analysis will definitely result in serious errors.

The reverse process of adsorption is desorption. Desorption on the matrix surface can be thought of as the first flow mechanism of gas in shale reservoirs. After the free gas is produced, the adsorbed gas desorbs from the matrix surface when the pressure in the reservoir decrease, to prevent the decrease in concentration and to minimize changes in equilibrium. In this way, desorption ensures that the pressure in the reservoir is maintained for an extended period of time by acting as an additional source of free gas.

Production of the adsorbed gas is time consuming. Desorption starts when the reservoir pressure has dropped to critical desorption pressure. A reduction in pressure in tight shale formations with extremely low permeability will happen slowly and can result in more of a long-term production. The rate of desorption has a significant effect on the production since it reduces the pressure drop in the well and increases the gas production rate.

Gas is assumed to be adsorbed on the internal surface of nanopores inside kerogen. It is supposed to first desorb from the surface of the nanopores into the matrix pores which then feeds the fracture. Though adsorbed gas is in contact with matrix pressure, initially it may be under saturated and therefore at equilibrium with a lower pressure as observed in many CBM reservoirs (Shi and Durucan, 2005). It's only when the matrix pressure reaches this lower pressure, termed as critical desorption pressure ($P_{critdes}$), that the adsorbed gas starts desorbing (Swami, Settari and Javadpour, 2013).

From equation 2.4, adsorbed volume in scf can be written as:-

$$V_{des} = V_L V_b \rho_R \frac{P}{(P+P_L)} \qquad 2.5$$

Where,

V_b – bulk volume, ft^3

ρ_R – density of shale at initial reservoir pressure, lbm/ft^3

Gas rate (scf/sec) from desorption into total matrix pore space can then be found by differentiating equation 2.5 with respect to time. We get,

$$\dot{Q}_{des} = -\frac{\partial V_{des}}{\partial t} = -V_L\, V_b\, \rho_R \frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t} \qquad 2.6$$

$$\dot{m}_{des} = -\frac{\partial V_{des}}{\partial t} = -V_L\, V_b\, \rho_R \rho_{ntp} \frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t} \qquad 2.7$$

Equation 2.6 gives the volumetric rate in scf/sec whereas equation 2.7 gives us the mass rate in kg/sec of gas desorbed.

In the above equation, negative sign indicates that adsorbed gas content decreases with time as gas desorbs into the matrix.

The adsorbed gas at any stage of depletion has its own equilibrium pressure (*Pad*) which is different from the matrix pressure. Once matrix pressure reaches critical desorption pressure and desorption commences, this equilibrium pressure (P_{ad}) remains higher than the matrix pressure due to a time lag caused by sorption time and possibly phase behaviour effects of adsorbed gas (Firoozabadi, 2012). This sorption time decreases the ease of desorption and the lag between the adsorbed gas and matrix pressure (Swami, Settari & Javadpour, 2013). However, for simplicity, this effect has been neglected in the model presented, i.e., sorption time approaches zero and the system will tend to attain instant equilibrium between adsorbed phase and matrix. Gas desorption rate is considered to depend only upon the matrix pressure. The lower the matrix pressure, the higher the higher the rate of desorption.

2.4 Gas in Place

The gas in shale reservoirs is stored in three different ways:

- Free gas in pores and fractures
- Adsorbed gas onto organic matter and clay minerals in the matrix
- Dissolved gas in oil and water (not considered in this thesis)

Therefore, the total amount of gas in a shale gas reservoir is the sum of free gas present and the adsorbed gas. The free gas as mentioned earlier is considered to be present between the region of cube and sphere whereas as the size of sphere gives the amount of adsorbed gas which is pressure dependent given by Langmuir's isotherm.

The original gas in place in ft^3, including the adsorbed gas at initial temperature is then given by:

$$OGIP = Free\ gas + adsorbed\ gas \qquad 2.8$$

$$OGIP = V_C \left(\frac{\emptyset\, S_g}{B_{gi}}\right) + V_s \left(V_L \frac{P_i}{P_i + P_L}\right) \qquad 2.9$$

Where,

V_C - Volume of cube, ft^3
V_S - Volume of sphere, ft^3
$\emptyset$ - Porosity of matrix, fraction
S_g - saturation of gas
B_{gi} - gas formation volume factor, scf/rcf
V_L - Maximum amount of adsorbed gas, function of the organic richness (or TOC), rcf/scf
P_i - Initial reservoir pressure, psi
P_L - Langmuir's pressure, the pressure at which 50% of the gas is desorbed, psi

However, in equation 2.9, we are considering presence of free gas in the nanopores of sphere as well. Thus, the free gas comes from total volume of cube whereas adsorbed is limited to volume of sphere.

It differs from conventional calculation of gas in place as it includes the adsorbed gas. Another advantage of this technique is that the desorption rate and free gas rate can be obtained separately. The assumptions used in this technique, apart from conventional assumptions for the material balance are:

- Desorption of gas is pressure dependent which is defined by Langmuir's isotherm.
- Free gas and desorbed gas attains equilibrium immediately once the pressure in the reservoir reaches critical desorption pressure.
- Flow of desorbed gas from the matrix to the fracture follows Darcy's flow.
- Single phase flow of gas in considered, i.e., it is assumed that the reservoir is a dry-gas reservoir or that it contains insignificant amount of water.
- The composition of free gas and desorb gas is same and there is no difference in the specific gravities of the two gases.
- The desorb gas does not interact with the matter present in the region outside of sphere.

It is difficult to estimate the total recoverable gas in this kind of reservoirs. The production is dependent on desorption of gas from organic matter which is dependent of pressure. Also, the extremely low permeability influence the sustainability of production and thus it is very time consuming to study the economic feasibility of the production. Hence, total recoverable gas is not addressed and is beyond the scope of work for this thesis.

2.5 Introduction to FSGP Simulator

In this research, the numerical coding has been done on FORTRAN 90 compiler to model the flow of gas in two dimensional porous and fractured reservoirs. The FORTRAN code for Shale Gas Production (FSGP) is designed to simulate the single phase flow of gas from the linearly oriented porous cubes through the vertical fractures and finally to the horizontal well. The sphere considered in the model is treated as a source term which provides gas to the porous region after the pressure has depleted to critical desorption pressure.

Fluid flow of gas occurs under pressure and viscous forces according to the Darcy's law. The gravity forces are neglected in this model. The simulator can take different porosities in the matrix and the fracture as an input to represent dual-porosity model. The derivation of mass-balance difference equation for single phase flow of gas is limited to beta-formulation and describes the fluids by the traditional formation volume factor which is a function of pressure only. The diffusivity equation obtained is solved numerically using finite difference method. The time is discretized using first order finite difference scheme. The finite discrete linear equations are solved fully implicitly and pressures in each block are calculated using Gauss Elimination method. The implicit approach has proven to be computationally efficient in modelling linear single phase flow problem in 2D reservoir and it also has the flexibility in handling reservoir heterogeneity.

In the model, the gas is produced at a constant bottom-hole pressure and the code facilitates the generation of production rate at each time steps which then can be plotted in Microsoft Excel. FSGP also provides pressure in each block at all time-steps in the output file. The amount of gas desorbed from each cell is also obtained as an output. Efforts have been made to make the simulator user friendly and that the heterogeneous properties can be assigned to replicate actual reservoir scenario. The user can define varying values of permeability, porosity, cell size, fracture width and radius of sphere along with suitable Langmuir's parameter to each cell to simulate as per reservoir characteristics. The entire FORTRAN code for the simulator, the input data file and the output file can be found in appendix A.

2.6 Fracture model

To make gas flow from extremely low-permeable formations, hydraulic fracturing becomes an important phenomenon. The variously scaled natural fractures need to be connected to artificially created fractures to provide flow channel for gas into producing wells. Therefore, all the simulators developed to model the production of gas must have the capability of handling fracture media, both natural and hydraulic fractures.

The model presented in this thesis gives emphasis on modelling of fracture. The naturally occurring fractures are considered to be present in the region between the cube and the sphere. The flow of gas is through this natural fracture to the main hydraulic vertical fracture and then to the horizontal well. In sort, the horizontal well is cased and perforated. There is therefore no contact between the reservoir and the wellbore other than through the vertical fractures. Darcy flow is considered in both the fractures with different permeability. The simulator developed has the facility to user-define the properties of fracture such as its permeability and dimension. However, only a single vertical fracture is used in the simulator to link horizontal well to the reservoir.

Chapter 4 addresses the analytical solution for linear flow of gas from the formation to the fracture and then to the horizontal well; and comparison has been made with the results obtained through numerical model in chapter 5.

Chapter 3
Mathematical and Numerical Model

FSGP simulator has been developed to model the production of gas from tight shale formations. The gas is considered to be present in the state of free gas in the porous media in the cube and adsorb gas onto the shale matrix depicted by the sphere. The model is developed for single phase flow of gas in a 2 dimensional reservoir. The flow of gas is from the matrix to the fracture and then to the horizontal well. The gas is produced at a constant bottom-hole pressure and the simulator has the facility to generate production rate at each time step. Also, through FSGP simulator, it is possible to study the variation in block pressure throughout the life of the well.

This chapter presents detailed information on single phase two dimensional model formulation for the flow of gas. It highlights the techniques and the subsequent Subroutines used in FORTRAN to run the numerical model.

The derivation described below is based on the derivation of single phase 1 dimensional flow presented in Lecture notes for Reservoir Simulation course by Svein M. Skjæveland

(2001) and Svein M. Skjæveland & Jann-Rune Ursin (2005). The derivation has been modified to 2D flow of gas in shale reservoirs.

Font Convention – These lecture notes are written in three different font types. Ordinary text is written like this. Mathematical symbols are described using Latin letters and are set in italics: *x, y, z.* In addition, programming codes are written in type writer font: `DEX(1:NX1:MX) = 100.d0.`

3.1 Diffusivity Equation

The expression of Darcy's law and the conservation of mass is given by Diffusivity equation. The derivation presented in this chapter is limited to *beta*-formulation and thus the fluid is described by the traditional formation volume factor like B_g, R_{sg}, B_o, B_w which all are functions of pressure only. Hence, the derivation doesn't apply to the processes in the reservoir where large changes in composition take place.

We begin with linear, horizontal flow of a single phase in one dimension in a reservoir with constant permeability and porosity.

3.2 Conservation of Mass

Let us consider one-dimensional flow of mass along the x-axis and out of a volume element ΔV (ft^3) of length ΔX (ft) and the cross sectional area A (ft^2). The continuity equation for such a system in terms of gas density is given by:

$$\frac{\partial}{\partial x}\left(\rho_g u_g\right) = -\frac{\partial}{\partial t}\left(\varnothing \rho_g\right) \qquad 3.1$$

The gas is the only phase present in the reservoir, i.e., the crossing of the dew point line is not permitted in order to avoid condensate fallout in the pores. Fluid behaviour is governed by Black Oil fluid model.

$$\mathrm{\rho_g} = \frac{\mathrm{\rho_{gs}}}{\mathrm{B_g}} = \frac{\mathrm{constant}}{\mathrm{B_g}} \qquad 3.2$$

The continuity equation is then written in terms of formation volume factor instead of density which is given by equation 3.3. This is the standard way for β-models.

$$\frac{\partial b_g u_g}{\partial x} - q_g = -\emptyset \frac{\partial b_g}{\partial t} \qquad 3.3$$

Where, q_g is the source/sink term. Note that q_g is positive for injection and it has negative value for production. The equation expresses the conservation of surface volumes of gas which amounts to the same thing as conserving mass since the gas composition is constant.

Here, $b_g = \frac{1}{B_g}$ (inverse of formation volume factor, Bg [rcf/scf])

which is more convenient to use in the simulation equations.

Darcy's law is expressed as:

$$u_g = -\frac{CK_x}{\mu_g}\frac{\partial p_g}{\partial x} \qquad 3.4$$

Where, C is the conversion factor; K_x is the permeability in x-direction in [mD]; μ_g is the viscosity of gas in [cP]; p_g is the gas pressure in [psi] and x is the distance along the flow direction [ft].

We now introduce the Darcy velocity in equation 3.3, we get

$$\frac{\partial}{\partial x}\left(\frac{CK_x b_g}{\mu_g}\frac{\partial p_g}{\partial x}\right) + q_g = \emptyset \frac{db_g}{dp_g}\frac{\partial p_g}{\partial t} \qquad 3.5$$

This is the diffusivity equation we have to solve numerically in the general case. It expresses fluid flow in x-direction plus production or injection is equal to the fluid expansion or compression.

Note that if practical rate Q_g [scf/d] is produced from a volume ΔV, the source term in equation 3.5 is $q_g = Q_g/\Delta V$ where ΔV is in ft^3.

In the model, we have two dimensional flow of gas because of vertical flow in fracture along z-axis. Therefore equation 3.5 for 2D flow can be written as:

$$\frac{\partial}{\partial x}\left(\frac{CK_x b_g}{\mu_g}\frac{\partial p_g}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{CK_z b_g}{\mu_g}\frac{\partial p_g}{\partial z}\right)+q_g = \emptyset\frac{db_g}{dp_g}\frac{\partial p_g}{\partial t} \qquad 3.6$$

The gas adsorbed in the sphere is not included in the equation 3.6. As per the model described earlier, the adsorbed gas acts as a source to the pores space in the cube, thus it can be treated as an injection well. The injection of gas/gas desorption starts when the pressure in the reservoir reaches critical desorption pressure. The amount of adsorbed gas is given by Langmuir's isotherm.

$$V_E = V_L \frac{P}{(P+P_L)} \qquad 3.7$$

The rate of desorption is dependent on pressure as defined in chapter 2 is given by:

$$\dot{Q}_{des} = -\frac{\partial V_{des}}{\partial t} = -V_L\, V_b\, \rho_R\, \frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t} \qquad 3.8$$

Thus, for a grid cell/cube containing adsorbed gas, the source term in equation 3.6 will be given by:

$$q_g = \frac{\dot{Q}_{des}}{V_b} \qquad 3.9$$

Equation 3.6 becomes

$$\frac{\partial}{\partial x}\left(\frac{CK_x b_g}{\mu_g}\frac{\partial p_g}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{CK_z b_g}{\mu_g}\frac{\partial p_g}{\partial z}\right)+V_L\,\rho_R\,\frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t} = \emptyset\frac{db_g}{dp_g}\frac{\partial p_g}{\partial t} \qquad 3.10$$

This is the final continuity equation for two dimensional flow of gas for the shale gas model presented in this thesis.

For the grid cells containing fracture or production/injection well and no adsorbed shale gas, the continuity equation will be same as for the conventional reservoir which is given by:

$$\frac{\partial}{\partial x}\left(\frac{CK_x b_g}{\mu_g}\frac{\partial p_g}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{CK_z b_g}{\mu_g}\frac{\partial p_g}{\partial z}\right)+q_{g\,(i,k)} = \emptyset\frac{db_g}{dp_g}\frac{\partial p_g}{\partial t} \qquad 3.11$$

Where $q_{g\,(i,k)}$ is the source/sink term. If a practical rate Q_g [scf/d] is produced from a volume ΔV, the source term in eq. 3.11 is $q_{g\,(i,k)} = \frac{Q_g}{\Delta V}$ where ΔV is in ft^3.

3.3 Diffusivity for two phases

We can extend the equation 3.10 for two phases for the flow of gas and water in shale gas reservoir, without derivation. Different diffusivity equations define the flow of gas and water which are given by:

For gas:

$$\frac{\partial}{\partial x}\left(\frac{CK_xK_{rg}b_g}{\mu_g}\ \frac{\partial p_g}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{CK_zK_{rg}b_g}{\mu_g}\ \frac{\partial p_g}{\partial z}\right)+\ V_L\ \rho_R\ \frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t}=\ \emptyset\frac{\partial(b_gS_g)}{\partial t} \qquad 3.12$$

For water:

$$\frac{\partial}{\partial x}\left(\frac{CK_xK_{rw}b_w}{\mu_w}\ \frac{\partial p_w}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{CK_zK_{rw}b_w}{\mu_w}\ \frac{\partial p_w}{\partial z}\right)+\ V_L\ \rho_R\ \frac{1}{(P+P_L)^2}\frac{\partial P}{\partial t}=\ \emptyset\frac{\partial(b_wS_w)}{\partial t} \qquad 3.13$$

and the two constraining equations will be

$$S_g+\ S_w=1,$$

$$p_{cgw}=\ p_g-\ p_w$$

Here, S is saturation, p_{cgw} is the gas-water capillary pressure. K_{rg} and K_{rw} represent the relative permeability which depend on the saturation of gas and water.

However, in this thesis, only single phase flow of gas in formation is considered. In the following text, we will expand eq. 3.11 with the assumption that b_g varies linearly with pressure and that the viscosity is constant. These are reasonably good approximations.

3.4 Numerical Formulation

The diffusivity equation 3.11 has to be solved numerically in general. The equation contains derivative with respect to both time and distance. The finite difference method is used for both approximation with respect to time and space. The model formulation described below is done in a way to make the coding in FORTRAN easier.

3.4.1 Differentiation with respect to X

Let us consider one dimensional reservoir which is split into three blocks as shown in figure 3.1.

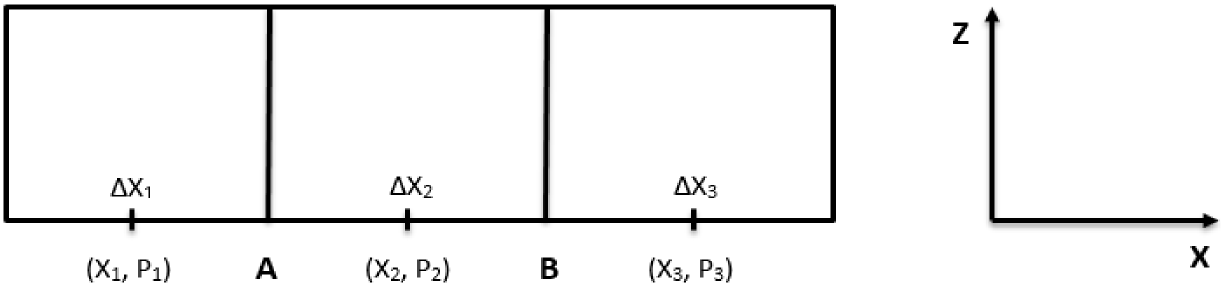


Figure 3.1 One-dimensional reservoir with three blocks.

In the figure, ΔX_i denotes the length of block no. i, X_i the distance to the midpoint of block i and Pi the pressure at the midpoint.

A denote the boundary between block 1 and 2 and B the boundary between 2 and 3. The derivatives at the boundaries are approximated in the following manner,

At boundary A, $$\left.\frac{dP}{dx}\right| at\ A \approx \frac{P_1 - P_2}{X_1 - X_2} = -\frac{P_1 - P_2}{X_2 - X_1}$$

Similarly for boundary B, $$\left.\frac{dP}{dx}\right| at\ B \approx \frac{P_3 - P_2}{X_3 - X_2}$$

Now defining some terms to simplify the discretization. We get,

$$\Delta P_2^+ = P_3 - P_2$$

$$\Delta P_2^- = P_1 - P_2$$

$$\Delta X_2^+ = X_3 - X_2 = \frac{1}{2}(\Delta X_2 + \Delta X_3)$$

$$\Delta X_2^- = X_2 - X_1 = \frac{1}{2}(\Delta X_1 + \Delta X_2) = \Delta X_1^+,$$

$$N_{x2}^{+} = \frac{C\left[\frac{K_x\, b}{\mu}\right]_2^{+}}{\Delta X_2^{+}},$$

$$N_{x2}^{-} = \frac{C\left[\frac{K_x\, b}{\mu}\right]_2^{-}}{\Delta X_2^{-}}.$$

The notation is that for an arbitrary variable Y, $[Y]_2^+$ denotes its value at the boundary between blocks 2 and 3, or an average value between the blocks.

The term $[N]_{X2}^{+}$ denotes the average flow coefficient or transmissibility between block 2 and 3. The volume factor b and viscosity μ may depend on the pressure *P(x,t).* When the simulation program moves from time t to time $t+\Delta t$, it may be shown that the best stability and accuracy are achieved for the pressure solution if time averaged values are used for b and μ in the expression for N_X. Hence, for the b-value at the boundary B is used

$$[b]_2^+ = \frac{1}{4}\left(b\big(P(X_2, t+\ \Delta t)\big) + b\big(P(X_3, t+\ \Delta t)\big) + b\big(P(X_2, t)\big) + b(P(X_3, t))\right), \qquad 3.14$$

i.e., averaged both in time and distance.

Similarly differentiation with respect to Z can be done and we can extend the above obtained conventions for the Z-direction.

3.4.2 Discretization in time and space

Equation 3.11 contains derivatives both with respect to time and space. To solve the equation numerically, we need to discretize it. The figure 3.2 shows block *(i,k)* and its neighbouring block in 2D reservoir.

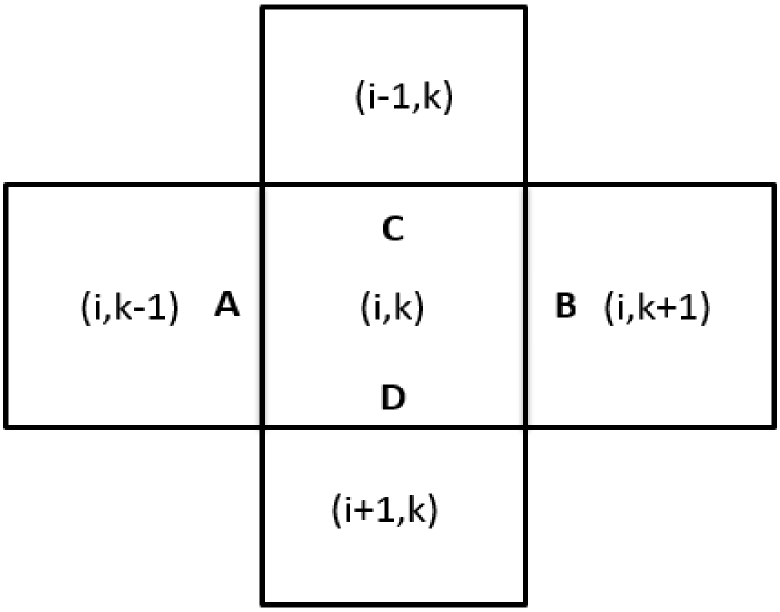


Figure 3.2 General block numbering in 2D

A and B denotes boundary of block *(i,k)* in the negative and positive X-direction respectively. Similarly, C and D denote block boundary in negative and positive Z-direction.

To simplify the discretization, we define the term U and V in equation 3.11 which is equal to

$$U = \frac{CK_x b_g}{\mu_g} \frac{\partial p_g}{\partial x}$$

$$V = \frac{CK_z b_g}{\mu_g} \frac{\partial p_g}{\partial z}$$

The equation 3.11 can now be written as:

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial z} + q_{g\,(i,k)} = \emptyset \frac{db_g}{dp_g} \frac{\partial p_g}{\partial t} \qquad 3.15$$

We now discretize equation 3.15, the left hand side of the equation in X and Z-direction and right hand side in time, and we get,

$$\frac{U_{i,k}|B - U_{i,k}|A}{\Delta X_{i,k}} + \frac{V_{i,k}|D - V_{i,k}|C}{\Delta Z_{i,k}} + q_{g\,(i,k)} = \emptyset \frac{db}{dp} \frac{p_{i,k}(t+\Delta t) - p_{i,k}(t)}{\Delta t} \qquad 3.16$$

Further we approximate,

$$U_{i,k}|_B = \left[\frac{CK_x b}{\mu}\frac{\partial p}{\partial x}\right],$$

$$\approx \left[\frac{CK_x b}{\mu}\right]\left[\frac{\partial p}{\partial x}\right],$$

$$\approx \left[\frac{CK_x b}{\mu}\right]_{i,k}^{+}\frac{\Delta p_{i,k}^{+}}{\Delta X_i^{+}},$$

$$\approx N_{x\,i,k}^{+}\,.\,\Delta p_{i,k}^{+}$$

Similarly for other terms and boundaries,

$$U_{i,k}|_A \approx -N_{x\,i,k}^{-}\,.\,\Delta p_{i,k}^{-}$$

And for Z-direction, we get,

$$V_{i,k}|_C \approx -N_{Z\,i,k}^{-}\,.\,\Delta p_{i,k}^{-}$$

$$V_{i,k}|_D \approx N_{Z\,i,k}^{+}\,.\,\Delta p_{i,k}^{+}$$

We now define,

$$O_{x\,i,k}^{+} = \frac{N_{x\,i,k}^{+}}{\Delta X_{i,k}},$$

$$O_{x\,i,k}^{-} = \frac{N_{x\,i,k}^{-}}{\Delta X_{i,k}},$$

$$O_{z\,i,k}^{+} = \frac{N_{z\,i,k}^{+}}{\Delta Z_{i,k}},$$

$$O_{z\,i,k}^{-} = \frac{N_{z\,i,k}^{-}}{\Delta Z_{i,k}},$$

And to further simplify the writing, $A2 = \emptyset\, db/dp$.

Substituting all the definitions into equation 3.16, we get the diffusivity equation of the following form:

$$O_{x\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{x\,i,k}^{-}.\Delta p_{i,k}^{-} + O_{z\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{z\,i,k}^{-}.\Delta p_{i,k}^{-} - q'_{g\,i,k} = A2_{i,k}(p_{i,k}(t+\Delta t) - p_{i,k}(t))/\Delta t \qquad 3.17$$

For the grid blocks containing adsorbed gas, replacing the source term with the desorption rate per volume of block, we get,

$$O_{x\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{x\,i,k}^{-}.\Delta p_{i,k}^{-} + O_{z\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{z\,i,k}^{-}.\Delta p_{i,k}^{-} - V_L\,\rho_R\,\frac{1}{(p_{i,k}(t)+P_L)^2}\frac{p_{i,k}(t+\Delta t)-p_{i,k}(t)}{\Delta t} = A2_{i,k}\frac{p_{i,k}(t+\Delta t)-p_{i,k}(t)}{\Delta t} \qquad 3.18$$

Desorption term will be positive as we are giving a gas source to the formation.

To solve this equation, a computer program is written on FORTRAN compiler which is named as FSGP (FORTRAN code for Shale Gas Production). The general structure of the program is an initialization segment which assigns starting values for all the variable at time t=0, and a time-step loop that calculates the pressures in each numerical block after a specified timestep *Δt*, when all pressures are known at time level *t*.

3.4.3 Implicit Formulation

All variables in equation 3.18 are known at time level *t* and the simulation program updates them to time level *t+Δt.* The equation has pressure at both time levels as a consequence of the finite difference approximation to the time derivative.

However, we need to decide at which time step to evaluate the terms $\Delta p_{i,k}^{\pm}$. There are three most common choices:

Numerical Formulation	**Time level for $\Delta p_{i,k}^{\pm}$**
Explicit	*T*
Implicit	*t+Δt*
Crank-Nicolson	*t+Δt/2*

Table 3.1 The three most common formulations.

In this thesis, we will focus only on Implicit formulation method to evaluate pressures in each block, i.e., the time level at which pressure is evaluated is *t+Δt.*

In order to simplify the notation in equation 3.18, we denote pressure evaluated at time *t* as $p_{i,k}(t)$, while $p_{i,k}(t+\Delta t)$ is simplified to $p_{i,k}$.

$$O_{x\,i,k}^{+}\left(p_{i,k+1}-p_{i,k}\right)+O_{x\,i,k}^{-}\left(p_{i,k-1}-p_{i,k}\right)+O_{z\,i,k}^{+}\left(p_{i-1,k}-p_{i,k}\right)+$$
$$O_{z\,i,k}^{-}\left(p_{i+1,k}-p_{i,k}\right)-V_L\,\rho_R\,\frac{1}{(p_{i,k}(t)+P_L)^2}\frac{p_{i,k}-p_{i,k}(t)}{\Delta t}=\;A2_{i,k}\frac{p_{i,k}-p_{i,k}(t)}{\Delta t}\qquad 3.19$$

Rearranging the equation, we get,

$$O_{x\,i,k}^{+}\cdot p_{i,k+1}+O_{x\,i,k}^{-}\cdot p_{i,k-1}+\Big(-O_{x\,i,k}^{+}\;-O_{x\,i,k}^{+}-O_{z\,i,k}^{+}-O_{z\,i,k}^{-}-$$
$$\frac{V_L\rho_R}{\Delta t}\frac{1}{\left(p_{i,k}(t)+P_L\right)^2}-\frac{A2_{i,k}}{\Delta t}\Big)p_{i,k}+O_{z\,i,k}^{+}\cdot p_{i-1,k}+\;O_{z\,i,k}^{-}\cdot p_{i+1,k}=\Big(-A2_{i,k}-$$
$$V_L\rho_R\frac{1}{\left(p_{i,k}(t)+P_L\right)^2}\Big)\frac{p_{i,k}(t)}{\Delta t}\qquad 3.20$$

Now we define,

$$b_{i,k}=O_{x\,i,k}^{+}+O_{x\,i,k}^{+}+O_{z\,i,k}^{+}+O_{z\,i,k}^{-}+\frac{V_L\rho_R}{\Delta t}\frac{1}{\left(p_{i,k}(t)+P_L\right)^2}+\frac{A2_{i,k}}{\Delta t}$$

$$a_{i,k}=\;O_{x\,i,k}^{-}/b_{i,k}$$

$$c_{i,k}=\;O_{x\,i,k}^{+}/b_{i,k}$$

$$e_{i,k}=\;O_{z\,i,k}^{-}/b_{i,k}$$

$$f_{i,k}=\;O_{x\,i,k}^{+}/b_{i,k}$$

$$d_{i,k}=\left[\left(A2_{i,k}+V_L\rho_R\frac{1}{\left(p_{i,k}(t)+P_L\right)^2}\right)\frac{p_{i,k}(t)}{\Delta t}\right]/b_{i,k}$$

And the simulation equation is then given by:

$$-a_{i,k}\cdot p_{i,k-1}-c_{i,k}\cdot p_{i,k+1}+p_{i,k}-e_{i,k}\cdot p_{i+1,k}-f_{i,k}\cdot p_{i-1,k}=\;d_{i,k}\qquad 3.21$$

For each block we will have one equation with 5 unknowns. In this way, we have same number of equations and unknowns. The equation 3.21 helps us to calculate pressure in each block containing adsorb gas.

For the block containing fracture, the equation will not have the source/sink term and we can write the coefficient for the equation 3.21 as follows:

$$b_{i,k} = O^{+}_{x\ i,k} + O^{+}_{x\ i,k} + O^{+}_{z\ i,k} + O^{-}_{z\ i,k} + \frac{A2_{i,k}}{\Delta t}$$

$$a_{i,k} = O^{-}_{x\ i,k}/b_{i,k}$$

$$c_{i,k} = O^{+}_{x\ i,k}/b_{i,k}$$

$$e_{i,k} = O^{-}_{z\ i,k}/b_{i,k}$$

$$f_{i,k} = O^{+}_{x\ i,k}/b_{i,k}$$

$$d_{i,k} = [A2_{i,k}\ \frac{p_{i,k}(t)}{\Delta t}]/b_{i,k}$$

Consider a system with 6x3 number of grid blocks as shown in figure below.

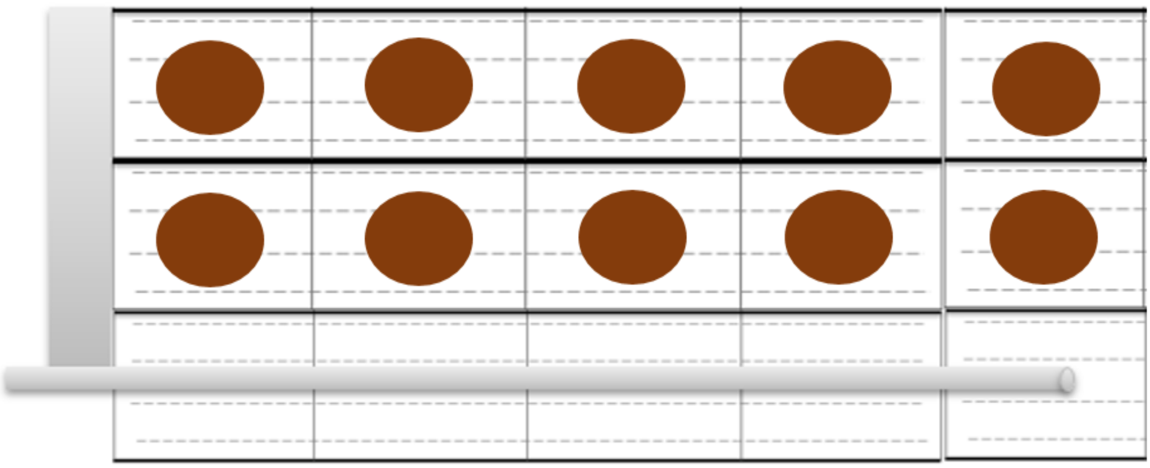


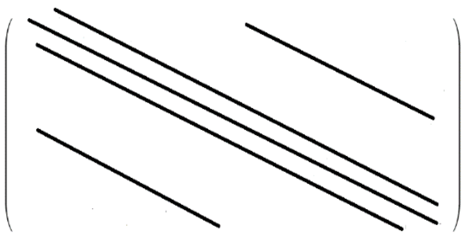
Figure 3.3 A system of 6x3 number of blocks.

Assuming there is no transmissibility of gas in z-direction for the blocks containing adsorb gas, we get a matrix of the form:

$$AX = B$$

$$\begin{pmatrix} 1 & -c_{11} & 0 & 0 & 0 & 0 & -e_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ -a_{12} & 1 & -c_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -a_{13} & 1 & -c_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -a_{14} & 1 & -c_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -a_{15} & 1 & -c_{15} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -a_{16} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -f_{21} & 0 & 0 & 0 & 0 & 0 & 1 & -c_{21} & 0 & 0 & 0 & 0 & -e_{12} \\ 0 & 0 & 0 & 0 & 0 & 0 & -a_{22} & 1 & -c_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_{23} & 1 & -c_{23} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_{24} & 1 & -c_{24} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_{25} & 1 & -c_{26} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -a_{26} & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -f_{31} & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} P_{11} \\ P_{12} \\ P_{13} \\ P_{14} \\ P_{15} \\ P_{16} \\ P_{21} \\ P_{22} \\ P_{23} \\ P_{24} \\ P_{25} \\ P_{26} \\ P_{31} \end{pmatrix} = \begin{pmatrix} d_{11} \\ d_{12} \\ d_{13} \\ d_{14} \\ d_{15} \\ d_{16} \\ d_{21} \\ d_{22} \\ d_{23} \\ d_{24} \\ d_{25} \\ d_{26} \\ d_{31} \end{pmatrix}$$

Matrix A is a penta-diagonal banded matrix with main diagonal having a unit value for a 2D reservoir.



FSGP simulator has the facility to simulate pressure for (NX*MX) number of grid blocks in 2D (NX represents number of rows and MX represents number of columns). It calculates the pressure for each grid block by creating matrix coefficients in subroutine MATRIXCOEFF. The matrix coefficients are then passed to subroutine MATRIX where pressure values are calculated using LU factorization and Gauss-Elimination method. The MATRIX subroutine calculates the value of pressure in each block at each time steps which is produced in the output file. The entire FORTRAN code used in FSGP simulator is described in appendix A.

3.4.4 Well Production Definition

In equation 3.17,

$$O_{x\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{x\,i,k}^{-}.\Delta p_{i,k}^{-} + O_{z\,i,k}^{+}.\Delta p_{i,k}^{+} + O_{z\,i,k}^{-}.\Delta p_{i,k}^{-} - q'_{g\,i,k} =$$

$$A2_{i,k}(p_{i,k}(t+\Delta t) - p_{i,k}(t))/\Delta t$$

The well rate term will be non-zero for the block containing production well. Since, our equation is formulated on per volume basis, the flow rate $q'_{g\,i,k}$ must also be on a per volume basis. It is here defined as positive for production well and negative for injection well. The gas can be produced successfully under two boundary conditions – constant well production rate and constant bottom-hole pressure. Both the cases are described below. However, in FSGP simulator, gas is produced at constant bottom-hole pressure.

Constant Well Production Rate

To produce gas at constant production rate of Q_g at surface condition, the per volume rate in equation 3.17 is given by:

$$q'_{g\ i,k} = \frac{Q_g}{A\Delta X_{i,k}}$$

For a well rate at reservoir conditions, the per volume rate is given by:

$$q'_{g\ i,k} = \frac{Q_g b_{g\ i,k}}{A\Delta X_{i,k}}$$

Constant Well bottom-hole pressure

To produce the well at constant bottom-hole pressure $P_{bh\ i,k}$, the sink/source term, i.e., per volume rate is computed in the following way:

$$q'_{g\ i,k} = \frac{Q_g}{A\Delta X_{i,k}} = \frac{WC_{i,k} b_{g\ i,k}(P_{i,k} - P_{bh\ i,k})}{A\Delta X_{i,k}\mu_g} = \frac{wc_{i,k} b_{g\ i,k}(P_{i,k} - P_{bh\ i,k})}{\mu_g}$$

Where $WC_{i,k}$ is the well constant or the productivity index of well, and $wc_{i,k}$ is the same on per volume basis. The well constant can either be computed from Darcy's equation or through productivity tests of the well.

Method 1

Assuming well to be in the middle of the grid block, we may consider radial in-flow to the well with block volume as the drainage volume:

$$WC_{i,k} = \frac{2\pi k_{i,k} h}{ln\left(\frac{r_e}{r_w}\right)}$$

Where r_w is the wellbore radius, and the drainage radius can be theoretically defined as:

$$r_e = \sqrt{\frac{\Delta Z_{i,k} \Delta Y}{\pi}}$$

For reservoir simulation purposes, this formula can be written as:

$$r_e = c\sqrt{(\Delta Z_{i,k} \Delta Y)}$$

Where the value c may vary depending on well location inside the grid block.

A commonly used formula is the one derived by Peaceman (1978) which is given as :

$$r_e = 0.20\sqrt{(\Delta Z_{i,k} \Delta Y)}$$

<u>Method 2</u>

For the simple linear case, with a well is at the end of the system, at the left or right faces, the well constant would be computed from the linear Darcy's equation which is given by:

$$WC_{i,k} = \frac{k_{i,k} A}{\Delta Z_{i,k}/2}$$

The FSGP simulator has facility to calculate well constant using any of the two methods using IWC value. As an input in the data file,

IWC = 1, indicate method 1

IWC = 2, indicate method 2 to calculate well constant in FSGP simulator.

Below mentioned FORTRAN code shows calculation of well constants by two different ways:

```
1. IF (IWC.EQ.1) THEN
   DR = SQRT(DEZ(NX,1)*DEY/PI)        ! Drainage radius
   WC = 2*PERMCONST*PI*KF*H/log10(DR/RW)
   ! Well constant definition

2. ELSEIF (IWC.EQ.2)THEN
   WC = PERMCONST*KF*(DEX(3,1)*DEY)/(DEZ(3,1)/2)
   ! Alternate method to define well constant
```

The coefficients for the block containing production well will be different from the blocks having adsorbed gas.

The implicit solution simulation equation 3.21, we derived above is:

$$-a_{i,k}.p_{i,k-1} - c_{i,k}.p_{i,k+1} + p_{i,k} - e_{i,k}.p_{i+1,k} - f_{i,k}.p_{i-1,k} = d_{i,k}$$

The coefficients for the block containing production well is then given by:

$$b_{i,k} = O^{+}_{x\,i,k} + O^{+}_{x\,i,k} + O^{+}_{z\,i,k} + O^{-}_{z\,i,k} + \frac{A2_{i,k}}{\Delta t} - \frac{WC_{i,k} b_{g\,i,k}}{A\Delta X_{i,k}\mu_g}$$

$$a_{i,k} = O^{-}_{x\,i,k}/b_{i,k}$$

$$c_{i,k} = O^{+}_{x\,i,k}/b_{i,k}$$

$$e_{i,k} = O^{-}_{z\,i,k}/b_{i,k}$$

$$f_{i,k} = O^{+}_{x\,i,k}/b_{i,k}$$

$$d_{i,k} = [A2_{i,k}\ \frac{p_{i,k}(t)}{\Delta t} - \frac{WC_{i,k} b_{g\,i,k}(P_{bh\,i,k})}{A\Delta X_{i,k}\mu_g}]/b_{i,k}$$

<u>No flow boundary condition</u>

No flow at boundaries are assigned, i.e., transmissibility value is zero at boundaries. For our two dimensional system, this type of condition applies for the end blocks. Also, transmissibility in z-direction for the blocks containing adsorbed gas are assigned zero value. This in FORTRAN is defined as:

```
OXPLUS(1:NX,MX) = 0.
OXMIN(1:NX,1) = 0.
OZPLUS(1,1) = 0.
OZMIN(NX,1) = 0.
OZMIN(1:NX,2:MX) = 0.
OZPLUS(1:NX,2:MX) = 0.
```

3.4.5 Varying Variables

In the FSGP simulator, the user can define varying value of permeability, porosity and block length to each block to generate a heterogeneous reservoir system. Also, the size of the fracture (width) can be varied in different grid block in the decreasing order from the horizontal well to the top of the formation.

For a varying fracture width, the grid representation would look like as shown below in figure 3.4 and 3.5. The figure also shows comparison with the uniform fracture width size.

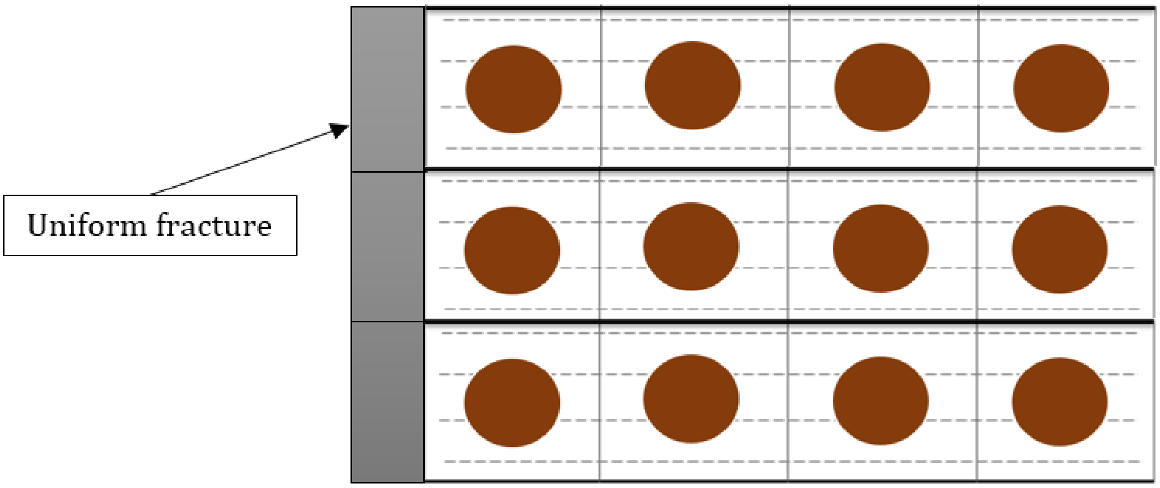


Figure 3.4 Uniform fracture width

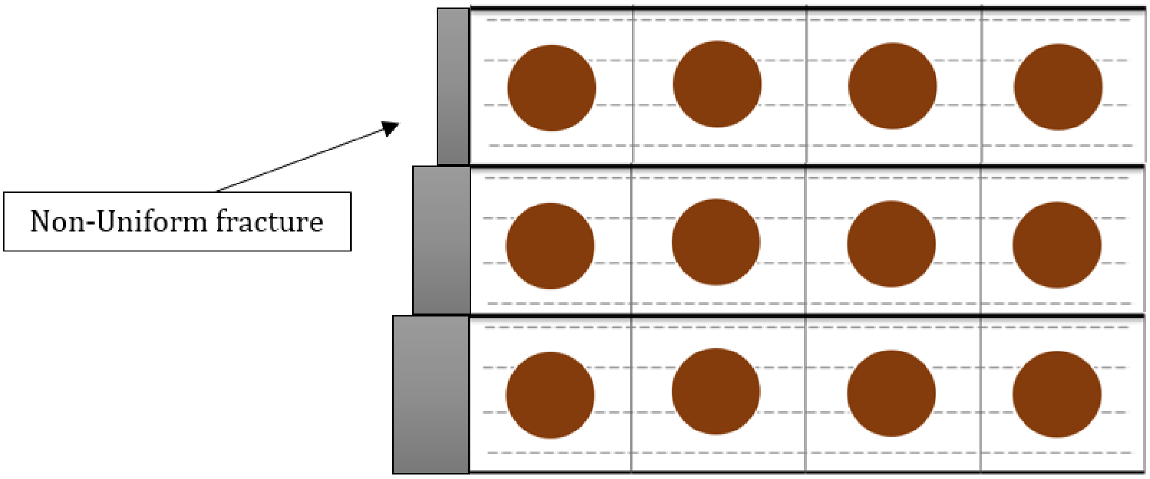


Figure 3.5 Non-uniform fracture width

For varying permeability, block length and porosity, the evaluation has been done in following ways:

Let $ip = k + 1$ and $im = k - 1$. Then for an system with an uniform properties,

$$O_{x\ i,k}^{-} = \frac{\left(\frac{Ckb}{\mu}\right)_{i,k}^{-} / \Delta X_{i,k}^{-}}{\Delta X_{i,k}} = \frac{Ck_{i,k}^{-}\overline{\overline{\left(\frac{b}{\mu}\right)}} / \Delta X_{i,k}^{-}}{\Delta X_{i,k}}$$

$$O_{x\ i,k}^{+} = \frac{\left(\frac{Ckb}{\mu}\right)_{i,k}^{+} / \Delta X_{i,k}^{+}}{\Delta X_{i,k}} = \frac{Ck_{i,k}^{+}\overline{\overline{\left(\frac{b}{\mu}\right)}} / \Delta X_{i,k}^{+}}{\Delta X_{i,k}}$$

Here $\overline{\overline{\left(\frac{b}{\mu}\right)}}$ is time or distance average, (μ is constant), $k_{i,k}^{\pm}$ is permeability taken at block boundaries.

For non-uniform permeability or heterogeneity, we have $k_{i,k} \neq k_{i,ip}, k_{i,im}$. Here we use mean average value between the blocks, i.e.,

$$\frac{\frac{\Delta X_{i,k}}{2} + \frac{\Delta X_{i,ip}}{2}}{k_{i,k}^{+}} = \frac{\frac{\Delta X_{i,k}}{2}}{k_{i,k}} + \frac{\frac{\Delta X_{i,ip}}{2}}{k_{i,ip}}$$

Since $\frac{\Delta X_{i,k}}{2} + \frac{\Delta X_{i,ip}}{2} = \Delta X_{i,k}^{+}$, we get

$$k_{i,k}^{+} = \frac{2\Delta X_{i,k}^{+}}{\frac{\Delta X_{i,k}}{2} + \frac{\Delta X_{i,ip}}{2}}$$

Or

$$O_{x\ i,k}^{+} = \frac{2C\overline{\overline{\left(\frac{b}{\mu}\right)}}}{\left(\frac{\Delta X_{i,k}}{k_{i,k}} + \frac{\Delta X_{i,ip}}{k_{i,ip}}\right)\Delta X_{i,k}},$$

$$O_{x\ i,k}^{-} = \frac{2C\overline{\overline{\left(\frac{b}{\mu}\right)}}}{\left(\frac{\Delta X_{i,k}}{k_{i,k}} + \frac{\Delta X_{i,im}}{k_{i,im}}\right)\Delta X_{i,k}}$$

In terms of FORTRAN coding, the constant in x-direction is calculated as:

```
CKX(I,K)=2*CKBAK/(DEX(I,K)/KX(I,K)+
DEX(I,IM)/KX(I,IM))/DEX(I,K)
```

Centre position in cell is calculated by running a loop for different values of `I` and `k`.

```
X(I,K) = (DEX(I,K-1)+DEX(I,K))/2+X(I,IM)
```

And

```
OXMIN(I,K) = CKX(I,K)*(BGIJ(I,K)+ BGIJ(I,IM))/2.

OXPLUS(I,IM) = OXMIN(I,K)*DEX(I,K)/DEX(I,IM)
```

In similar way, the variables are calculated for flow in the fracture in z-direction.

The varying gas property is defined under subroutine FLUIDPROP which is shown below. Also the below mentioned code shows a simple way of writing a subroutine which is called from the main program at each time steps.

Similarly, subroutine MATRIXCOEFF has been defined in the program to calculate the flow coefficients for each block at each time step which passes the coefficient values to the subroutine MATRIX.

The subroutine MATRIX then solves the matrix of the form $AX= B$ using LU factorization and Gauss-Elimination method.

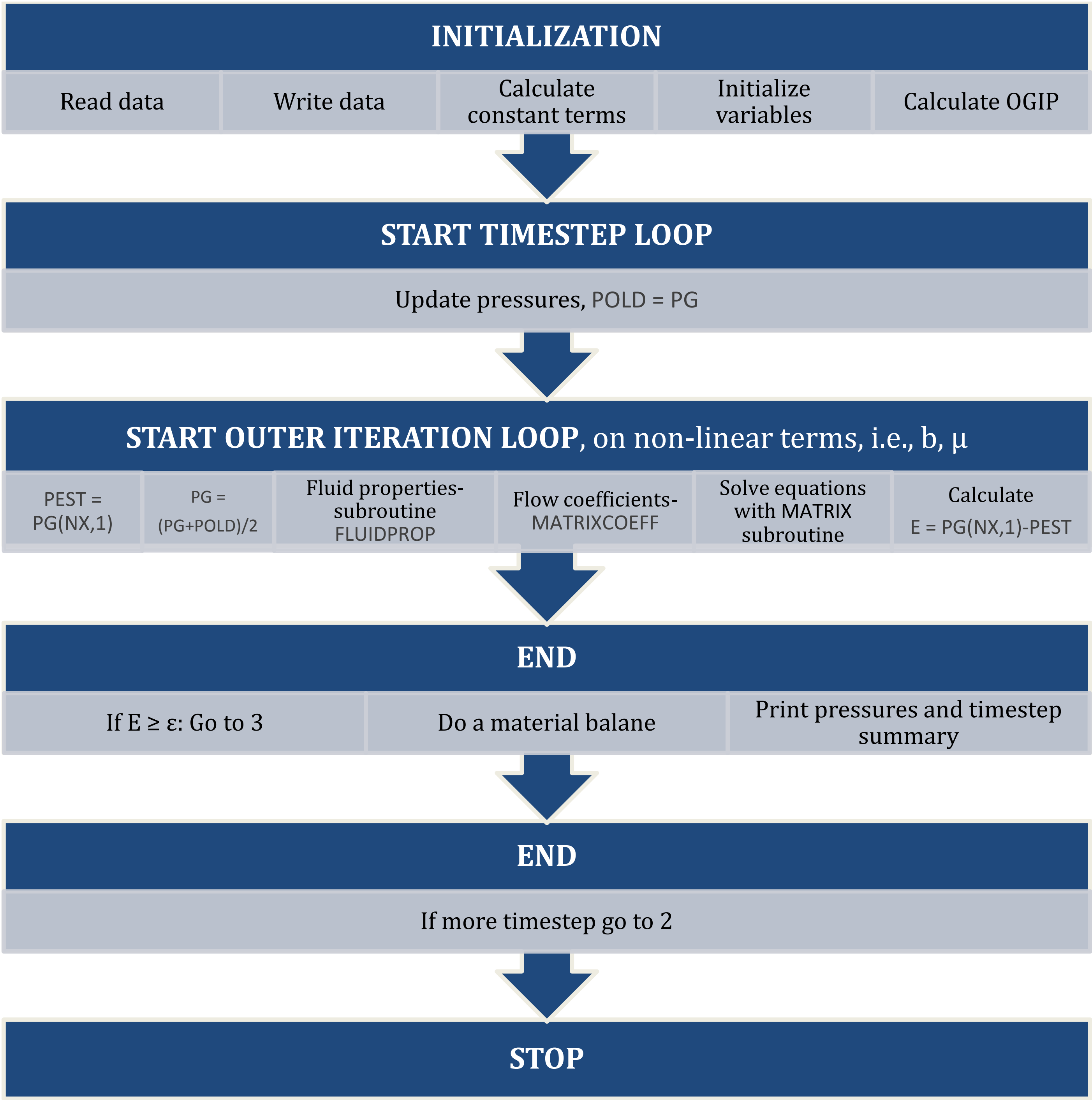
```
C    *****************************************************************
C    *                SUBROUTINE FLUIDPROP
C    *****************************************************************
C
      SUBROUTINE FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX)
C     IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DOUBLE PRECISION BGIJ,PORIG,DBDP,BORIG,
     +A,C,D,AL,S,COMP,PG,E,F,OZMIN,DEZ,
     +POLD,OXPLUS,OXMIN,A9,CKX,DEX,A2,OZPLUS
      INTEGER I,MX,NX
C
      DIMENSION BGIJ(20,20)
C
      COMMON /BLK1/A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
     +COMP(20,20),PG(20,20),E(20,20),F(20,20)
      COMMON /BLK2/ POLD(20,20),OXPLUS(20,20),OXMIN(20,20),A9(20,20),
     +CKX(20,20),DEX(20,20),A2(20,20),DEZ(20,20),OZMIN(20,20),
     +OZPLUS(20,20)
C
C     * Volume factors
C
      DO 20 I = 1,NX
         DO 977 K = 1,MX
  977    BGIJ(I,K)  =  BORIG + (PG(I,K)-PORIG) * DBDP
   20   CONTINUE
```

```
C
      RETURN
      END
C     ****************************************************************
C     *           END OF SUBROUTINE FLUIDPROP
C     ****************************************************************
```

All the equations shown above and the different subroutines mentioned help to calculate the block pressures, well production rate and block desorbed volume at each time-step.

3.5 FORTRAN Flow diagram

A basic sketch of a flow diagram for the FSGP program is shown below:


INITIALIZATION
Read data
Write data
Calculate constant terms
Initialize variables
Calculate OGIP
START TIMESTEP LOOP
Update pressures, POLD = PG
START OUTER ITERATION LOOP, on non-linear terms, i.e., b, μ
PEST = PG(NX,1)
PG = (PG+POLD)/2
Fluid properties- subroutine FLUIDPROP
Flow coefficients- MATRIXCOEFF
Solve equations with MATRIX subroutine
Calculate E = PG(NX,1)-PEST
END
If E ≥ ε: Go to 3
Do a material balane
Print pressures and timestep summary
END
If more timestep go to 2
STOP

Chapter 4
Analytical Fracture Model

This chapter presents an analytical fracture model for the flow of gas towards one single vertical fracture connected to a horizontal well. The derived formula shows a way to calculate pressure at any point in the vertical fracture. In the fracture model presented here, a rectangular fracture is considered where the flow of fluid is according to the Darcy law. The inflow of fluid from the formation is linear.

The pressures obtained in the fracture through analytical model is then compared with the numerical solution to study the stability and applicability of the numerical model. The results are presented in chapter 5.

The derivation of the equations is based on the model for radial in-flow of fluid, derived by Professor Jann Rune Ursin, presented in "Shale Gas Production – fluid towards wellbore" submitted as Bachelor Thesis by Ida Espevold and Linn Skoglund, 2013. This model has been modified for a linear inflow of fluid into a rectangular fracture.

It is a finite-conductivity fracture model where the pressure drop inside the fracture is taken into account. The fracture length Z_0 is kept constant in the calculations. In reality the fracture length will vary with the fracture width.

Definition of all the variables used in derivation are given in nomenclature.

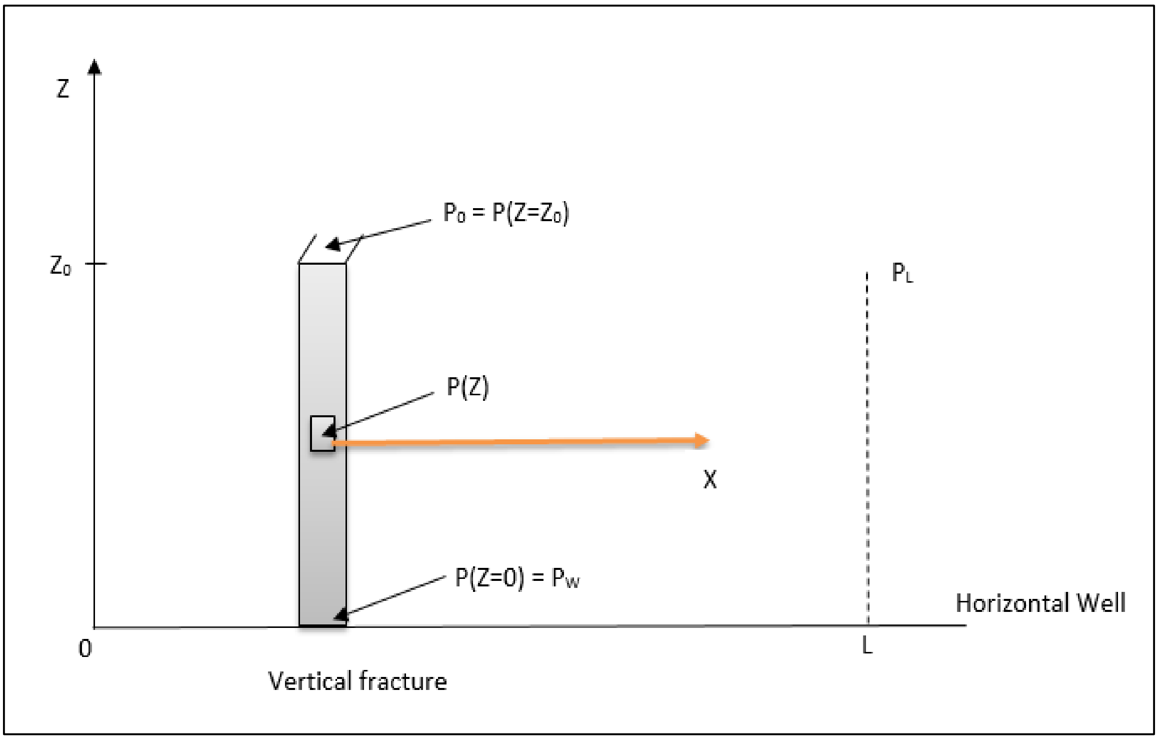


Figure 4.1 Representation of fracture model used for derivation of pressure equation.

(Modified from Ida Espevold and Linn Skoglund)

4.1 Equation for linear flow towards a rectangular fracture

Darcy's law give us an equation:

$$q = -\frac{K_m A}{\mu}\frac{\Delta p}{L} \tag{4.1}$$

For a rectangular fracture, A = h.ΔY

$$q = -\frac{K_m h \Delta Y}{\mu}\frac{dp}{dx} \tag{4.2}$$

Rearranging and integrating, we get,

$$\int_{\Delta x}^{L} q\,dx = -\int_{p}^{p_e}\frac{K_m h \Delta Y}{\mu}\,dp$$

$$q = -\frac{K_m h \Delta Y (p_e - p)}{\mu (L - \Delta x)}$$

$$q(Z) = -\frac{(Z_0 - Z)\Delta Y K_m(p_e - p(z))}{\mu(L - \Delta x)} \qquad 4.3$$

Rearranging based on pressure difference instead of flow rate, we get,

$$p_e - p(z) = -\frac{q(Z)\mu(L - \Delta x)}{(Z_0 - Z)\Delta Y K_m} \qquad 4.4$$

At the top of the fracture, the length Z is equal to the fracture length Z_0.

Thus from equation 4.3, we get,

$$For\ z = Z_0 \ \rightarrow \ q(Z_0) = 0 \qquad 4.5$$

This implies there will be no drainage at the top of the fracture.

Similarly, at the bottom of the fracture, Z= 0, thus,

$$q(0) = -\frac{Z_0 \Delta Y K_m(p_e - p(0))}{\mu(L - \Delta x)} \qquad 4.6$$

4.2 Equation for linear flow in the fracture

Again from Darcy's law, for the flow in fracture, we have:

$$q = -\frac{K_f A_f}{\mu}\frac{dp}{dz} \qquad 4.7$$

Where A_f represents the cross sectional area of the rectangular fracture.

$$A_f = \Delta x . \Delta y$$

$$q(Z) = -\frac{K_f \Delta x . \Delta y}{\mu}\frac{dp}{dz} \qquad 4.8$$

Since it is a connected system as per figure 4.1, we can equate equation 4.8 into equation 4.3, we get,

$$-\frac{(Z_0 - Z)\Delta Y K_m(p_e - p(z))}{\mu(L - \Delta x)} = -\frac{K_f A_f}{\mu}\frac{dp}{dz}$$

Rearranging above equation, we get,

$$\frac{(Z_0-Z)\big(p_e-p(z)\big)}{(L-\Delta x)}\frac{\Delta Y K_m}{K_f\,A_f} = \frac{dp}{dz} \tag{4.9}$$

Defining,

$$a = \frac{\Delta Y K_m}{(L-\Delta x)K_f\,A_f}$$

Substituting a in 4.9, we get,

$$a(Z_0 - Z)\big(p_e - p(z)\big) = \frac{dp}{dz}$$

$$\frac{dp}{(p_e-p(z))} = a(Z_0 - Z)dz$$

Integrating, we get,

$$-ln\big(p_e - p(z)\big) = a\left(Z_0Z - \frac{1}{2}Z^2\right) + C \tag{4.10}$$

At $Z = Z_0$, pressure in the fracture is equal to well pressure, i.e.,

$$p = p_w$$

This implies,

$$-\ln(p_e - p_w) = C$$

Substituting in equation 4.10, we get,

$$ln\left(\frac{p_e-p}{p_e-p_w}\right) = -a\left(Z_0Z - \frac{1}{2}Z^2\right)$$

$$\left(\frac{p_e-p}{p_e-p_w}\right) = e^{-a\left(Z_0Z-\frac{1}{2}Z^2\right)}$$

Or

$$P_Z = P_e - (P_e - P_{well})\,e^{-a(z_0z-{}^1/_2\,z^2)} \tag{4.11}$$

Where, $a = \frac{\Delta Y\,K_m}{(L-\Delta X)\,K_f\,A_f}$

Using equation 4.11, we can calculate pressure at any height or point in the vertical fracture for linear inflow from the formation and linear flow in the fracture.

The results obtained through equation 4.11 has been compared with the numerical model shown in chapter 3. A detailed analysis of the result is shown in chapter 5.

However, I would like to emphasise that the comparison has been made with the pressures in the fracture only and not with the pressures in the formation. To obtain pressures analytically in the shale gas formation for such a model is much more complicated and is not addressed in this thesis.

Chapter 5
FSGP SIMULATION RESULTS AND DISCUSSIONS

This chapter shows the results that have been produced by the FSGP simulator. A detailed analysis has been done on the obtained production profile and its long term well performance characteristics. It also explains the pressure behaviour of each cell at different time step. This chapter also include study of efficiency of the simulator when heterogeneous property is introduced. Moreover, sensitivity analysis has been done in terms of size of the sphere and the amount of adsorbed gas. Lastly, a comparison of the analytical fracture model has been made with the numerical solution, i.e., fracture pressures have been compared to study the stability and applicability of the numerical solution.

The following data has been used in simulator. Data for Langmuir's isotherm are taken from Barnett Shale. Sensible and applicable data has been chosen to describe shale gas characteristics and reservoir properties.

Parameter	***Value***	***Units***	***Source***
Initial reservoir pressure	3100	psi	Cong Wang, 2013
Gas viscosity	0.0184	cp	Cong Wang, 2013
Gas formation volume factor, 1/Bg	1.35	scf/rcf	Assumption
Initial dbg/dp, compressibility	6.30E-05	1/psi	Cong Wang, 2013
Density of Gas	6.42	lb/ft3	Cong Wang, 2013
Matrix Permeability	0.001	mD	Assumption
Porosity	0.05	fraction	Assumption
Cell length	100	ft	Assumption
Cell width	100	ft	Assumption
Cell height	100	ft	Assumption
Fracture length	20	ft	Assumption
Fracture Permeability	500	mD	Assumption
Well radius	0.3	ft	Cong Wang, 2013
Bottom-hole pressure	2550	psi	Assumption
Perforation length	20	ft	Assumption
Langmuir's Volume	0.09914	scf/lb	Cong Wang, 2013
Langmuir's pressure	2695.57	psi	Cong Wang, 2013
Critical desorption pressure	2800	psi	Assumption
Density of shale rock	168.55	lb/ft3	Cong Wang, 2013

Table 5.1 Shale Gas characteristics and Reservoir properties used in the simulator.

5.1 Langmuir’s Isotherm

The following plot shows comparison between the amount of free gas and the adsorbed gas present in one cell. The adsorbed gas content has been plotted using the Langmuir’s Isotherm for Barnett Shale, as discussed in chapter 3, whereas the free gas is calculated using the volumetric gas capacity of reservoir with respect to pressure .

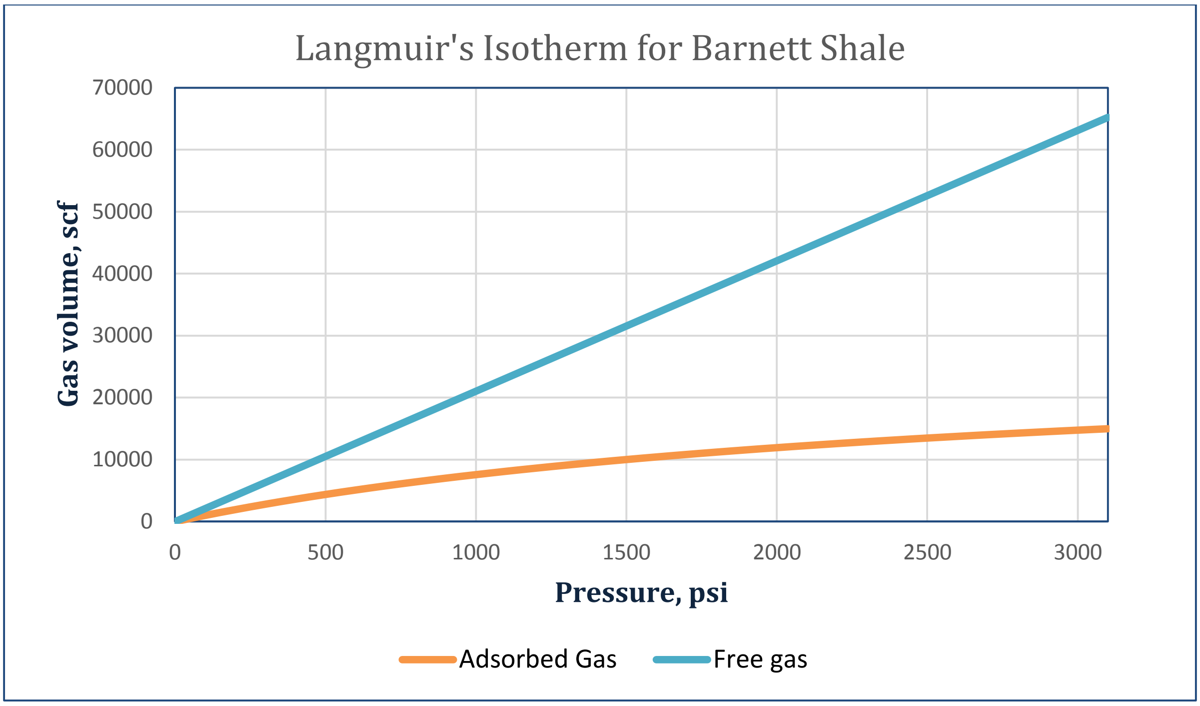


Figure 5.1 Free gas and adsorbed gas content vs pressure.

Figure 5.1 shows significant amount of adsorbed gas content present in a sphere of radius 20 ft. Neglecting the amount can cause serious errors both in production forecast and in calculation of original gas in place.

5.2 Production Profile

On using the data from table 5.1 and homogeneous reservoir property, we obtain the following plot for production forecast through FSGP simulator.

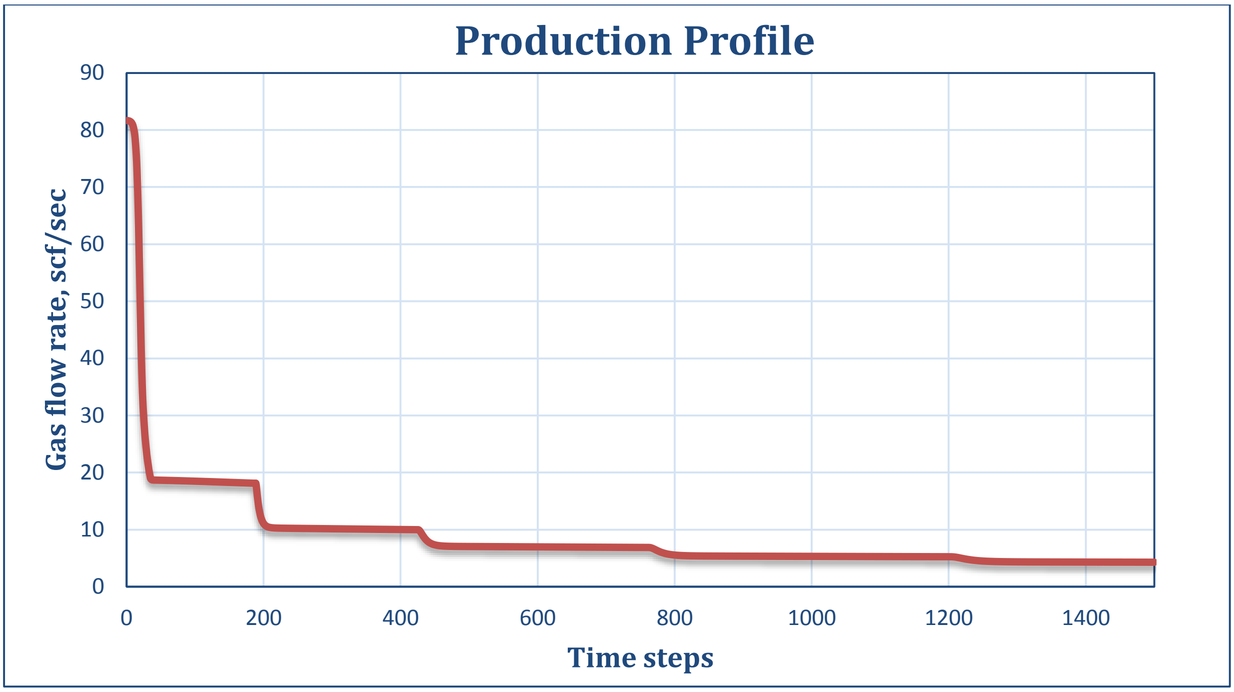


Figure 5.2 Gas flow rate vs time steps.

The production plot, figure 5.2, shows a long term well performance characteristics as desired in case of shale gas production. Here the initial reservoir pressure is 3100 psi and the gas is produced at constant bottom-hole pressure of 2550 psi. At an early stage of production, free gas present in the natural fracture and pore space is produced until the pressure in the cell reaches critical desorption pressure. The adsorbed gas then feeds the porous area through desorption at a rate dependent on pressure changes.

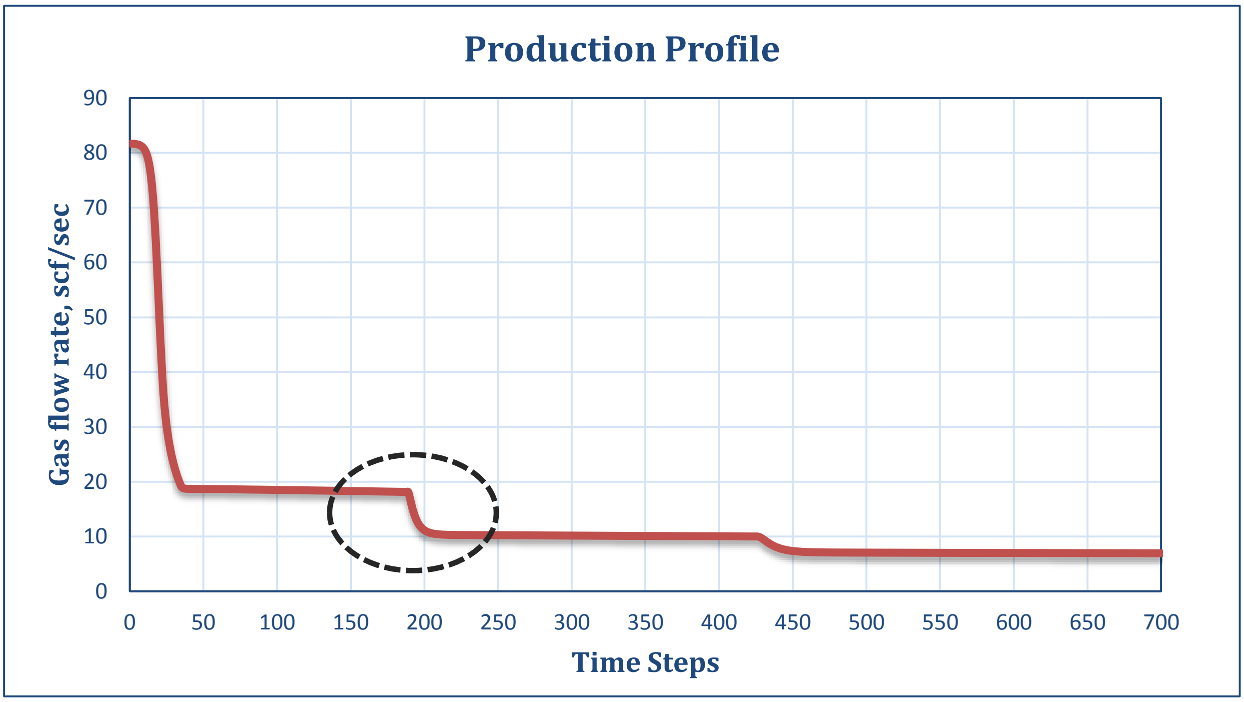


Figure 5.3 Gas flow rate vs time steps up to 700.

However, a small bump or drop in the production rate is observed as shown in figure 5.3. This is because of the fact that the free gas will be produced first from the cells closest to the fracture, thus the pressure in that cell will reach critical desorption pressure faster than other cells. As a result, the production rate stabilizes. After certain amount of time, when all the adsorbed gas has desorbed from the nearest cell to the well fracture, free gas will start coming out from the next adjacent cell until critical desorption pressure is reached, for adsorbed gas to be produced and stabilize the production rate again. Thus, we see a slight decrease in production rate when gas being produced moves from one cell to another.

Until now, we saw production rate plots versus time steps. Figure 5.4 shows Gas production rate versus time in days. The figure is to make comparison between time steps and time in days conversion defined in FSGP. The plot shown is up to 700 time steps which is equivalent to 6802 days.

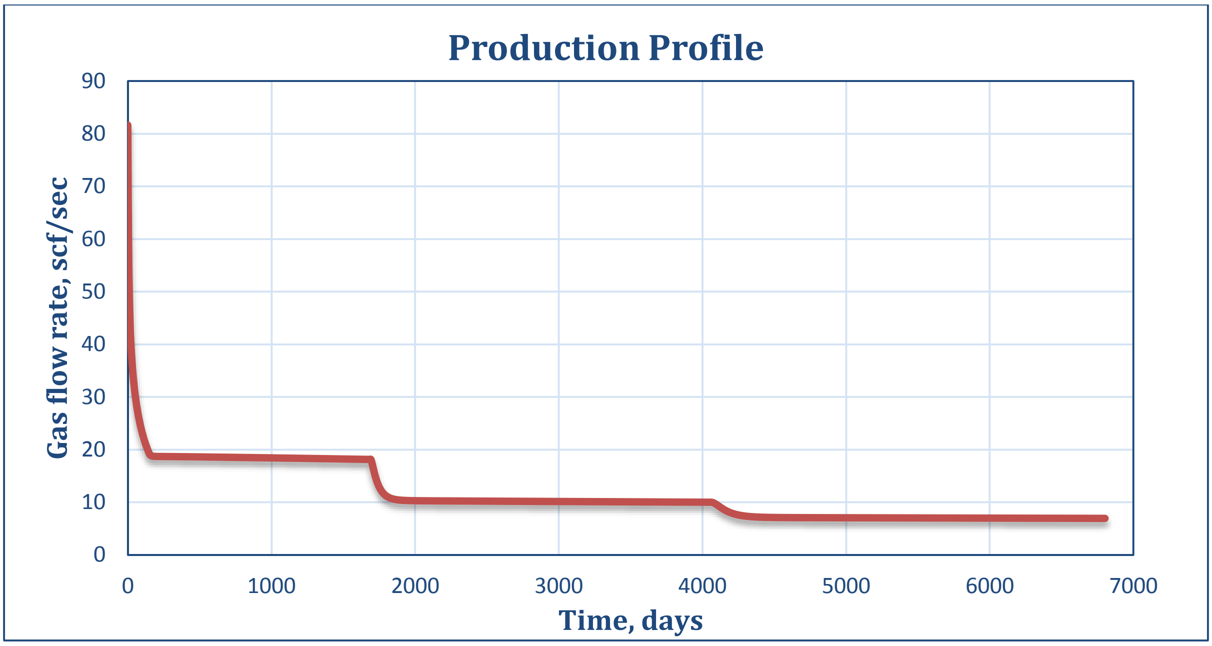


Figure 5.4 Gas production rate vs time in days.

However, rest of the plots shown in this chapter are against time steps. This is the way I found it more convenient to express the results obtained through FSGP simulator.

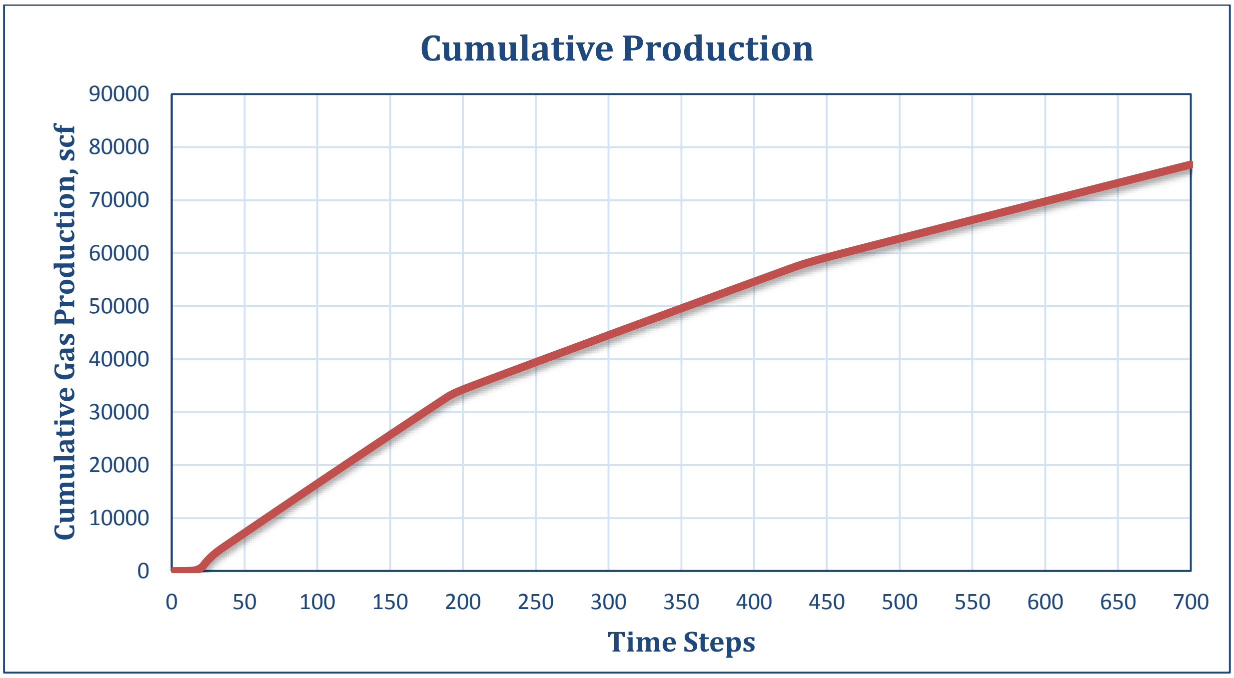


Figure 5.5 Cumulative production vs time steps

Figure 5.5 shows cumulative gas produced up to 700 time steps. The trend is similar to what we see in a conventional gas reservoir. However, we see very low production initially is because of the time step length. The time step length at the beginning is very low in the range of 10E-04 which increases later on up to 10 days per time step interval. This is the way it has been defined in the FSGP simulator to analyse in more detail the changes in pressure and flow rate at an initial stage of production.

5.3 Fracture Pressure

In this section, the variation in fracture pressure with time is plotted. Since only linear flow as per Darcy law is considered in the simulation, the flow rate is directly dependent on pressure. As a result, we see a very similar trend for fracture pressure as observed in case of gas flow rate in figure 5.3.

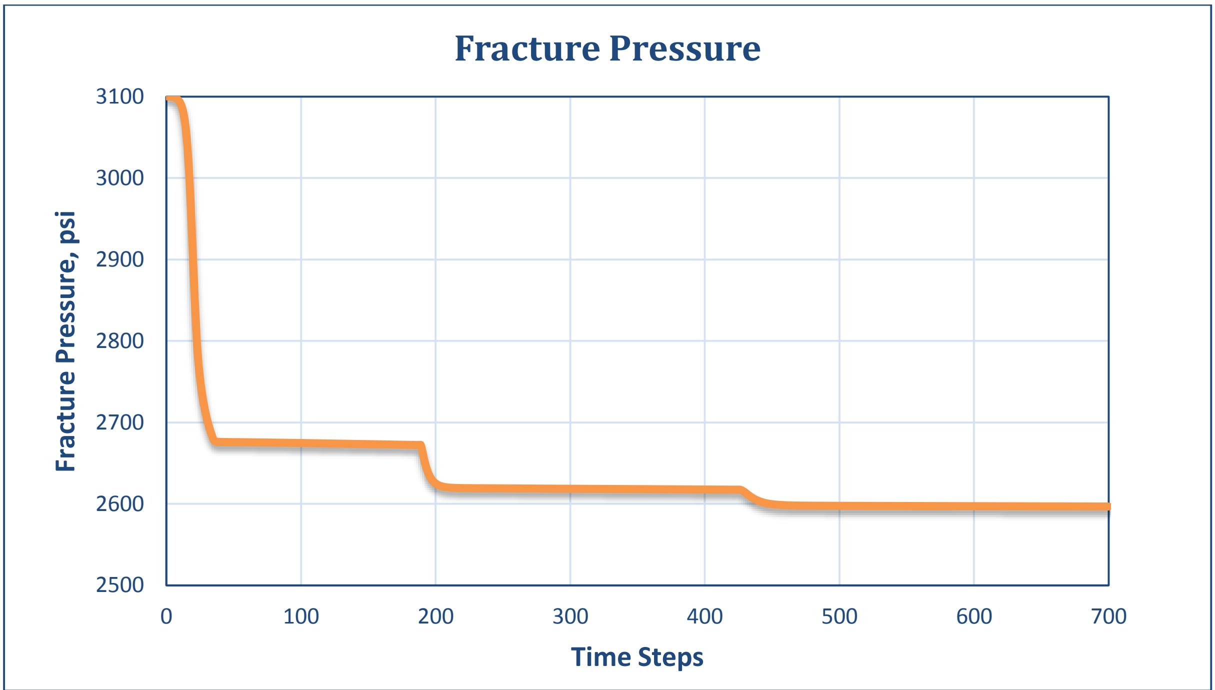


Figure 5.6 Variation in fracture pressure with time.

The pressure shown in figure 5.6 is the pressure obtained at centre point in the fracture length. The pressure drop along the fracture is not significant as gravitational losses are neglected. Moreover, the inflow of gas from the formation to the fracture is considered linear as well as the flow in the fracture is considered to be linear. The fracture pressure stabilizes after an initial drop which is due to desorbed gas coming out of sphere from the nearest cell. At around 220th time step, we see a drop since all the adsorbed gas has been produced from the nearest cell and it takes some time to reach critical desorption pressure for the next adjacent cell.

5.4 Pressure variation in Cells

In this section, we will see how the pressure varies in each cells for the proposed model of shale gas production.

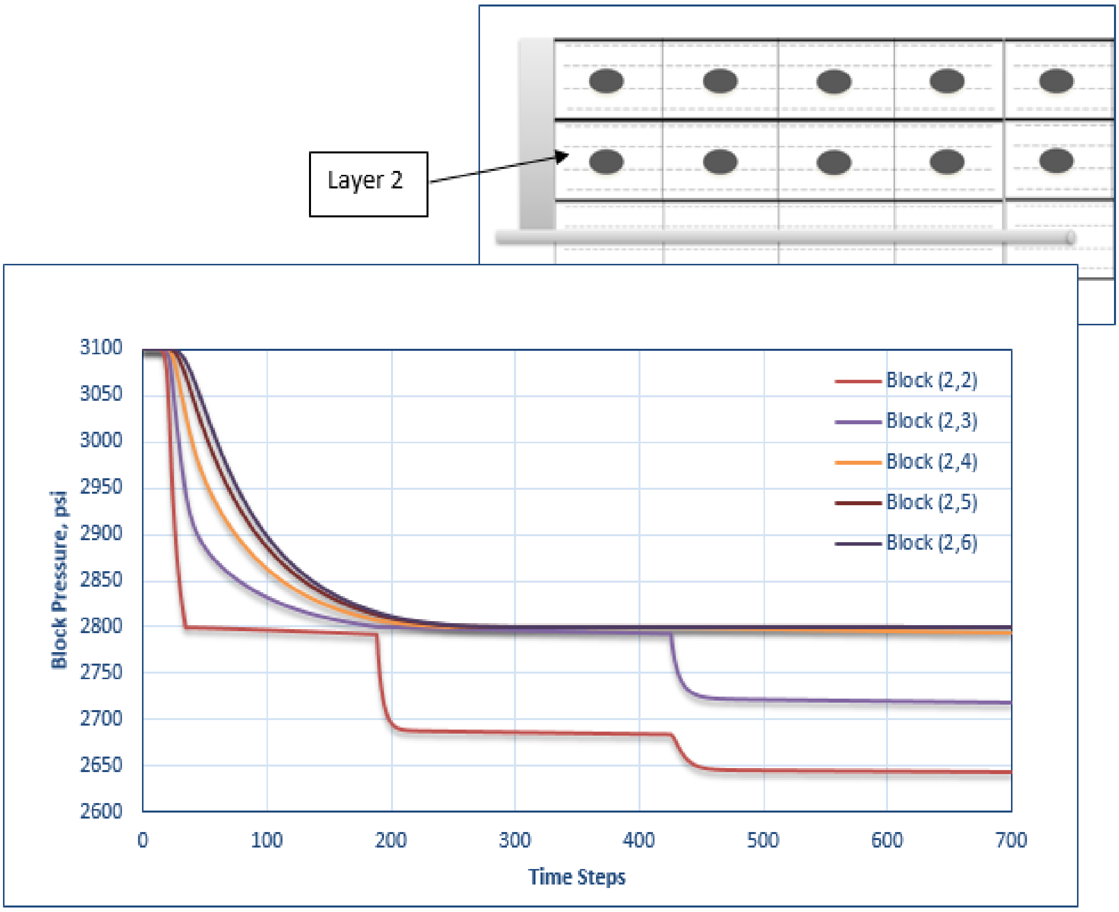


Figure 5.7 Pressure changes with time in each block of layer 2.

Considering a 6x3 dimension 2D reservoir, we get a pressure plot for each block in layer 2 as shown in figure 5.7. From the plot, we see that each cell will have its own independent behaviour with time. At an early stage of production free gas will be produced first and faster from the first block (2,2) which is closest to the fracture. Hence, pressure drop is much faster. After certain period of time, the pressure stabilizes which is due to desorption of gas as critical desorption pressure is reached. However, we see a continued drop in pressure in the remaining cells as it takes time for the gas to flow due to low matrix permeability.

Similar trend we see for layer 1 of the reservoir which is shown in figure 5.8. This plots are made from the data generated through FSGP simulator.

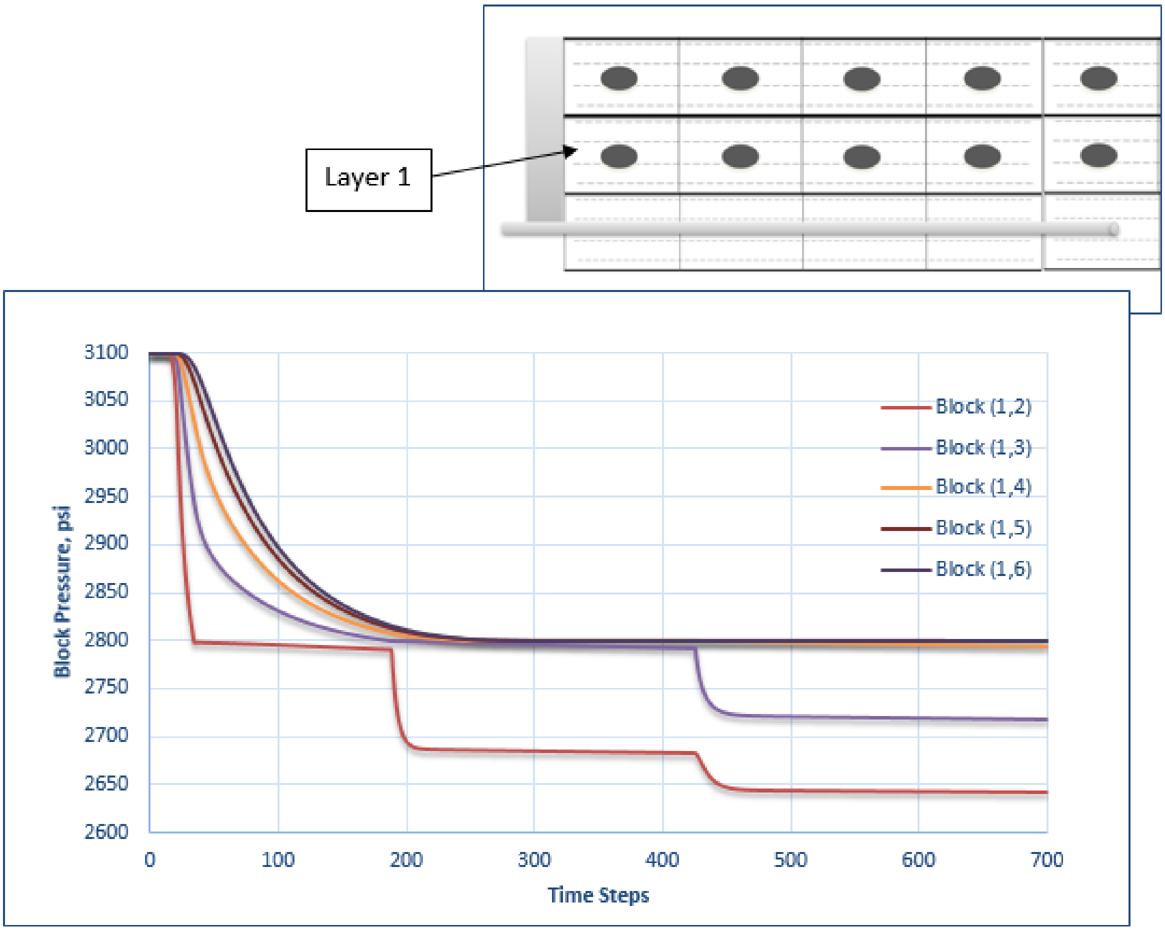


Figure 5.8 Pressure changes with time in each block of layer 1.

One point to note is that the transmissibility of gas in z-direction within different layers is not considered. This assumption is acceptable because of low matrix permeability and thus the flow of gas will be towards fracture where pressure is low and not towards the adjacent cell in z-direction. Overall, the flow in z-direction is considered only in the fracture.

Following figure shows how the pressure in the cell varies with distance from the vertical fracture at different time steps.

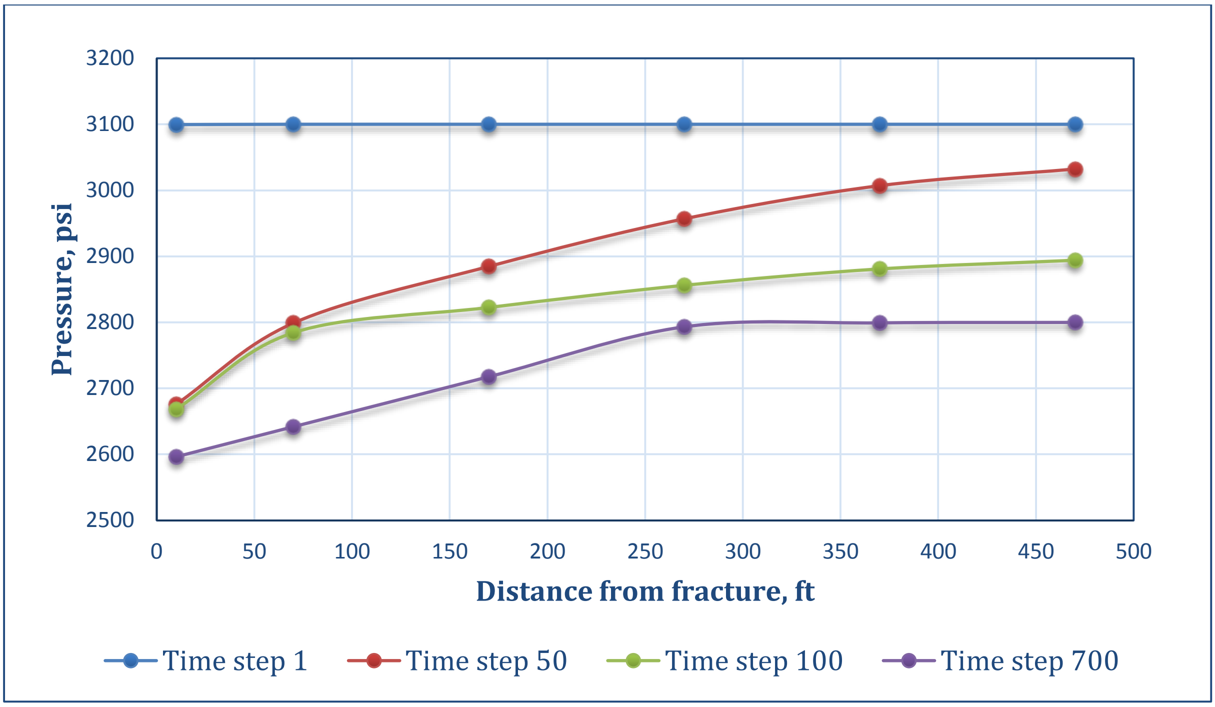


Figure 5.9 Pressure variation in layer 2 with distance from fracture at different time steps.

Figure 5.9 shows the pressure changes in layer 2 with distance from fracture. Initially, at zero time step, all the blocks are at reservoir pressure of 3100 psi. As the time increases and with production of gas, the pressure depletes in the cell closer to the fracture faster than the remaining cells. The critical desorption pressure is defined at 2800 psi and we observe that after 700 time steps, the pressure in block (2,5) and (2,6) is still close to or above 2800 psi, Thus, the adsorbed gas is yet to be produced from those cells. However, all the cells prior to those have already or still producing the adsorbed gas. Similar trend we see for layer 1 which is shown in figure 5.10.

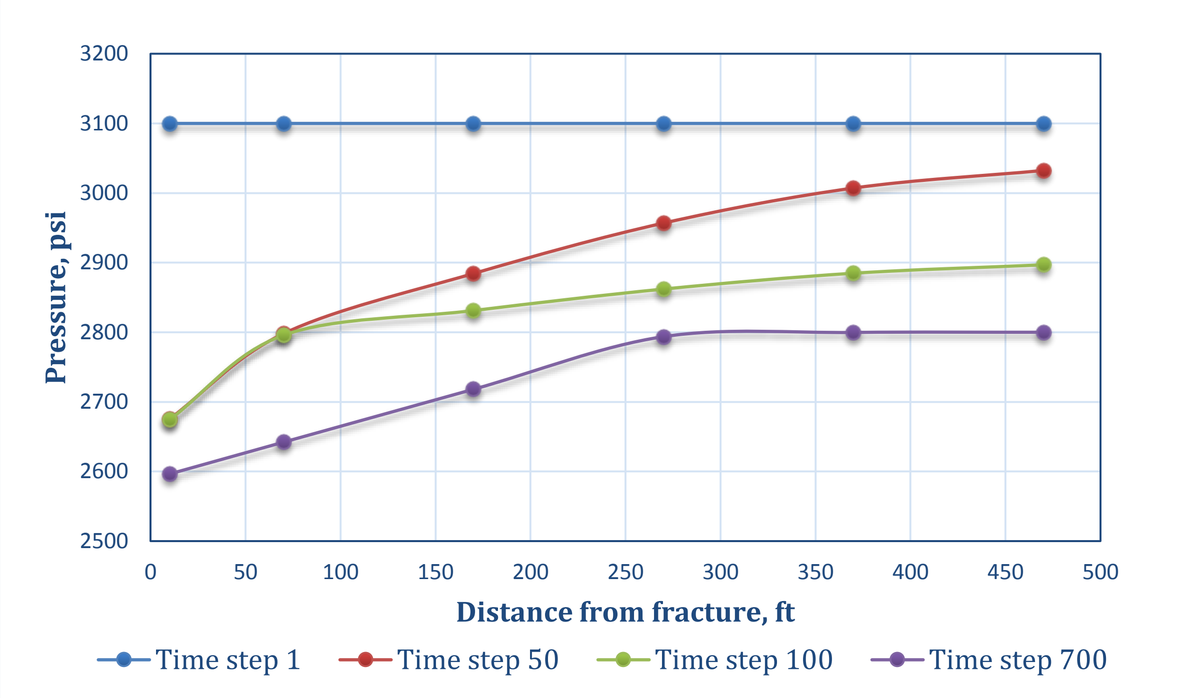


Figure 5.10 Pressure variation in layer 1 with distance from fracture at different time steps.

5.5 Gas Desorption Volume

Figure 5.11 shows the volume of gas desorbed in each cell with time. The desorbed gas is produced first from the block (2,2) which is nearest to the vertical fracture and hence the pressure will be depleted faster. Desorption of gas will stabilize the pressure and flow rate until all the gas has been desorbed from that cell. Next, pressure in the adjacent will deplete and reach critical desorption pressure which will feed gas to the pore space. Such a trend will continue through the reservoir for a homogeneous system. For a heterogeneous system, we might observe some change in the order of desorption from the cell because of difference in porosity and permeability.

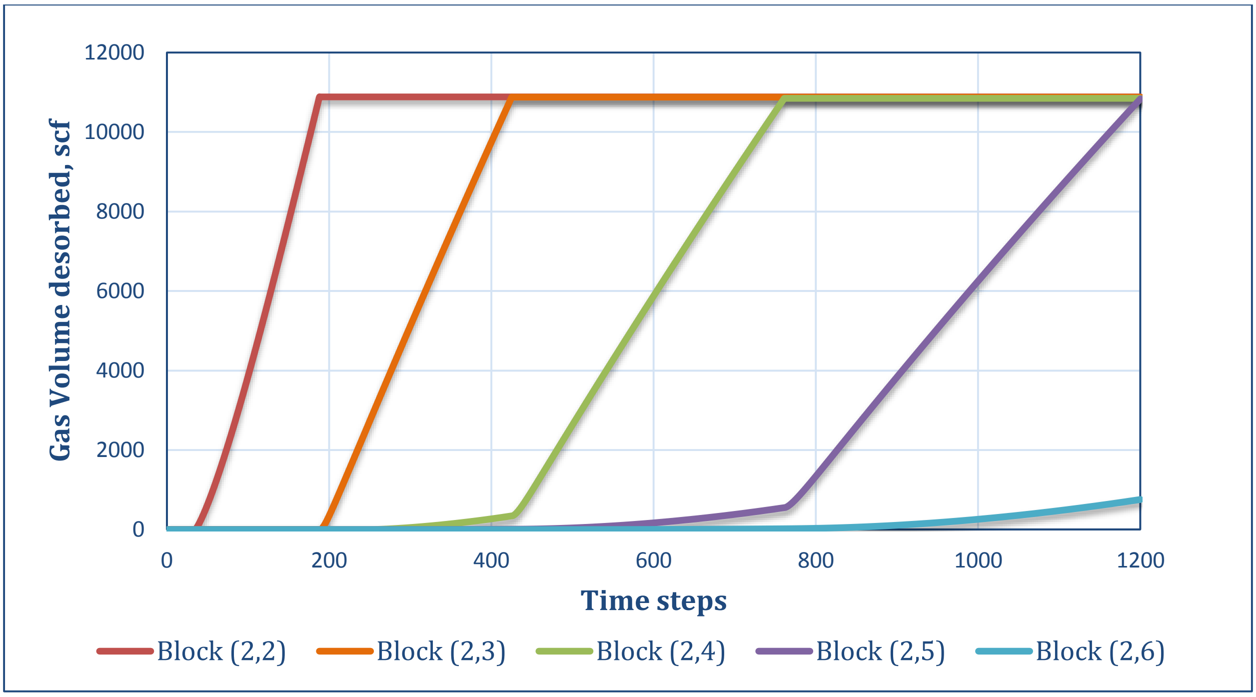


Figure 5.11 Gas volume desorbed from each cell with time.

5.6 Sensitivity Analysis

Until now, the results shown are with homogeneous reservoir properties, i.e., the permeability and porosity in each cell is kept constant. In this section, we will analyse the response of FSGP simulator when heterogeneous properties are introduced for the production of shale gas. This section also includes the comparison of production profile with varying size of the sphere or varying amount of adsorbed gas content. Also, we will look into detail the implications of non-uniform fracture width.

5.6.1 Varying Permeability

Figure 5.12 shows the production profile for a varying permeability in each cell. The permeability has been assigned randomly to each cell in the range of 10^{-02} to 10^{-06} mD.

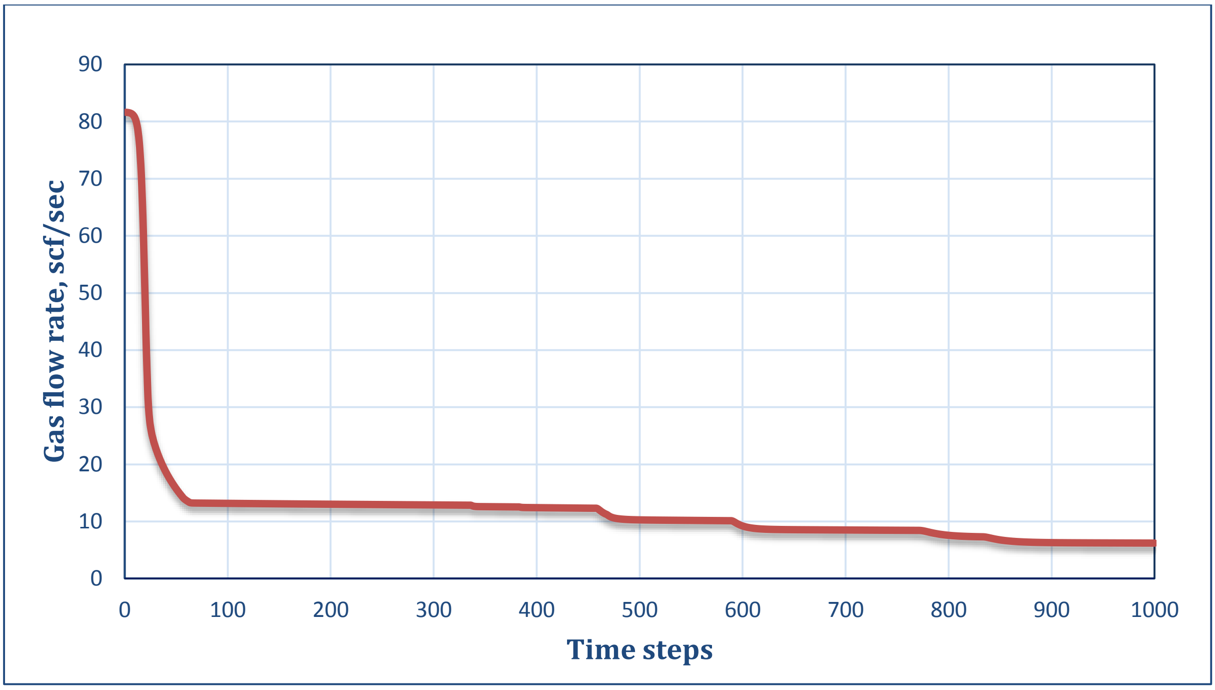


Figure 5.12 Gas flow rate vs time for heterogeneous reservoir permeability.

Here we observe that FSGP simulator gives stable production profile for varying permeability in the reservoir. We still observe long term well performance characteristic for the production of shale gas. However, the plot is much more linear compared to the homogenous permeability which is probably because of the reason that it is taking lesser time for its adjacent cell to reach critical desorption pressure when the adsorbed gas is produced from that cell.

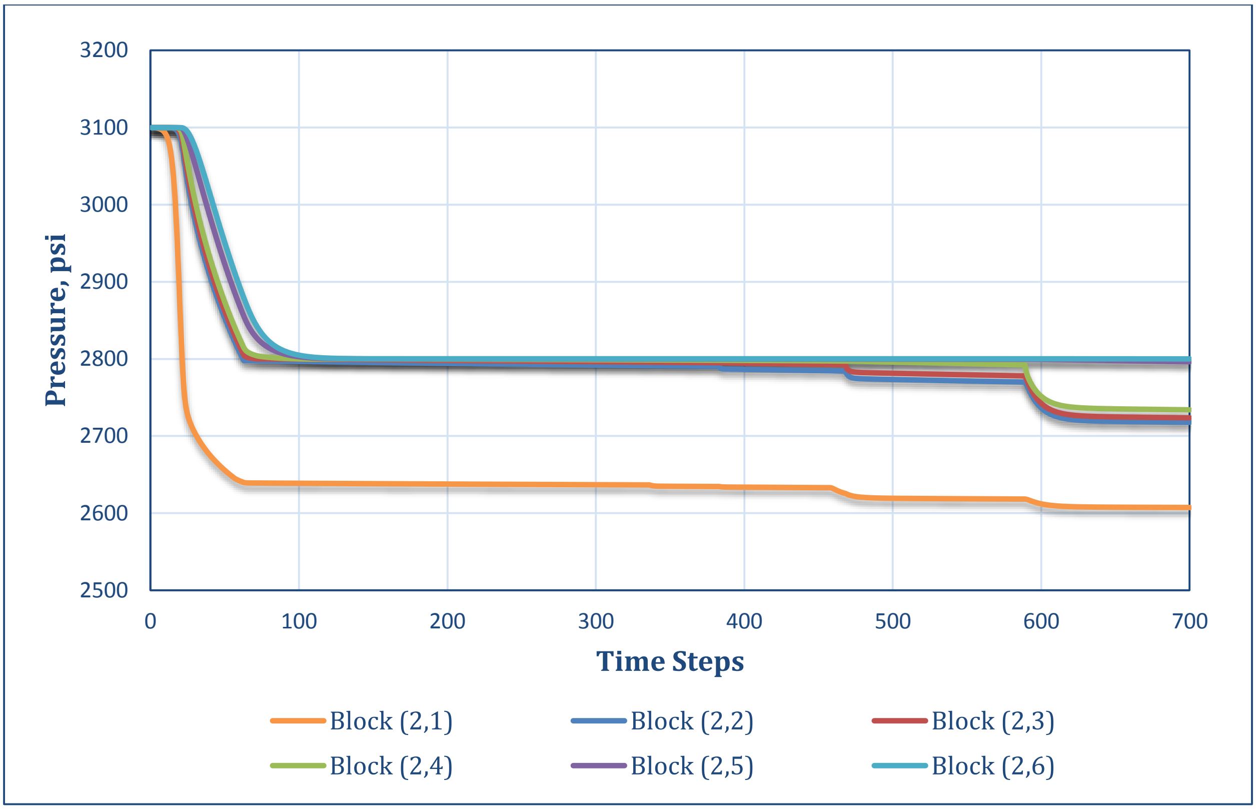


Figure 5.13 Effect of different permeability's on block pressure.

Pressure in block (2,1) represents fracture pressure (fig. 5.13) and thus the trend observed is very similar to one in case of production rate. Here, compared to figure 5.7, we see that each cell reaches critical desorption pressure at about similar time which may be due to varying permeability but higher values of permeability assigned to couple of adjacent blocks. Thus, we obtained a much more linear and smooth rate of production of shale gas.

5.6.2 Varying Porosity and Permeability

The porosity range has been defined from 0.5% to 7% and the permeability ranges between 10^{-02} to 10^{-06} mD. The plot obtained in figure 5.14 defines the stability and efficiency of the FSGP simulator.

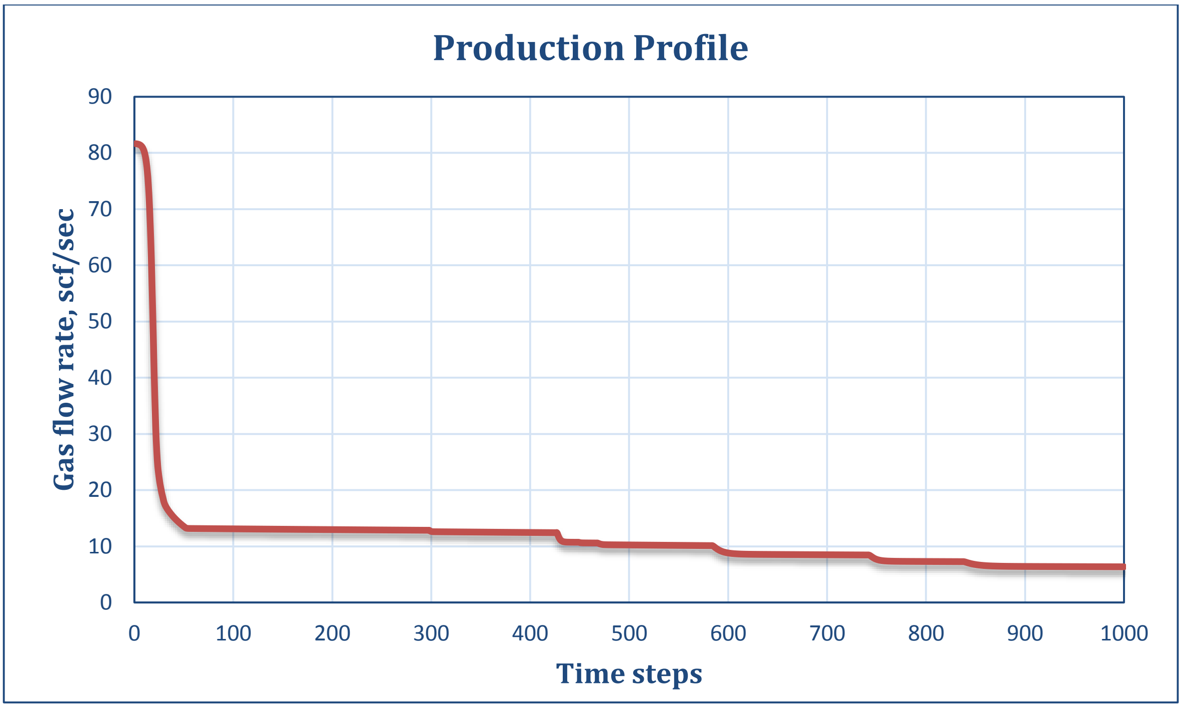


Figure 5.14 Effect of varying porosity and permeability on gas production rate.

5.6.3 Size of sphere

In this section, a comparison between production profiles for various sizes of sphere has been made. Larger the size of sphere means higher the amount of organic content and the more amount of adsorbed gas. The comparison has been made for 3 different radius of spheres: 15 ft, 20 ft and 40 ft. Also, heterogeneous reservoir property has been used to obtain the production profile (fig. 5.15).

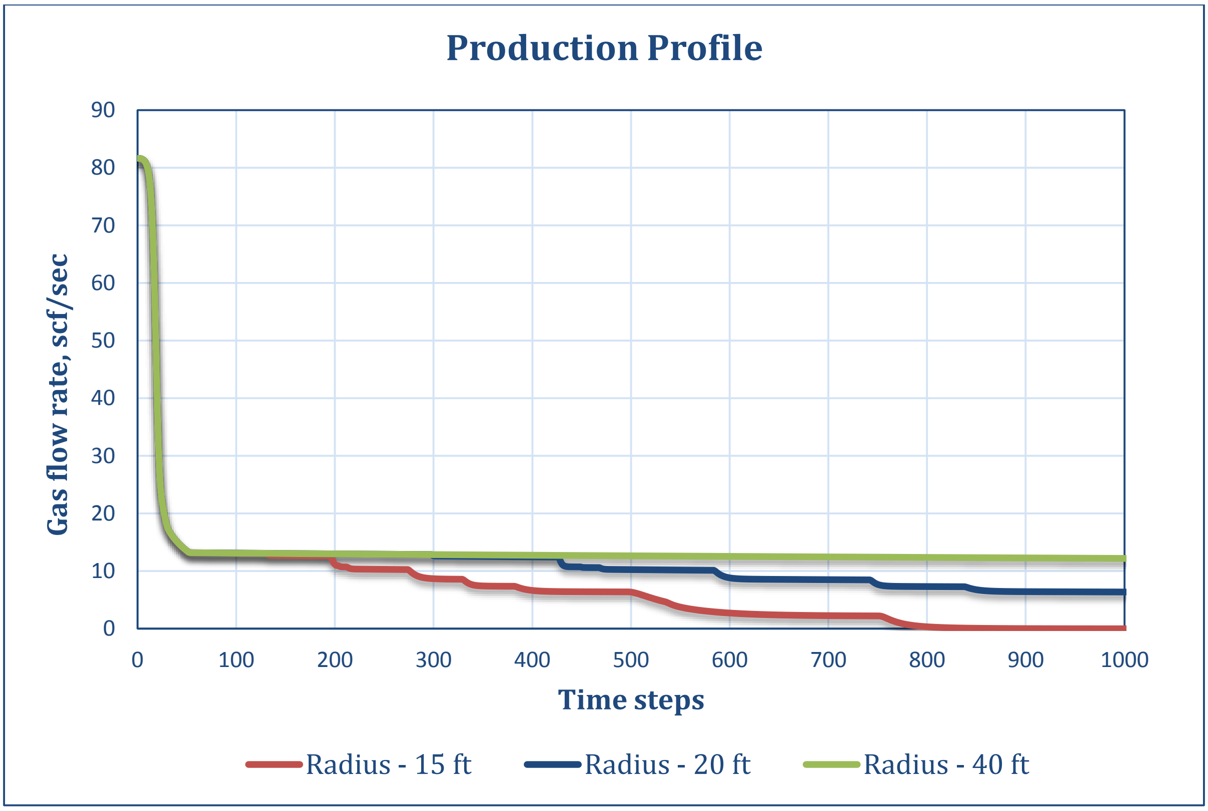


Figure 5.15 Comparison between production profiles for 3 different sizes of sphere.

The production for sphere of radius 40 ft sustains much longer at a good rate compared to spheres of radius 10 and 20 ft. This is because of the higher amount of gas content adsorbed due to presence of more organic matter. However, sphere with same size can also have different production profile if the adsorbed gas density is different. If a gas is much more densely packed or adhered onto the organic matter or has higher amount of total organic carbon (TOC) content, more gas will be desorbed from that cell.

Since the amount of gas adsorbed also depends on the density of gas, the following plot shows flow rate comparison between two different gas densities adsorbed onto the same size of sphere. We are now considering a sphere of radius 20 ft and gas densities of 6.42 lb/ft^3 and 15 lb/ft^3. The production will sustain longer in case of higher gas density because gas is more densely packed onto the organic matter and thus more amount of adsorbed gas. The overall Gas-in-place will also be larger with higher gas density. The obtained result is shown in figure 5.16.

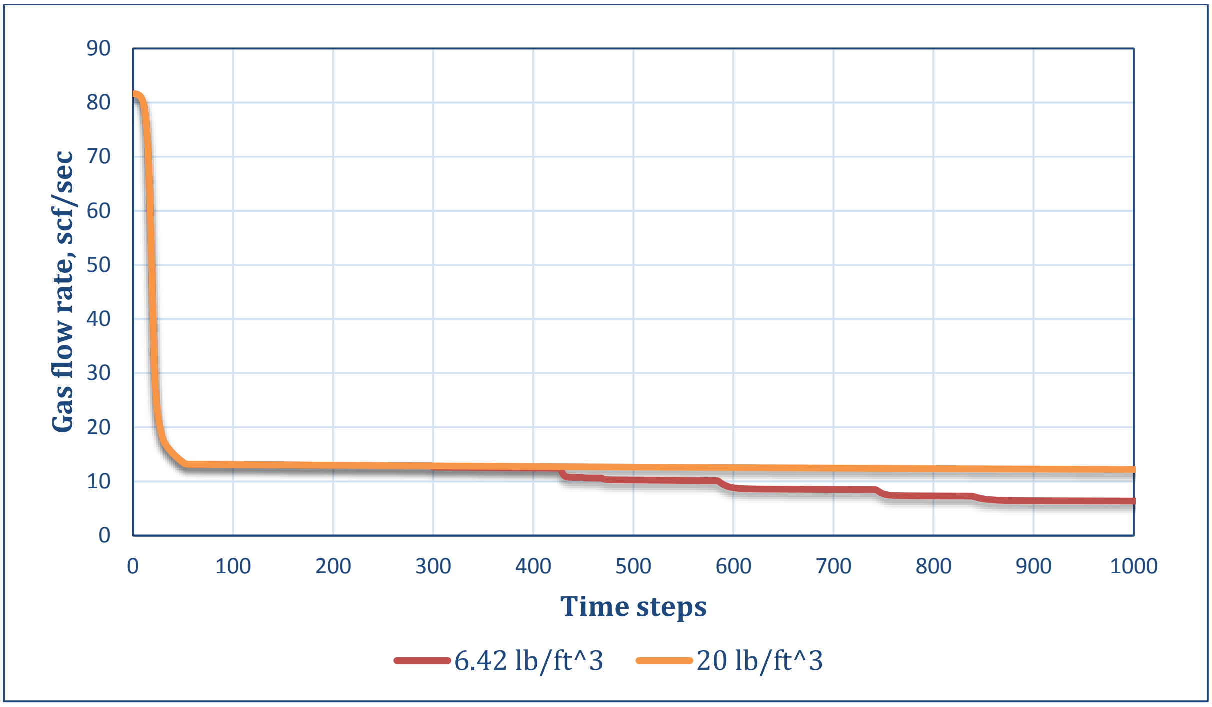


Figure 5.16 Effect of Gas density on production profile.

5.6.4 Fracture Width

Until now, we had a uniform fracture width of 100 ft. Now in this section, we will compare the production profile for a constant fracture width with non-uniform fracture width. In the newly defined fracture, we are varying the width in the range of 20 ft to 60 ft as shown in chapter 3 in figure 3.5. The production profile obtained for such a case is shown below:

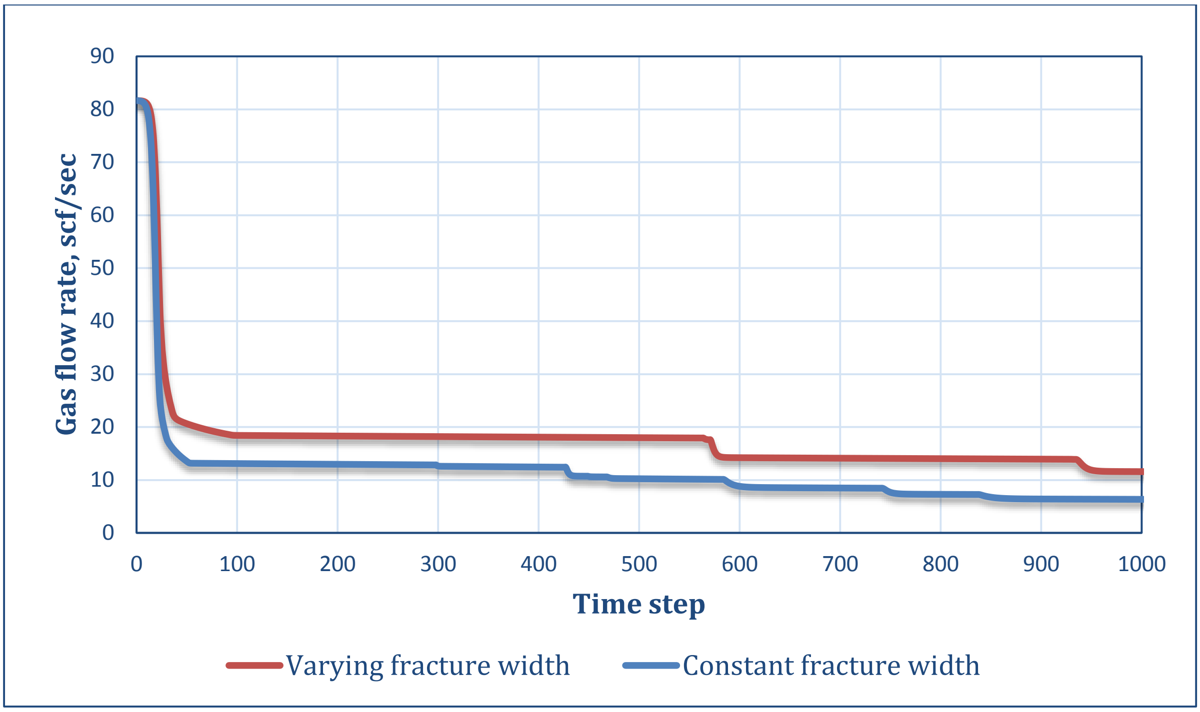


Figure 5.17 Effect of fracture width on production profile.

For a uniform and constant fracture width, we see a low rate of production compared to non-uniform fracture width which is understandable as larger flow area is offered in case on non-uniform fracture width. The constant fracture width used is 20 ft.

It would also be interesting to see how the pressure in block will behave with the change in fracture width. One such comparison is shown in figure 5.18 for block (2,3) at 2 different fracture width of 20 ft and 40 ft.

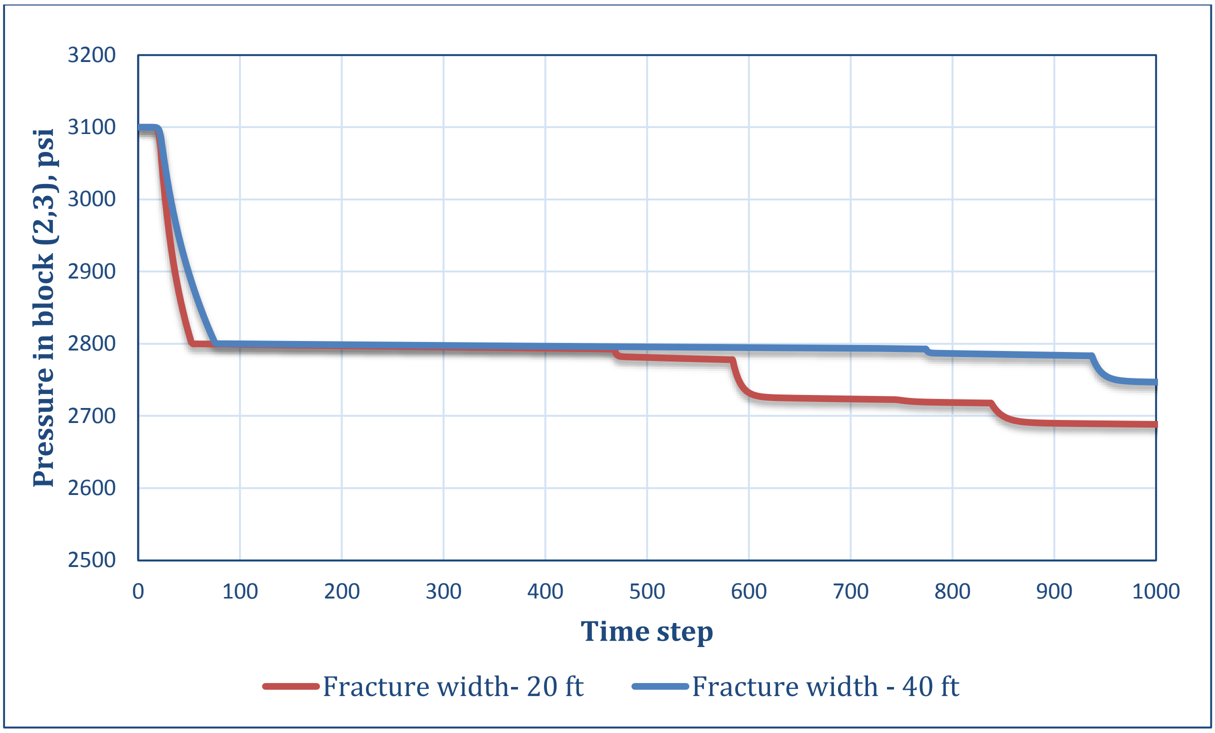


Figure 5.18 Effect of fracture width on pressure in block (2,3).

It shows that critical desorption pressure is reached at a later stage for fracture with width 40 ft compared to that of fracture with width 20 ft. Also, the pressure in that block sustains for longer time. However, it's important to note that the plot shown is with heterogeneous reservoir properties which will also have an effect on the pressure variation in each blocks with time. Thus, it is difficult to predict how the pressure change will behave with facture width.

Such more sensitivity analysis of the FSGP simulator for production of shale gas can be done with other parameters such as grid size, Langmuir's isotherm parameters and bottom-hole pressure and also by producing gas at constant rate. However, results obtained by varying this parameters has not been included in this thesis.

5.7 Comparison- Analytical vs Numerical solution

In chapter 4, we derived an analytical model to calculate pressure in a vertical rectangular shaped fracture. The analytical model considers linear inflow of fluid from the reservoir as well as linear flow in the fracture.

The pressure equation derived in chapter 5 is given by:

$$P_Z = P_e - (P_e - P_{well})\, e^{-a(z_0 z - {}^1/_2\, z^2)} \qquad 5.1$$

Where, $a = \dfrac{\Delta Y\, K_m}{(L - \Delta X)\, K_f\, A_f}$

Figure 5.18 shows the comparison between the pressures obtained through equation 5.1 with that of a numerical model defined in chapter 3. Pressure in the middle of fracture is compared with numerical solution, i.e., for analytical model, *Z = 150 ft* and for numerical model, the centre point of block (2,1) is used.

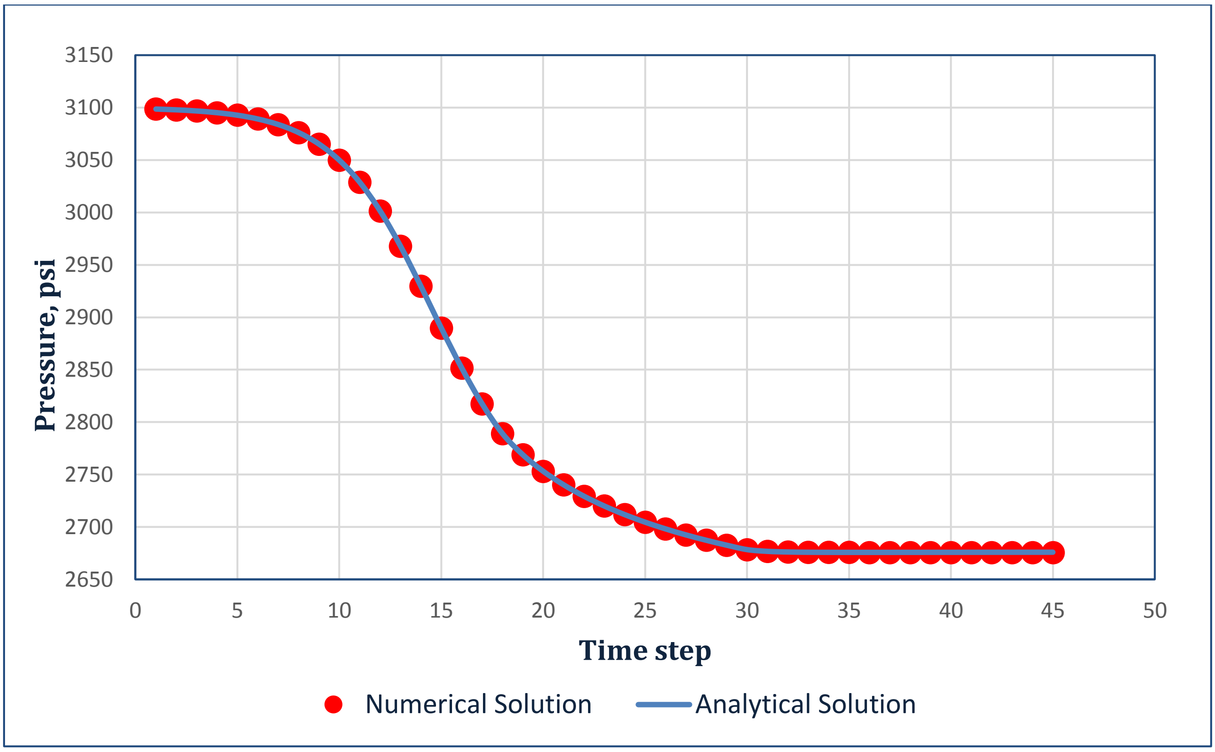


Figure 5.19 Comparison between analytical and numerical fracture pressure.

The fracture pressure obtained numerically matches perfectly with the analytical model at various time steps. This shows the stability and applicability of the numerical model derived in chapter 3. However, one must note that figure 5.19 compares only the pressure in the vertical fracture. The analytical model shown in chapter 4 is to calculate fracture pressure only. Derivation of an equation to calculate pressures analytically in the formation is much more complicated and is beyond the scope of this thesis.

Chapter 6
CONCLUSIONS

This thesis explores a new modelling approach for the production of shale gas. It localizes the presence of organic matter and inorganic matter within the shale to different places. The gas is stored through the means of compression as free gas and as an adsorbed gas onto the kerogen or organic matter. The transport mechanism considered are diffusion for the transport of gas within the matrix and the Darcy flow for the flow in micro-fractures and fractures created through stimulation job. However, in the FSGP simulator the transport of gas through diffusion is neglected as it is a very slow process because of low matrix permeability.

The thesis also provides an insight into how the simulator is developed for a single phase flow of gas in 2D reservoir. The mathematical model used in the simulator is described in detailed and the analysis of the results obtained is thoroughly done. Moreover, this thesis makes comparison between the analytical model and numerical solution to study the efficiency of the numerical solution.

6.1 Conclusions

1. We discussed a shale gas flow model by considering a sphere inside a cube. The sphere comprises of organic matter where the transport of gas is through

diffusion into the nanopores or matrix. Outside the sphere is the inorganic matter where we have linear Darcy flow of gas in the naturally occurring micro-fractures. The depletion of reservoir is pressure dependent for the production of free gas whereas inside the sphere it is both pressure dependent for desorption process and concentration dependent for diffusion. The flow model shows a simple yet applicable way of modelling gas production to depict the long term well performance characteristics.

2. The representation of shale gas reservoir in such a way makes it easier to efficiently calculate the original gas in place. The total gas is considered to be stored in two ways: free gas and adsorbed gas onto the organic matter.
3. The adsorbed gas content is given by Langmuir's isotherm and consists of significant amount of gas which cannot be neglected. However, the transport of gas through diffusion is neglected as diffusion is a very slow process and the time needed to reach a new balance between adsorbed gas and free gas is so short that it can be neglected.
4. We discussed a framework for mathematical modelling of gas production from unconventional reservoirs considering desorption of gas and linear Darcy flow in a 2D reservoir. Desorption has been treated as source term in the model which feeds gas to the pore space. The model formulation uses implicit solution scheme for the single phase flow of gas. The fracture is treated similar to the grid cell with much higher permeability than that of matrix. The mathematical model also gives an insight into the development of a simulator which has been drafted on FORTRAN compiler.
5. The production profile obtained through FSGP simulator shows long term well performance characteristics as desired in case of shale gas production. The presence of additional gas source in terms of adsorbed gas stabilizes the production after an initial drop when pressure in the cell reaches critical desorption pressure.
6. Gas adsorption/desorption is incorporated into the simulator and the simulator produces the amount of gas desorbed from the cells at each time steps. Barnett shale data have been used for Langmuir parameters. Our simulation results show that desorption contribute significant amount of gas to the production.

7. The FSGP simulator generates pressure data for all the cells at each time steps. The resultant plot shows that each cell behaves independently. Desorption of gas is triggered first in the cell closest to vertical fracture. Also, the pressure in the fracture has been analysed and it has similar trend as of production rate because the production is considered to be pressure dependent only.
8. The simulator has been tested with heterogeneous inputs of permeability, porosity and grid size. The results has been convincing showing that the FSGP simulator is able to handle variable inputs and efficient in forecasting production of shale gas. Moreover, the simulator is also able to non-uniform fracture width as an input.
9. Larger the size of sphere in the simulator depicts more amount of gas adsorbed or stored in the sphere. Also, the same size of sphere can have different quantity of gas adsorbed if the gas present is of different liquid like densities.
10. We also proposed an analytical fracture model for a rectangular shaped fracture. The inflow of fluid from the formation as well as the flow in the fracture is considered to be linear as per Darcy's law. The analytical model shows an efficient way of calculating pressures and flow rate at any point in the fracture depending on the well pressure.
11. The pressure obtained analytically in the fracture has been compared with the numerical solution for a given well pressure. The result shows a perfect match between the two models. This also implies the applicability, stability and efficiency of our numerical model.

6.2 Future Work

1. We will keep tracking the latest study on the shale gas reservoir characterizations and simulation and continue improving the simulator according to the latest study. We also hope to collaborate with academy organizations or industry to collect more field data for model application.
2. We will continue updating model for two phase flow of gas and water in three dimensional reservoir with PVT data.
3. Since the unconventional reservoirs have low matrix permeability, the flow will be highly turbulent. Thus, we wish to incorporate non-linear flow mechanisms

such as non-darcy flow, klinkerberg effect and geomechanic effect into the model.

4. For now the diffusion of gas in the sphere has been neglected. It would be interesting to study the difference it can cause to the results.
5. We also wish to incorporate multiple fractures and complex fracture network into the model to make production of shale gas more efficient.

NOMENCLATURE

μ_g	Viscosity of gas, cP
A2	Ødb/dp
A_f	Cross section area of fracture, ft2
$a_{i,k}$	Coefficient of pressure in simulation equation
B_g	Gas formation volume factor, rcf/scf
b_g	Inverse of gas formation volume factor, scf/rcf
$b_{i,k}$	Coefficient of pressure in simulation equation
b_w	Inverse of water formation volume factor, scf/rcf
C	Constant for Darcy's velocity
$c_{i,k}$	Coefficient of pressure in simulation equation
$C_{i,m}$	Concentration of gas within matrix
D_a	Diffusion Constant
$D_{e,m}$	Effective Diffusion coefficent of the matrix
$d_{i,k}$	Coefficient of pressure in simulation equation
$e_{i,k}$	Coefficient of pressure in simulation equation
$f_{i,k}$	Coefficient of pressure in simulation equation
H	Perforation height, ft
K_f	Fracture permeability, mD
K_m	Matrix permeability, mD
K_{rg}	Relative permeability of gas
K_{rw}	Relative permeability of water
K_x	Permeability in x-direction, mD
K_z	Permeability in z-direction, mD
L	Linear extent of the reservoir, ft
P	Reservoir gas pressure, psi
P(Z)	Pressure at point Z along the fracture, psi
P_{bhp}	Bottom-hole pressure, psi
P_{cgw}	Capillary pressure between gas and water
$P_{i,k}$	Pressure in cell (I,k), psi

P_L	Langmuir's pressure, the pressure at which 50% of the gas is desorbed, psi
P_w	Well pressure, psi
q_g	Source/sink term per volume basis in differential equation
Q_g	Gas flow rate, scf/sec
$q'g$	Source/sink term in discretized equation
R	Radius of sphere, ft
r_e	Drainage radius, ft
r_w	Well radius, ft
S_g	Saturation of gas
S_w	Saturation of water
TOC	Total Organic Carbon
u_g	Darcy's velocity of gas, ft/sec
V_b	Bulk volume, ft3
V_c	Volume of cube, ft3
V_{des}	Adsorbed volume, scf
V_E	Gas content or Langmuir's volume in scf/ton (standard volume adsorbed per unit rock mass)
V_L	Maximum amount of adsorbed gas, function of the organic richness (or TOC), scf/ton
V_p	P- wave velocity, m/sec
V_s	S-wave velocity, m/sec
V_S	Volume of sphere, ft3
WC	Well constant
Wc	Well constant per volume basis
Z_0	Total fracture length, ft
ΔV	Volume of cell, ft3
ΔX	Block length in x-direction
ΔY	Block length in y-direction
ΔZ	Block length in z-direction

Greek symbols	***Description***
μ_g	Viscosity of gas, cP
$\emptyset_m$	Matrix porosity, fraction
ρ_g	Density of gas, lbm/ft3
ρ_R	Density of shale rock, lbm/ft3
$\dot{\varphi}_{des}$	Gas desorption rate, scf/sec
$\dot{m}_{des}$	Mass desorption rate, kg/sec
ρ_{ntp}	Density at normal temperature, pressure condition, lbm/ft3

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APPENDIX A

Below mentioned is the full code written in FORTRAN compiler for FSGP simulator. The code developed by Prof. Jann Rune Ursin & Svein M. Skjaeveland for the course Reservoir Simultion, 2001 for single phase flow of oil in 1D reservoir has been used as reference for FSGP simulator.

However, to run FSGP simulator, one would require to link the FORTRAN compiler to NAG library.

File name: FSGP_Simulator.FOR

```
C    *****************************************************************
C    *           FORTRAN CODE FOR SHALE GAS PRODUCTION
C                           (FSGP)
C                       FOR 2D RESERVOIR
C                AT CONSTANT BOTTOM HOLE PRESSURE
C    *               ---------------------
C                 FOR MASTER THESIS PROJECT
C       MODELLING OF GAS PRODUCTION FROM TIGHT SHALE FORMATIONS
C                    - AN INNOVATIVE APPROACH
C    *
C    * BY DHRUVIT BERAWALA
C    *
C    * DATE      : JUNE 2015
C    *
C    ****************************************************************
C
C    * All real variables are defined using DOUBLE PRECISION
C
C     IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DOUBLE PRECISION KX,NT,NI,NP,NPC,
     +PHI,PORIG,BORIG,VISORG,DBDP,DELT1,DELT,TIMEINC,
     +DEX,DEY,DEZ,EPS,PI,VOL,VOLPHI,CKBAK,OGIP,FGIP,
     +CTIM,PTEST,
     +A,C,D,AL,S,COMP,PG,
     +POLD,OXPLUS,OXMIN,A9,A2,
     +QG,BGIJ,X,CKZ,
     +DELMAX,DELMIN,DPMAX,DTMULT,DPMX,DPP,DELP,
     +OMEGA,E,F,VOLDES,
     +CKX,KF,OZMIN,OZPLUS,
     +VL,PL,DPDT,RHOR,ADGAS,ADGASTOT,
     +BHP,WC,RW,DR,PCONST,H,
     +RHOG,RADSPH,VOLSPH,CRITDESPR,
     +FRACX,CUBESIZE,
     +TIME,TIMEYRS,PERMCONST,TOTDES
C
      INTEGER STMAX,
     +L,MX,NX,ISOL,IPE,ISKIP,IWRITE,IFLAG,LCYSW,
     +IM,KCY,MXP1,II,IWC,ICRN,G,INJCONST,J
```

```
C
C     CHARACTER PFILE*6
C
C    * Present dimensioning allows the simulation of a 20 block
C    * linear system.
C
      DIMENSION QG(20,20),BGIJ(20,20),X(20,20),PTEST(20,20),
     +         VOL(20,20),VOLPHI(20,20),PHI(20,20),KX(20,20),
     +    G(20,20),VOLDES(20,20),INJCONST(20,20),VOLSPH(20,20),
     +         ADGAS(20,20)
C
C   * Common storage area is used between this, the main program
C   * and the subroutines.
C
          COMMON /BLK1/ A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
     +COMP(20,20),PG(20,20),E(20,20),F(20,20)
          COMMON /BLK2/ POLD(20,20),OXPLUS(20,20),OXMIN(20,20),A9(20,20),
     +CKX(20,20),DEX(20,20),A2(20,20),DEZ(20,20),OZMIN(20,20),
     +OZPLUS(20,20)
C
C    * Open files for READING and WRITING:
C    * Simnagdata.dat is your SOURCE file,
C    * Simnagout.dat is your OUTPUT file.
C
      OPEN (5,FILE='FSGP_data.dat')
      OPEN (6,FILE='FSGP_output.dat')
      OPEN (7,FILE='FSGP_plotdata.dat')
C
C    * Read form source file.
C
      WRITE (6,3000)
      READ  (5,*) MX,NX,STMAX,IWC,IPE,ISKIP,IWRITE,IFLAG
      READ  (5,*) DEY,KF,RW,BHP,H  ! KF = Fracture Permeability
      READ  (5,*) PORIG,BORIG,VISORG,DBDP
      READ  (5,*) DELT1,EPS,OMEGA
      READ  (5,*) DELMIN,DELMAX,DPMAX,DTMULT
      READ  (5,*) VL,PL,RHOR,CRITDESPR  ! Langmuir's Parameter
      READ  (5,*) RHOG,RADSPH   ! Gas density and radius of sphere
      READ  (5,*) FRACX,CUBESIZE
C
C   Source term definition of the blocks
       QG(1:NX,1:MX) = 0
C
C   Matrix permeability in X-direction
       DO 656 I = 1,NX
          READ (5,*) (KX(I,K), K = 1,MX)
  656   CONTINUE
C
C   Block length in x-direction
       DEX(1:NX,1) = FRACX       ! DEFINITION OF FRACTURE WIDTH
C
```

```
      DO 655 I = 1,NX
       READ (5,*) (DEX(I,K), K = 2,MX) ! WIDTH OF MAIN MATRIX CELLS
  655   CONTINUE
C
C   Block length in z-direction
                   DEZ(1:NX,2:MX) = DEX(1:NX,2:MX)
C            ! BLOCK LENGTH = BLOCK HEIGHT SINCE ITS A CUBE
        DEZ(1:NX,1) = DEX(1:NX,2)
C
C   Defining porosity in each block
      DO 658 I = 1,NX
           READ (5,*) (PHI(I,K), K = 1,MX)
C  ! POROSITY OF EACH CELL
  658   CONTINUE
C
C     * Write to output file.
C
     WRITE (6,3010) MX,NX,(NX*MX),STMAX,IWC,IPE,ISKIP,IWRITE,IFLAG
     WRITE (6,3020)PORIG,BORIG,VISORG,DBDP,DELT1,EPS,CUBESIZE,FRACX
     WRITE (6,3021) DELMAX,DELMIN,DPMAX,DTMULT,OMEGA
     WRITE (6,3022) VL,PL,RHOR,RHOG,CRITDESPR,RADSPH
C
      DO 972 I = 1,NX
       WRITE (6,3035) (I,K,DEX(I,K), K = 1,MX)
             !Print block length in X-direction
  972    CONTINUE
C
      WRITE (6,3080)
      DO 657 I = 1,NX
         WRITE (6,3038) (I,K,DEZ(I,K), K = 1,MX)
             !Print block length in Z-direction
 657    CONTINUE
C
      WRITE (6,3080)
      DO 971 I = 1,NX
         WRITE (6,3036) (I,K,PHI(I,K), K = 1,MX)   !Print Porosity
 971    CONTINUE
C
      WRITE (6,3080)
      DO 970 I = 1,NX
        WRITE (6,3037) (I,K,KX(I,K), K = 1,MX)
            ! Print matrix permeability
 970    CONTINUE
      WRITE (6,3080)
C
C     * Define constants.
C
      PI  =3.1415926D0
      PERMCONST = 1.06235D-14
      CKBAK =  0.00632827/VISORG       ! constant
      CKZ = 0.00632827*KF/DEZ(NX,1)/VISORG/DEZ(NX,1)
```

```
  ! constant for flow in      fracture
C
C     * Initializing variables.
C
      OXPLUS(1:NX,MX) = 0.
      OXMIN(1:NX,1) = 0.
      OZPLUS(1,1) = 0.
      OZMIN(NX,1) = 0.
      OZMIN(1:NX,2:MX) = 0.
      OZPLUS(1:NX,2:MX) = 0.
      OXMIN(NX,2:MX)=0.
      OXPLUS(NX,2:MX)=0.
      ADGASTOT = 0.
      MXP1 = MX + 1
      TIMEINC = 0.
      NI = 0.
      NP = 0.
      CTIM = 0.
      KCY = 0
      OGIP = 0.0
      DPMX = 0.0
      DELT = DELMIN
      TIME = 0.
      G(1:NX,1:MX)= 0
      INJCONST(1:NX,1:MX)= 0
      VOLSPH(1:NX,2:MX) = 4*PI*(RADSPH**3)/3   ! Volume of Sphere in each cell
      VOLSPH(1:NX,1) = 0.
      FGIP = 0.0
C
      IM = 1
      DO 989 I = 1,NX
        DO 988 K = 1,MX
         IF(K .GT. 1) IM = K-1
         CKX(I,K) = 2*CKBAK/(DEX(I,K)/KX(I,K) + DEX(I,IM)/KX(I,IM))
     +            /DEX(I,K)
         A2(I,K) = PHI(I,K)*DBDP
         VOL(I,K) = (DEX(I,K)*DEY*DEZ(I,K)) - VOLSPH(I,K)
  ! Volume in block where free gas is stored(ft3)
         VOLPHI(I,K) = VOL(I,K)*PHI(I,K)       ! Pore volume in block
         FGIP = FGIP + (VOLPHI(I,K)*BORIG)
  988    CONTINUE
  989   CONTINUE
C
c       Amount of Gas adsorbed in a block
       ADGAS(1:NX,1) = 0.
       ADGAS(NX,2:MX) = 0.
       DO 650 I = 1,NX-1
        DO 651 K = 2,MX
         ADGAS(I,K) = RHOG*(1-PHI(I,K))*VOLSPH(I,K)*VL*PORIG/(PORIG+PL)
         ADGASTOT = ADGASTOT + ADGAS(I,K)*BORIG
  651   CONTINUE
```

```
 650   CONTINUE
C
C      Drainage Radius = DR
     DR = sqrt(DEZ(NX,1)*DEY/PI)
C
C      Well constant = WC
     IF (IWC.EQ.1) THEN
      WC = 2*PERMCONST*PI*KF*H/log10(DR/RW)     ! Well constant definition
     ELSEIF (IWC.EQ.2)THEN
      WC = PERMCONST*KF*(DEX(3,1)*DEY)/(DEZ(3,1)/2)
 ! Alternate method to define well constant
     ENDIF
     PCONST= 6.89475E06*WC*BORIG/VISORG/VOL(NX,1)      ! Pressure constant
C    * Reservoir boundary conditions.
C
C    * Define center of position in cells (pressure points).
C
     X(1:NX,1) = DEX(1:NX,1)/2.
     DO 32 I = 1,NX
       DO 987 K = 2,MX
        IM = K-1
 987   X(I,K) = (DEX(I,K-1) + DEX(I,K))/2 + X(I,IM) ! Center position in cells
  32   CONTINUE
      DO 969 I = 1,NX
        WRITE (6,3040) (I,K,X(I,K), K = 1,MX)  !Print center position in cells
 969    CONTINUE
     WRITE (6,3080)
C
C    * Initializing rates and pressures.
C
     DO 10 I = 1,NX
      DO 986 K = 1,MX
        QG(I,K) = QG(I,K)/VOL(I,K)        ! Redefinition of injection rate.
        A9(I,K) = QG(I,K)              ! Source/sink in equation.
        POLD(I,K) = PORIG            ! Original Gas pressure.
        PG(I,K) = PORIG
C         OGIP = OGIP + (VOLPHI(I,K)+ADGAS(I,K))*BORIG
           ! Original Gas in Place (Free gas + Adsorbed gas).
 986  CONTINUE
 10   CONTINUE

C     * Define original GIP.
      OGIP = FGIP + ADGASTOT
C
      DO 967 I = 1,NX
        WRITE (6,3050) (I,K,PG(I,K), K = 1,MX)
 967    CONTINUE
     WRITE (6,3080)
     WRITE (6,3090) ADGASTOT
 3090 FORMAT(' Adsorbed Gas in place; ADGASTOT (scf) ........',D12.4/)
     WRITE (6,3100) FGIP
```

```
 3100 FORMAT(' Free Gas in place; GIP (scf) ................',D12.4/)
     WRITE (6,3110) OGIP
 3110 FORMAT(' Total Original Gas in place; OGIP (scf) ......',D12.4/)
C
C    * Start time step loop.
C
     DO 6070 L = 1,STMAX        ! Main loop.

          POLD(1:NX,1:MX)=PG(1:NX,1:MX)
C
     LCYSW=0
C
C    * Time step calculation.
C
     DELT = DELT*DTMULT
     DELP = DPMX*DTMULT
     IF( DELP .GT. DPMAX ) THEN
        DELT = DELT*0.8*DPMAX/DELP
        ENDIF
     IF( DELT .LT. DELMIN) DELT = DELMIN
     IF( DELT .GT. DELMAX) DELT = DELMAX
C
     TIMEINC = DELT             ! DELT increases with time.
     WRITE (6,3070)
C
C
C    * Start iteration procedure.
C
 7744 CONTINUE
     KCY = KCY + 1              ! No. of iterations done.
     DO 30 I = 1,NX
       DO 984 K = 1,MX
        PTEST(I,K) = PG(I,K)          ! Pressure before iteration
        PG(I,K) = (PG(I,K)+POLD(I,K))/2.
  984    CONTINUE
  30   CONTINUE
C
C
     CALL FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX) ! Volume factors.
     CALL MATRIXCOEFF(MX,BGIJ,DELT,ICRN,VL,PL,G,RHOR,NX,CKZ,
    +BHP,PCONST,INJCONST,CRITDESPR)     ! Matrix coefficients.

     CALL MATRIX(NX,MX)           ! Direct solution.
C
C    * Check on pressure change in all blocks.
C
     DPMX = DABS( PG(NX,1)-POLD(NX,1) )
     II = 1
     J = NX-1
     DO 33 I = 1,J
       DO 982 K = 1,MX
```

```
        DPP = DABS( PG(I,K)-POLD(I,K) )
        IF( DPP .GT. DPMX ) THEN
          DPMX = DPP
           II = I
        ENDIF
 982    CONTINUE
  33    CONTINUE
C
C     * If pressure change is larger than DPMAX, then time
C     * step length is reduced, message written and new
C     * time step length calculated.(Stability criteria)
C
      IF( DPMX .GT. DPMAX ) THEN
        DELT = DELT*0.8*DPMAX/DPMX
        WRITE(6,3031) DPMX,II
        LCYSW = 0
        GOTO 7744
      ENDIF
 3031 FORMAT(' Time-step reduction caused by pressure change; (DPMX)
     +',f8.3,'  in block (II)  ',I3 //)
C
      LCYSW = LCYSW+1
      IF (LCYSW .GE. 4) GO TO 6071
      DO 31 I = 1,NX
        DO 981 K = 1,MX
 981    IF( DABS( PG(I,K)-PTEST(I,K)) .GT. EPS ) GO TO 7744
 31     CONTINUE
C
C     * End iteration procedure.
C
      J = NX-1
      DO 750 I = 1,J
          DO 751 K = 2,MX
            IF (VOLDES(I,K).GT.(ADGAS(I,K))) THEN
              INJCONST(I,K) = 1
            ENDIF
 751    CONTINUE
 750    CONTINUE
C
      TOTDES = 0.
      J = NX-1
      DO 889 I = 1,J
       DO 980 K = 2,MX
        IM = K - 1
        DPDT = DABS( PG(I,K) - POLD(I,K) )
        IF ((G(I,K) .EQ. 1).AND.(INJCONST(I,K).EQ.0)) THEN
         VOLDES(I,K) = VOLDES(I,K) + ((VL*PL*DPDT*RHOR*VOL(I,K))/
     + (DELT*(POLD(I,K)+PL)**2.)*TIMEINC)
C
        ENDIF
        TOTDES = TOTDES + VOLDES(I,K)
```

```
 980  CONTINUE
 889  CONTINUE
C
C     Well Flow rate calculation
      QG(NX,1) = (6.89475D06)*WC*(PG(NX,1)-BHP)*BORIG/VISORG
C
C    * Start mass balance calculation.
C
 6071 CONTINUE
C
     CTIM = CTIM + TIMEINC           ! Sum time increment.
C
     CALL FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX) ! New volume factors.
C
     NT = 0.
     J = NX-1
     DO 20 I = 1,J
       DO 979 K = 2,MX
         NT = NT + (VOLPHI(I,K)+ADGAS(I,K)) * BGIJ(I,K)
  979 CONTINUE
   20 CONTINUE
C
     NP = NP+QG(NX,1)*TIMEINC
C
     NPC = NP/(OGIP)*100.                    ! Mass balance.
C
     IF (IWRITE .NE. 1) GO TO 401           ! Printout if IWRITE not 1.
      DO 968 I = 1,NX
        WRITE (6,3050) (I,K,PG(I,K), K = 1,MX)    ! Print Pressure in each cell
  968    CONTINUE
C
      WRITE (6,3080)
      J = NX-1
      DO 652 I = 1,J
        WRITE (6,3030) (I,K,VOLDES(I,K), K = 2,MX)
            ! Print volume of Gas Desorbed from each cell.
  652    CONTINUE
C
      WRITE (6,3080)
      WRITE (6,3120) QG(NX,1)
 3120 FORMAT(' Gas Production Rate ; QG (scf/sec) ..........',F15.4/)
    ! Print Gas production rate

C       WRITE (6,3050) (I,PO(I),I=1,MX)
C       WRITE (6,3080)
      WRITE (6,3060)L,CTIM,NP,DELT,KCY,TOTDES,NT,NPC
  401 CONTINUE
C
       TIME = TIME+TIMEINC       ! Time in days
       TIMEYRS = TIME/365        ! Time in years
       CALL PLOTFILES(QG,PG,TIME,NP,VOLDES,NX) ! To generate data in plot-file.
```

```
C     * End mass balance calculation.
C
 6070  CONTINUE               ! End time step loop
C

C
C     * Close files.
C
      CLOSE(5)
      CLOSE(6)
      CLOSE(7)
C
C     * Format statements.
C
 3000 FORMAT (1HO/
    +  '     ***** TWO DIMENSIONAL, ONE PHASE SIMULATOR *****    '/
    +  '     *****     FOR PRODUCTION OF SHALE GAS      *****    '/
    +  '     *****   AT CONSTANT BOTTOM-HOLE PRESSURE   *****    '/
    +  '          -----------------------------------          '//
    +  '  BASIC ASSUMPTIONS OF THIS MODEL INCLUDE:             '//
    +  '  - HORIZONTAL FLOW OF A COMPRESSIBLE FLUID            '/
    +  '    TOWARDS VERTICAL WELL FRACTURE                     '/
    +  '  - FLOW IS FROM MATRIX TO THE FRACTURE AND THEN       '/
    +  '    TO HORIZONTAL WELL                                 '/
    +  '  - DESORPTION OF GAS IS PRESSURE DEPENDENT            '/
    +  '    WHICH IS DEFINED BY LANGMUIR'S ISOTHERM.           '/
    +  '  - COMPOSITION OF FREE AND DESORBED GAS IS SAME       '/
    +  '  - PRESSURE INDEPENDENT PVT PROPERTIES                '/
    +  '  - HOMOGENEOUS ROCK PROPERTIES, THAT IS THE SAME      '/
    +  '    POROSITY AND PERMEABILITY IN ALL BLOCKS.           '/
    +  '  - GAS IS THE ONLY PHASE PRESENT IN RESERVOIR         '/
    +  '    CROSSING OF DEW POINT LINE IS NOT PERMITTED        '//)
C
 3010 FORMAT (
    +  '  NUMBER OF BLOCKS IN X-DIRECTION, MX .......... :', I3  /
    +  '  NUMBER OF BLOCKS IN Z-DIRECTION, NX .......... :', I3  /
    +  '  TOTAL NUMBER OF BLOCKS, NX*MX ................ :', I3  /
    +  '  MAXIMUM NUMBER OF TIME STEPS, STMAX .......... :', I3  /
    +  '  WELL CONSTANT DEFINITION METHOD, IWC ......... :', I3  /
    +  '  IPE .......................................... :', I3  /
    +  '  ISKIP ........................................ :', I3  /
    +  '  WRITE OPTION, IWRITE ......................... :', I3  /
    +  '  WRITE PLOTFILES, IFLAG ........................:', I3  //)
C
 3020 FORMAT (
    +  '  ORIGINAL GAS PRESSURE, PORIG, (PSIA) ......... :', F10.1/
    +  '  ORIGINAL GAS FVF, BORIG,(STD VOL / RES VOL)... :', F10.4/
    +  '  ORIGINAL GAS VISCOSITY, VISORG, (cP).......... :', F10.4/
    +  '  GAS FVF PRESSURE DERIVATIVE, DBDP,              ',      /
    +  '  (RES VOL / STD VOL / PSI)..................... :', F10.8/
    +  '  TIME INCRAMENT, DELT1, (DAYS)................. :', F10.4/
```

```
     +  '  PRESSURE TOLERENCE, EPS ..................... :', F10.4/
     +  '  DIMENSION OF CUBE, CUBESIZE, (FT)............ :', F10.1/
     +  '  FRACTURE WIDTH, FRACX, (FT).................. :', F10.1/
     /)
C
 3021 FORMAT(
     +  '  MAXIMUM TIMESTEP LENGTH ..................... :', F10.2 /
     +  '  MINIMUM TIMESTEP LENGTH ..................... :', F10.8 /
     +  '  MAXIMUM PRESSURE CHANGE PR. TIMESTEP (PSIA) .. :', F10.4 /
     +  '  MULTIPLICATION FACTOR ....................... :', F10.2 /
     +  '  RELAXATION PARAMETER, OMEGA ................. :', F10.4 /
     /)
C
 3022 FORMAT(
     +  '  MAXIMUM AMOUNT OF ADSORBED GAS, VL, (SCF/LBM)..:', F10.2 /
     +  '  LANGMUIR'S PRESSURE, PL, (PSIA).............. :', F10.2 /
     +  '  BULK DENSITY OF SHALE ROCK ,RHOR, (LBM/FT3)... :', F10.2 /
     +  '  SHALE GAS DENSITY, RHOG, (LBM/FT3) .......... :', F10.2 /
     +  '  CRITICAL DESORPTION PRESSURE, CRITDESPR, (PSI) :', F10.2 /
     +  '  RADIUS OF SPHERE, RADSPH, (FT)............... :', F10.1 /)
C
 3035 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   BLOCK LENGTH, DEX, (FT) .', F10.3)
C
 3038 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   BLOCK HEIGHT, DEZ, (FT) .', F10.3)
C
 3036 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   POROSITY, PHI, ......... ', F10.4)
C
 3037 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   PERMEABILITY, KX, (mD).. ', F12.4)
C
 3040 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   PRESSURE POINT, X(I), FT ', F8.1)
C
 3050 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   GAS PRESSURE, PSIA ..... ', F15.6)
C
 3030 FORMAT (
     +  '  BLOCK NO. :', I3, I3, '   GAS DESORBED, SCF ...... ', F15.6)
C
 3060 FORMAT (2X,'STEPS=',I4,T22,'TIME=',D12.4,T43,'NP=',D12.4/2X,
     + 'DELT=',D12.4,T22,'CUM CYCLE=',I4,T43,'TOTDES=',D12.4/2X,
     + 'NT=',D12.4,T22,'NPC=',D12.4)
C
 3070 FORMAT (18('****')/)
C
 3080 FORMAT (/)
      STOP
      END
```

```
C1
C    ***************************************************************
C    *              END OF MAIN PROGRAM
C    ***************************************************************
C
C
C    ***************************************************************
C    *              SUBROUTINE MATRIX
C    ***************************************************************
C
      SUBROUTINE MATRIX(NX,MX)
C      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DOUBLE PRECISION A,C,D,AL,S,COMP,PG,E,F,a_full,b,ipiv
      INTEGER N,lda,ldb,nrhs,I,J,K,L
      COMMON /BLK1/ A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
     +            COMP(20,20),PG(20,20),E(20,20),F(20,20)
      DIMENSION a_full(20,20),b(20,20),ipiv(20)
C
      N = (NX*MX) - MX + 1      ! No. of equations
      lda= size(a_full,1)
      ldb = size(b,1)
      nrhs = 1
C
C       Defining coefficients of matrix A for equation AX = B
       a_full(1:N,1:N) = 0.0d0
C
       DO 501 I = 1,N
        a_full(I,I) = 1.0d0     ! Defining main diagonal as unit
  501  CONTINUE
C
       K = 2
       J = 1
       DO 502 I = 1,N-1
           a_full(I+1,I) = -A(J,K)
              ! Defining diagonal in lower part of main diagonal
           IF (K.LT.MX) THEN
              K = K+1
           ELSE
              K = 1
              J = J+1
           ENDIF
   502  CONTINUE
C
       K = 1
       J = 1
       DO 503 I = 1,N-1
           a_full(I,I+1) = -C(J,K)
               ! Defining diagonal in upper part of main diagonal
           IF (K.LT.MX) THEN
              K = K+1
           ELSE
```

```
            K = 1
            J = J+1
         ENDIF
 503  CONTINUE
C
      K = 1
      J = 2
      L = 1
      DO 504 I = MX+1,N
         a_full(I,K) = -F(J,L)
            ! Defining farthest diagonal in lower part of main diagonal
         K = K + 1
         IF (L.LT.MX) THEN
            L = L + 1
         ELSE
            L = 1
            J = J + 1
         ENDIF
 504 CONTINUE
C
      K = 1
      J = 1
      L = 1
      DO 505 I = MX+1,N
         a_full(K,I) = -E(J,L)
            ! Defining farthest diagonal in upper part of main diagonal
         K = K + 1
         IF (L.LT.MX) THEN
            L = L + 1
         ELSE
            L = 1
            J = J + 1
         ENDIF
 505 CONTINUE
C
C
C      Defining Coefficient of Matrix B
      K = 1
      J = 1
      DO 506 I = 1,N
       b(I,1) = D(J,K)
       IF (K.LT.MX) THEN
         K = K + 1
       ELSE
         K = 1
         J = J + 1
       ENDIF
 506  CONTINUE
C
C
C    Matrix is solved by linking the compiler with NAG library
```

```
      !    Factorize
      !    The NAG name equivalent of dgetrf is f07adf
      Call dgetrf(n,n,a_full,lda,ipiv,info)
c
      If (info==0) Then
!        Compute solution
!        The NAG name equivalent of dgetrs is f07aef
      Call dgetrs('NoTranspose',n,nrhs,a_full,lda,ipiv,b,ldb,info)

      Else
        Write (*,*) 'The factor U is singular'
      stop
      End If
C       After compilation, the output is stored in Matrix B
       K = 1
       J = 1
       DO 507 I = 1,N
C
        PG(J,K) = b(I,1)
C
        IF (K.LT.MX) THEN
          K = K + 1
        ELSE
          K = 1
          J = J + 1
        ENDIF
  507  CONTINUE

      RETURN
      END
C
C    ****************************************************************
C    *             END OF SUBROUTINE MATRIX
C    ****************************************************************
C
C
C    ****************************************************************
C    *                SUBROUTINE FLUIDPROP
C    ****************************************************************
C
      SUBROUTINE FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX)
C      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DOUBLE PRECISION BGIJ,PORIG,DBDP,BORIG,
     +A,C,D,AL,S,COMP,PG,E,F,OZMIN,DEZ,
     +POLD,OXPLUS,OXMIN,A9,CKX,DEX,A2,OZPLUS
      INTEGER I,MX,NX
C
      DIMENSION BGIJ(20,20)
C
      COMMON /BLK1/A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
     +COMP(20,20),PG(20,20),E(20,20),F(20,20)
```

```
      COMMON /BLK2/ POLD(20,20),OXPLUS(20,20),OXMIN(20,20),A9(20,20),
     +CKX(20,20),DEX(20,20),A2(20,20),DEZ(20,20),OZMIN(20,20),
     +OZPLUS(20,20)
C
C    * Volume factors
C
      DO 20 I = 1,NX
        DO 977 K = 1,MX
  977     BGIJ(I,K) = BORIG+(PG(I,K)-PORIG)*DBDP
   20    CONTINUE
C
      RETURN
      END
C    ****************************************************************
C    *           END OF SUBROUTINE FLUIDPROP
C    ****************************************************************
C
C
C    ****************************************************************
C    *             SUBROUTINE MATRIXCOEFF
C    ****************************************************************
      SUBROUTINE MATRIXCOEFF(MX,BGIJ,DELT,ICRN,VL,PL,G,RHOR,NX,CKZ,
     +BHP,PCONST,INJCONST,CRITDESPR)
C     IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      DOUBLE PRECISION BGIJ,DELT,A2,B,E,F,
     +A,C,D,AL,S,COMP,PG,POLD,OXMIN,OXPLUS,A9,
     +DEX,CKX,VL,PL,RHOR,DEZ,CKZ,OZMIN,OZPLUS,
     +BHP,PCONST,CRITDESPR
      INTEGER  MX,I,IM,ICRN,G,NX,INJCONST,J
C
      DIMENSION BGIJ(20,20),G(20,20),INJCONST(20,20)
C
      COMMON /BLK1/A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
     +COMP(20,20),PG(20,20),E(20,20),F(20,20)
      COMMON /BLK2/ POLD(20,20),OXPLUS(20,20),OXMIN(20,20),A9(20,20),
     +CKX(20,20),DEX(20,20),A2(20,20),DEZ(20,20),OZMIN(20,20),
     +OZPLUS(20,20)
C
C    * Matrix coefficients.
C
       J = NX-1
      DO 701 I = 1,J
        K = 1
        IP = I+1
        OZMIN(I,K) = CKZ*(BGIJ(IP,K)+BGIJ(I,K))/2.
        OZPLUS(IP,K) = OZMIN(I,K)*DEZ(I,K)/DEZ(IP,K)
  701   CONTINUE
C
      DO 39 I = 1,J
       DO 919 K = 2,MX
        IM = K-1
```

```
        OXMIN(I,K) = CKX(I,K)*(BGIJ(I,K)+BGIJ(I,IM))/2.
  919     OXPLUS(I,IM) = OXMIN(I,K)*DEX(I,K)/DEX(I,IM)
   39    CONTINUE
C
      ! Implicit formulation.
C
      J = NX-1
      DO 975 I = 1,J
        K = 1
        B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)+A2(I,K)/DELT
        A(I,K) = OXMIN(I,K)/B
        C(I,K) = OXPLUS(I,K)/B
        D(I,K) = (A2(I,K)/DELT*POLD(I,K)+A9(I,K))/B
        E(I,K) = OZMIN(I,K)/B
        F(I,K) = OZPLUS(I,K)/B
  975    CONTINUE
C
        B = OXMIN(NX,1)+OXPLUS(NX,1)+OZMIN(NX,1)+OZPLUS(NX,1)+
     +       PCONST + A2(NX,1)/DELT
        A(NX,1) = OXMIN(NX,1)/B
        C(NX,1) = OXPLUS(NX,1)/B
        D(NX,1) = (A2(NX,1)/DELT*POLD(NX,1)+PCONST*BHP)/B
        E(NX,1) = OZMIN(NX,1)/B
        F(NX,1) = OZPLUS(NX,1)/B

       DO 51 I = 1,J
        DO 974 K = 2,MX
        IF ((POLD(I,K).LT.CRITDESPR).AND.(INJCONST(I,K).EQ.0))THEN
         B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)+(A2(I,K)+
     +   ((VL*PL*RHOR)/((POLD(I,K)+PL)**2.)))/DELT
         A(I,K) = OXMIN(I,K)/B
         C(I,K) = OXPLUS(I,K)/B
         D(I,K) =((A2(I,K)+((VL*PL*RHOR)/(POLD(I,K)+PL)**2.))/DELT*
     +           POLD(I,K))/B
         E(I,K) = OZMIN(I,K)/B
         F(I,K) = OZPLUS(I,K)/B
         G(I,K) = 1
       ELSE
        B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)+A2(I,K)/DELT
        A(I,K) = OXMIN(I,K)/B
        C(I,K) = OXPLUS(I,K)/B
        D(I,K) =(A2(I,K)/DELT*POLD(I,K)+A9(I,K))/B
        E(I,K) = OZMIN(I,K)/B
        F(I,K) = OZPLUS(I,K)/B
        G(I,K) = 0
       ENDIF
  974      CONTINUE
  51     CONTINUE
C
C
C
```

```
      RETURN
      END
C   *************************************************************
C   *           END OF SUBROUTINE MATRIXCOEFF
C   *************************************************************
C
C
C
C   *************************************************************
C   *           SUBROUTINE PLOTFILES
C   *************************************************************
      SUBROUTINE PLOTFILES(QG,PG,TIME,NP,VOLDES,NX)
      DOUBLE PRECISION QG,PG,TIME,NP,VOLDES

      DIMENSION QG(20,20),PG(20,20),VOLDES(20,20)
C
C
C   * Data is written to file.
C

      WRITE(7,4000) QG(NX,1)
 4000 FORMAT(F20.6,2X,F15.4)
C
C
      RETURN
      END
C
C   *************************************************************
C   *            END SUBROUTINE PLOTFILES
C   *************************************************************
```

APPENDIX B

The data file used as an input data for the FSGP simulation is defined as shown below.

File name: FSGP_data.dat

6,3,700,1,1,1,1,0	MX,NX,STMAX,IWC,IPE,ISKIP,IWRITE,IFLAG
100,500,0.30,2550,20	DEY,KF,RW,BHP,H
3100,1.35,0.0184,6.3D-05	PORIG,BORIG,VISORG,DBDP
0.002,0.001,1.0	DELT1,EPS,OMEGA
0.001,10,100,1.5	DELMIN,DELMAX,DPMAX,DTMULT
0.09914,2695.57,168.55,2800	VL,PL,RHOR,CRITDESPR
6.42,20	RHOG,RADSPH
20,100	FRACX,CUBESIZE
6*0.001	KX(I,K)
6*0.001	KX(I,K)
6*0.001	KX(I,K)
5*100	DEX(I,K)
5*100	DEX(I,K)
5*100	DEX(I,K)
6*0.05	PHI(I,K)
6*0.05	PHI(I,K)
6*0.05	PHI(I,K)

APPENDIX C

A sample of output file generated through FSGP simulator is shown below. The output shown below is upto 40 time steps only.

File name: FSGP_output.DAT

```
      ***** TWO DIMENSIONAL, ONE PHASE SIMULATOR *****
   *****    FOR PRODUCTION OF SHALE GAS     *****
   *****   AT CONSTANT BOTTOM-HOLE PRESSURE   *****
      ------------------------------------

 BASIC ASSUMPTIONS OF THIS MODEL INCLUDE:

 - HORIZONTAL FLOW OF A COMPRESSIBLE FLUID
   TOWARDS VERTICAL WELL FRACTURE
 - FLOW IS FROM MATRIX TO THE FRACTURE AND THEN
   TO HORIZONTAL WELL
 - DESORPTION OF GAS IS PRESSURE DEPENDENT
   WHICH IS DEFINED BY LANGMUIR'S ISOTHERM.
 - COMPOSITION OF FREE AND DESORBED GAS IS SAME
 - PRESSURE INDEPENDENT PVT PROPERTIES
 - HOMOGENEOUS ROCK PROPERTIES, THAT IS THE SAME
   POROSITY AND PERMEABILITY IN ALL BLOCKS.
 - GAS IS THE ONLY PHASE PRESENT IN RESERVOIR
   CROSSING OF DEW POINT LINE IS NOT PERMITTED


 NUMBER OF BLOCKS IN X-DIRECTION, MX .......... :  6
 NUMBER OF BLOCKS IN Z-DIRECTION, NX .......... :  3
 TOTAL NUMBER OF BLOCKS, NX*MX ................ : 18
 MAXIMUM NUMBER OF TIME STEPS, STMAX .......... :700
 WELL CONSTANT DEFINITION METHOD, IWC ......... :  1
 IPE ......................................... :  1
 ISKIP ....................................... :  1
 WRITE OPTION, IWRITE ......................... :  1
 WRITE PLOTFILES, IFLAG .......................:  0


 ORIGINAL GAS PRESSURE, PORIG, (PSIA) ......... :    3100.0
 ORIGINAL GAS FVF, BORIG,(STD VOL / RES VOL)... :    1.3500
 ORIGINAL GAS VISCOSITY, VISORG, (cP).......... :    0.0184
 GAS FVF PRESSURE DERIVATIVE, DBDP,
 (RES VOL / STD VOL / PSI).................... :0.00006300
 TIME INCRAMENT, DELT1, (DAYS)................ :    0.0020
 PRESSURE TOLERENCE, EPS ...................... :    0.0010
 DIMENSION OF CUBE, CUBESIZE, (FT)............ :     100.0
 FRACTURE WIDTH, FRACX, (FT).................. :      20.0

 MAXIMUM TIMESTEP LENGTH ..................... :     10.00
```

MINIMUM TIMESTEP LENGTH .... :0.00100000
MAXIMUM PRESSURE CHANGE PR. TIMESTEP (PSIA) .. : 100.0000
MULTIPLICATION FACTOR .... : 1.50
RELAXATION PARAMETER, OMEGA .... : 1.0000

MAXIMUM AMOUNT OF ADSORBED GAS, VL, (SCF/LBM)..: 0.10
LANGMUIR'S PRESSURE, PL, (PSIA).............. : 2695.57
BULK DENSITY OF SHALE ROCK ,RHOR, (LBM/FT3)... : 168.55
SHALE GAS DENSITY, RHOG, (LBM/FT3) .... : 6.42
CRITICAL DESORPTION PRESSURE, CRITDESPR, (PSI) : 2800.00
RADIUS OF SPHERE, RADSPH, (FT)................ : 20.0

BLOCK NO. : 1 1 BLOCK LENGTH, DEX, (FT) . 20.000
BLOCK NO. : 1 2 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 1 3 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 1 4 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 1 5 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 1 6 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 2 1 BLOCK LENGTH, DEX, (FT) . 20.000
BLOCK NO. : 2 2 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 2 3 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 2 4 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 2 5 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 2 6 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 3 1 BLOCK LENGTH, DEX, (FT) . 20.000
BLOCK NO. : 3 2 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 3 3 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 3 4 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 3 5 BLOCK LENGTH, DEX, (FT) . 100.000
BLOCK NO. : 3 6 BLOCK LENGTH, DEX, (FT) . 100.000

BLOCK NO. : 1 1 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 1 2 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 1 3 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 1 4 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 1 5 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 1 6 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 1 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 2 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 3 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 4 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 5 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 2 6 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 1 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 2 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 3 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 4 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 5 BLOCK HEIGHT, DEZ, (FT) . 100.000
BLOCK NO. : 3 6 BLOCK HEIGHT, DEZ, (FT) . 100.000

BLOCK NO. : 1 1 POROSITY, PHI, ... 0.0500
BLOCK NO. : 1 2 POROSITY, PHI, ... 0.0500
BLOCK NO. : 1 3 POROSITY, PHI, ... 0.0500
BLOCK NO. : 1 4 POROSITY, PHI, ... 0.0500
BLOCK NO. : 1 5 POROSITY, PHI, ... 0.0500
BLOCK NO. : 1 6 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 1 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 2 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 3 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 4 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 5 POROSITY, PHI, ... 0.0500
BLOCK NO. : 2 6 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 1 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 2 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 3 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 4 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 5 POROSITY, PHI, ... 0.0500
BLOCK NO. : 3 6 POROSITY, PHI, ... 0.0500

BLOCK NO. : 1 1 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 1 2 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 1 3 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 1 4 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 1 5 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 1 6 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 1 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 2 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 3 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 4 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 5 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 2 6 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 1 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 2 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 3 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 4 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 5 PERMEABILITY, KX, (mD).. 0.0010
BLOCK NO. : 3 6 PERMEABILITY, KX, (mD).. 0.0010

BLOCK NO. : 1 1 PRESSURE POINT, X(I), FT 10.0
BLOCK NO. : 1 2 PRESSURE POINT, X(I), FT 70.0
BLOCK NO. : 1 3 PRESSURE POINT, X(I), FT 170.0
BLOCK NO. : 1 4 PRESSURE POINT, X(I), FT 270.0
BLOCK NO. : 1 5 PRESSURE POINT, X(I), FT 370.0
BLOCK NO. : 1 6 PRESSURE POINT, X(I), FT 470.0
BLOCK NO. : 2 1 PRESSURE POINT, X(I), FT 10.0
BLOCK NO. : 2 2 PRESSURE POINT, X(I), FT 70.0
BLOCK NO. : 2 3 PRESSURE POINT, X(I), FT 170.0
BLOCK NO. : 2 4 PRESSURE POINT, X(I), FT 270.0

BLOCK NO. : 2 5 PRESSURE POINT, X(I), FT 370.0
BLOCK NO. : 2 6 PRESSURE POINT, X(I), FT 470.0
BLOCK NO. : 3 1 PRESSURE POINT, X(I), FT 10.0
BLOCK NO. : 3 2 PRESSURE POINT, X(I), FT 70.0
BLOCK NO. : 3 3 PRESSURE POINT, X(I), FT 170.0
BLOCK NO. : 3 4 PRESSURE POINT, X(I), FT 270.0
BLOCK NO. : 3 5 PRESSURE POINT, X(I), FT 370.0
BLOCK NO. : 3 6 PRESSURE POINT, X(I), FT 470.0

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

Adsorbed Gas in place; ADGASTOT (scf) .... 0.1463D+06

Free Gas in place; GIP (scf) .... 0.1053D+07

Total Original Gas in place; OGIP (scf) ...... 0.1199D+07

****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.942324
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.999998
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.937105
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.999998
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3099.926197

BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 81.6466

STEPS= 1 TIME= 0.1500D-02 NP= 0.1225D+00
DELT= 0.1500D-02 CUM CYCLE= 2 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.1051D-04
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.845831
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.999989
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.840009
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.999989
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3099.828329
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000

BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 81.6320

STEPS= 2 TIME= 0.3750D-02 NP= 0.3061D+00
DELT= 0.2250D-02 CUM CYCLE= 4 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.2627D-04
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.700220
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.999965
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.694361
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.999964
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3099.682641
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 81.6104

STEPS= 3 TIME= 0.7125D-02 NP= 0.5816D+00
DELT= 0.3375D-02 CUM CYCLE= 6 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.4990D-04

```
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3099.481924
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.999900
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3099.476064
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.999898
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3099.464345
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........     81.5780

 STEPS=   4        TIME=  0.1219D-01    NP=  0.9946D+00
 DELT=  0.5063D-02  CUM CYCLE=   8      TOTDES=  0.0000D+00
 NT=  0.7987D+06    NPC=  0.8534D-04
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3099.154875
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.999743
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3099.149017
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.999740
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
```

```
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3099.137301
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      81.5294

STEPS=   5        TIME=  0.1978D-01    NP=  0.1614D+01
DELT=  0.7594D-02  CUM CYCLE=  10       TOTDES=  0.0000D+00
NT=  0.7987D+06    NPC=  0.1385D-03
*************************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3098.665197
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.999369
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3098.659341
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.999365
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3098.647630
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
```

```
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........      81.4567

 STEPS=   6        TIME=  0.3117D-01    NP=  0.2542D+01
 DELT=  0.1139D-01  CUM CYCLE=  12      TOTDES=  0.0000D+00
 NT=  0.7987D+06    NPC=  0.2181D-03
***********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3097.932686
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.998503
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.999999
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3097.926834
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.998496
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999999
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3097.915130
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........      81.3480
```

```
 STEPS=   7        TIME=  0.4826D-01    NP=  0.3931D+01
 DELT=  0.1709D-01  CUM CYCLE=  14      TOTDES=  0.0000D+00
 NT=  0.7987D+06    NPC=  0.3374D-03
***********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3096.838415
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.996516
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.999998
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3096.832568
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.996505
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999998
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3096.820875
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........       81.1855

 STEPS=   8        TIME=  0.7389D-01    NP=  0.6012D+01
 DELT=  0.2563D-01  CUM CYCLE=  16      TOTDES=  0.0000D+00
 NT=  0.7987D+06    NPC=  0.5159D-03
***********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3095.207056
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.992002
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.999994
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3095.201217
```

```
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.991986
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999994
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3095.189540
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      80.9433

 STEPS=   9       TIME=  0.1123D+00    NP=  0.9124D+01
 DELT=  0.3844D-01  CUM CYCLE=  18      TOTDES=  0.0000D+00
 NT=  0.7987D+06    NPC=  0.7829D-03
************************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3092.782399
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.981820
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.999978
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3092.776572
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.981795
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999978
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3092.764918
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000
```

```
BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      80.5833

STEPS=  10        TIME=  0.1700D+00    NP=  0.1377D+02
DELT=  0.5767D-01  CUM CYCLE=  20      TOTDES=  0.0000D+00
NT=  0.7987D+06    NPC=  0.1182D-02
*********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3089.195028
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.959004
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.999926
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3089.189218
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.958968
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999926
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3089.177600
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000
```

Gas Production Rate ; QG (scf/sec) 80.0507

STEPS= 11 TIME= 0.2565D+00 NP= 0.2069D+02
DELT= 0.8650D-01 CUM CYCLE= 22 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.1776D-02
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3083.923145
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.908245
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.999752
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.999999
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3083.917362
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.908190
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.999751
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999999
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3083.905795
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 79.2680

STEPS= 12 TIME= 0.3862D+00 NP= 0.3098D+02
DELT= 0.1297D+00 CUM CYCLE= 24 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.2658D-02
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3076.252945
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.796317
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.999172
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.999997

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BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3076.247199
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.796235
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.999172
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3099.999997
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3076.235709
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      78.1293

STEPS=  13        TIME=  0.5809D+00    NP=  0.4619D+02
DELT=  0.1946D+00  CUM CYCLE=  26       TOTDES=  0.0000D+00
NT=  0.7987D+06    NPC=  0.3963D-02
**********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    3065.256556
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3099.552444
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.997270
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3099.999985
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    3065.250866
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3099.552323
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.997269
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3099.999985
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    3065.239485
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
```

BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 76.4967

STEPS= 14 TIME= 0.8728D+00 NP= 0.6852D+02
DELT= 0.2919D+00 CUM CYCLE= 28 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.5879D-02
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3049.826373
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.029878
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.991122
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.999929
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.999999
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3049.820762
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.029700
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.991120
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999929
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.999999
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3049.809538
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000

BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 74.2058

STEPS= 15 TIME= 0.1311D+01 NP= 0.1010D+03
DELT= 0.4379D+00 CUM CYCLE= 30 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.8668D-02
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3028.832021
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3097.936131
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.971686
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.999661
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.999996
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3028.826518
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3097.935871
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.971682
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999661
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.999996
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3028.815513
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 71.0889

STEPS= 16 TIME= 0.1968D+01 NP= 0.1477D+03
DELT= 0.6568D+00 CUM CYCLE= 32 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.1267D-01
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3001.478215

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3095.720620
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.912075
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.998430
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.999974
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3001.472860
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3095.720246
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.912065
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.998430
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.999974
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3001.462148
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 67.0278

STEPS= 17 TIME= 0.2953D+01 NP= 0.2137D+03
DELT= 0.9853D+00 CUM CYCLE= 35 TOTDES= 0.0000D+00
NT= 0.7987D+06 NPC= 0.1834D-01
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2967.876494
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3091.428599
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.736704
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.992996
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.999829
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.999996
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2967.871328
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3091.428069
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.736683
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.992995
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.999829
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.999996
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2967.860995

```
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      62.0391

STEPS=  18        TIME=  0.4431D+01    NP=  0.3054D+03
DELT=  0.1478D+01  CUM CYCLE=  38       TOTDES=  0.0000D+00
NT=  0.7986D+06    NPC=  0.2621D-01
************************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2929.615649
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3083.587043
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3099.248685
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3099.970349
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3099.998929
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3099.999962
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2929.610716
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3083.586308
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3099.248643
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3099.970347
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3099.998929
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.999962
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2929.600850
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
```

```
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       56.3587

 STEPS=  19        TIME=  0.6648D+01    NP=  0.4304D+03
 DELT=  0.2217D+01  CUM CYCLE=  41      TOTDES=  0.0000D+00
 NT=  0.7986D+06    NPC=  0.3693D-01
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2889.771556
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    3070.272910
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3097.984277
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3099.882744
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3099.993776
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3099.999673
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2889.766895
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    3070.271923
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3097.984194
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3099.882738
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3099.993776
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.999673
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2889.757574
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       50.4432

 STEPS=  20        TIME=  0.9973D+01    NP=  0.5981D+03
 DELT=  0.3325D+01  CUM CYCLE=  44      TOTDES=  0.0000D+00
 NT=  0.7985D+06    NPC=  0.5132D-01
```

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BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2851.789369
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3049.533044
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3094.983610
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.574165
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.967116
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.997443
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2851.785014
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3049.531768
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3094.983456
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.574150
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.967115
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.997443
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2851.776305
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 44.8042

STEPS= 21 TIME= 0.1496D+02 NP= 0.8216D+03
DELT= 0.4988D+01 CUM CYCLE= 47 TOTDES= 0.0000D+00
NT= 0.7983D+06 NPC= 0.7050D-01
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2817.621717
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3020.131746
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3088.558041
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3098.603521
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.845289
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.982331
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2817.617698
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3020.130172
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3088.557770
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3098.603484

```
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3099.845285
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.982330
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2817.609661
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........      39.7315

 STEPS=  22        TIME=  0.2244D+02    NP=  0.1119D+04
 DELT=  0.7482D+01  CUM CYCLE=  50       TOTDES=  0.0000D+00
 NT=  0.7980D+06    NPC=  0.9601D-01
*************************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2789.216095
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2985.801723
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3077.771992
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3096.329721
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3099.452965
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3099.914327
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2789.212412
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2985.799906
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3077.771567
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3096.329642
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3099.452952
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.914325
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2789.205047
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
```

```
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       35.5143

 STEPS=  23        TIME=  0.3244D+02    NP=  0.1474D+04
 DELT=  0.1000D+02  CUM CYCLE=  53      TOTDES=  0.0000D+00
 NT=  0.7976D+06    NPC=  0.1265D+00
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2768.992215
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2956.330200
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3065.738497
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3093.127258
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3098.768713
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3099.767162
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2768.988800
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2956.328239
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3065.737932
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3093.127130
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3098.768688
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.767157
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2768.981970
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       32.5119
```

STEPS= 24 TIME= 0.4244D+02 NP= 0.1799D+04
DELT= 0.1000D+02 CUM CYCLE= 56 TOTDES= 0.0000D+00
NT= 0.7973D+06 NPC= 0.1544D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2753.254676
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2931.063163
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3053.126331
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3089.104682
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3097.753016
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.508431
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2753.251482
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2931.061124
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3053.125644
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3089.104501
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3097.752976
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.508421
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2753.245096
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 30.1754

STEPS= 25 TIME= 0.5244D+02 NP= 0.2101D+04
DELT= 0.1000D+02 CUM CYCLE= 59 TOTDES= 0.0000D+00
NT= 0.7970D+06 NPC= 0.1803D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2740.352635
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2909.294188
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3040.385635
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3084.394846
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3096.387021
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.107476
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2740.349630

```
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2909.292115
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3040.384843
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3084.394609
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3096.386960
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3099.107460
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2740.343619
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........       28.2600

STEPS=  26        TIME=  0.6244D+02    NP=  0.2383D+04
DELT=  0.1000D+02  CUM CYCLE=  62       TOTDES=  0.0000D+00
NT=  0.7967D+06    NPC=  0.2045D+00
***********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2729.452178
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2890.403419
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3027.808480
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3079.133212
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3094.668537
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3098.537304
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2729.449334
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2890.401339
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3027.807600
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3079.132920
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3094.668454
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3098.537280
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2729.443647
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000
```

```
 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       26.6417

 STEPS=  27        TIME=  0.7244D+02    NP=  0.2650D+04
 DELT=  0.1000D+02  CUM CYCLE=  65      TOTDES=  0.0000D+00
 NT=  0.7964D+06    NPC=  0.2274D+00
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2720.070158
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2873.881749
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3015.576795
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3073.446114
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3092.607740
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3097.775705
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2720.067456
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2873.879681
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3015.575842
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3073.445768
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3092.607633
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3097.775669
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2720.062050
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000
```

```
Gas Production Rate ; QG (scf/sec) ..........       25.2488

 STEPS=  28        TIME=  0.8244D+02    NP=  0.2902D+04
 DELT=  0.1000D+02  CUM CYCLE=  68      TOTDES=  0.0000D+00
 NT=  0.7961D+06    NPC=  0.2490D+00
************************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2711.890790
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2859.320313
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    3003.797379
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3067.445250
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3090.223282
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3096.805724
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2711.888211
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2859.318269
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    3003.796366
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3067.444852
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3090.223148
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3096.805676
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2711.883053
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       24.0345

 STEPS=  29        TIME=  0.9244D+02    NP=  0.3143D+04
 DELT=  0.1000D+02  CUM CYCLE=  71      TOTDES=  0.0000D+00
 NT=  0.7958D+06    NPC=  0.2697D+00
************************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2704.689015
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2846.392421
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2992.526578
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3061.225891
```

```
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3087.539073
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3095.615668
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2704.686546
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2846.390408
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2992.525518
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3061.225445
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3087.538912
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3095.615605
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2704.681607
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......      0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......      0.000000


Gas Production Rate ; QG (scf/sec) ..........      22.9653

STEPS=  30       TIME=  0.1024D+03    NP=  0.3372D+04
DELT=  0.1000D+02  CUM CYCLE=  74      TOTDES=  0.0000D+00
NT=  0.7956D+06    NPC=  0.2894D+00
*********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2698.295424
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2834.836406
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2981.787366
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3054.867166
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3084.581807
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3094.198779
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2698.293052
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2834.834429
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2981.786268
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3054.866676
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3084.581618
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3094.198700
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2698.288309
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
```

```
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       22.0161

STEPS=  31        TIME=  0.1124D+03    NP=  0.3593D+04
DELT=  0.1000D+02  CUM CYCLE=  77       TOTDES=  0.0000D+00
NT=  0.7953D+06    NPC=  0.3083D+00
***********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2692.578195
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2824.441469
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2971.581047
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3048.433403
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3081.379142
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3092.552728
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2692.575911
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2824.439529
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2971.579919
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3048.432872
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3081.378925
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3092.552631
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2692.571344
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
```

```
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       21.1673

 STEPS=  32        TIME=  0.1224D+03    NP=  0.3804D+04
 DELT=  0.1000D+02  CUM CYCLE=  80      TOTDES=  0.0000D+00
 NT=  0.7951D+06    NPC=  0.3264D+00
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2687.432593
 BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2815.036566
 BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2961.895212
 BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3041.975930
 BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3077.958431
 BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3090.679003
 BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2687.430388
 BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2815.034664
 BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2961.894061
 BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3041.975361
 BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3077.958186
 BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3090.678887
 BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2687.425979
 BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
 BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


 BLOCK NO. :  1  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  2   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
 BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       20.4034

 STEPS=  33        TIME=  0.1324D+03    NP=  0.4008D+04
 DELT=  0.1000D+02  CUM CYCLE=  83      TOTDES=  0.0000D+00
 NT=  0.7949D+06    NPC=  0.3439D+00
**********************************************************************

 BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2682.774187
```

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2806.481845
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2952.709127
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3035.534972
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3074.345887
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3088.582269
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2682.772054
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2806.479980
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2952.707958
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3035.534369
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3074.345614
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3088.582134
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2682.767790
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 19.7118

STEPS= 34 TIME= 0.1424D+03 NP= 0.4205D+04
DELT= 0.1000D+02 CUM CYCLE= 86 TOTDES= 0.0000D+00
NT= 0.7947D+06 NPC= 0.3609D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2678.534155
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2798.662066
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2943.997345
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3029.141476
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3070.566081
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3086.269753
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2678.532088
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2798.660240
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2943.996163
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3029.140843
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3070.565780
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3086.269596
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2678.527955

BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 19.0823

STEPS= 35 TIME= 0.1524D+03 NP= 0.4396D+04
DELT= 0.1000D+02 CUM CYCLE= 89 TOTDES= 0.0000D+00
NT= 0.7944D+06 NPC= 0.3772D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2676.885305
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2798.642480
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2936.549229
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3022.912476
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3066.652470
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3083.752044
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2676.883247
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2798.640653
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2936.548034
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3022.911814
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3066.652142
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3083.751865
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2676.879131
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 28.246708
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000

```
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      28.246594
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       18.8375

STEPS=  36        TIME=  0.1624D+03    NP=  0.4585D+04
DELT=  0.1000D+02  CUM CYCLE=  92      TOTDES=  0.5649D+02
NT=  0.7943D+06    NPC=  0.3934D+00
**********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2676.240975
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2798.620599
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2930.102637
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3016.912514
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3062.639757
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3081.042828
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2676.238920
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2798.618772
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2930.101429
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3016.911825
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3062.639402
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3081.042626
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2676.234811
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......      59.803232
BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......      59.803007
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       18.7419

STEPS=  37        TIME=  0.1724D+03    NP=  0.4772D+04
DELT=  0.1000D+02  CUM CYCLE=  94      TOTDES=  0.1196D+03
NT=  0.7941D+06    NPC=  0.4095D+00
```

****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2675.984451
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2798.596869
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2924.460041
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3011.172760
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3058.560086
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3078.158151
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2675.982398
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2798.595042
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2924.458820
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3011.172046
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3058.559706
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3078.157927
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2675.978292
BLOCK NO. : 3 2 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 3 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 4 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 5 GAS PRESSURE, PSIA 3100.000000
BLOCK NO. : 3 6 GAS PRESSURE, PSIA 3100.000000

BLOCK NO. : 1 2 GAS DESORBED, SCF 94.026167
BLOCK NO. : 1 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 1 6 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 2 GAS DESORBED, SCF 94.025836
BLOCK NO. : 2 3 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 4 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 5 GAS DESORBED, SCF 0.000000
BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

Gas Production Rate ; QG (scf/sec) 18.7038

STEPS= 38 TIME= 0.1824D+03 NP= 0.4959D+04
DELT= 0.1000D+02 CUM CYCLE= 96 TOTDES= 0.1881D+03
NT= 0.7940D+06 NPC= 0.4255D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2675.877380
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2798.571568
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2919.469916
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3005.703351
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3054.441420
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3075.115583
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2675.875327
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2798.569742
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2919.468682
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3005.702614

```
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3054.441014
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3075.115336
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2675.871223
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......     130.514048
BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......     130.513616
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........      18.6879

STEPS=  39        TIME=  0.1924D+03    NP=  0.5146D+04
DELT=  0.1000D+02  CUM CYCLE=  98      TOTDES=  0.2610D+03
NT=  0.7939D+06    NPC=  0.4416D+00
**********************************************************************

BLOCK NO. :  1  1   GAS PRESSURE, PSIA .....    2675.827664
BLOCK NO. :  1  2   GAS PRESSURE, PSIA .....    2798.544893
BLOCK NO. :  1  3   GAS PRESSURE, PSIA .....    2915.014801
BLOCK NO. :  1  4   GAS PRESSURE, PSIA .....    3000.501508
BLOCK NO. :  1  5   GAS PRESSURE, PSIA .....    3050.307107
BLOCK NO. :  1  6   GAS PRESSURE, PSIA .....    3071.933427
BLOCK NO. :  2  1   GAS PRESSURE, PSIA .....    2675.825612
BLOCK NO. :  2  2   GAS PRESSURE, PSIA .....    2798.543066
BLOCK NO. :  2  3   GAS PRESSURE, PSIA .....    2915.013555
BLOCK NO. :  2  4   GAS PRESSURE, PSIA .....    3000.500748
BLOCK NO. :  2  5   GAS PRESSURE, PSIA .....    3050.306676
BLOCK NO. :  2  6   GAS PRESSURE, PSIA .....    3071.933156
BLOCK NO. :  3  1   GAS PRESSURE, PSIA .....    2675.821508
BLOCK NO. :  3  2   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  3   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  4   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  5   GAS PRESSURE, PSIA .....    3100.000000
BLOCK NO. :  3  6   GAS PRESSURE, PSIA .....    3100.000000


BLOCK NO. :  1  2   GAS DESORBED, SCF ......     168.985253
BLOCK NO. :  1  3   GAS DESORBED, SCF ......       0.000000
```

```
BLOCK NO. :  1  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  1  6   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  2   GAS DESORBED, SCF ......     168.984725
BLOCK NO. :  2  3   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  4   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  5   GAS DESORBED, SCF ......       0.000000
BLOCK NO. :  2  6   GAS DESORBED, SCF ......       0.000000


Gas Production Rate ; QG (scf/sec) ..........       18.6805

STEPS=  40        TIME=  0.2024D+03    NP=  0.5333D+04
DELT=  0.1000D+02  CUM CYCLE= 100       TOTDES=  0.3380D+03
NT=  0.7937D+06    NPC=  0.4576D+00
**********************************************************************
```

APPENDIX D

The table below gives the definitions of the real variables and integers used in FSGP simulator coding.

List of real variables used in FSGP simulator	
Kx	Permeability in x-direction, mD
Kz	Permeability in z-direction, mD
NT	Gas volume present at a given time, scf
NP	Gas volume produced, scf
NPC	Gas volume produced, %
VISORG	Original gas viscosity, cP
DBDP	db/dp, derivative of stay in output pressure
EPS	Pressure tolerance
DEX	delta X, ft
DEY	delta Y, ft
DEZ	delta Z, ft
VOL	volume of block, ft^3
VOLPHI	pore volume of block, ft^3
CKX	constant for flow in x-direction
CKZ	constant for flow in z-direction
A2	phi*dbdp
OGIP	Original gas in place, scf
FGIP	Free gas in place, scf
NI	Gas volume injected, scf
PORIG	Orginal reservoir pressure, psi
BORIG	Orginal gas formation volume factor, scf/rcf
DELT	time step size, days
TIMEINC	time increment interval, days
CTIM	Cumulative simulated time, days
A,C,D,AL,S,COMP	Variables defined for coefficients
PG	Gas pressure at a given time step, psi

POLD	Gas pressure at previous time step, psi
QG	Gas flow rate
DELMAX	Maximum time step size
DELMIN	Minimum time step size
DPMAX	Maximum allowed pressure change at a particular time step
VOLDES	Volume of gas desorbed, scf
KF	Fracture permeability, mD
OZMIN, OZPLUS	Transmissibility in z-direction
OXMIN, OXPLUS	Transmissibility in x-direction
VL	Langmuir' volume, scf/lb
Pl	Langmuir's pressure, psi
DPDT	Pressure difference at two consecutive time steps, psi
RHOR	density of rock, lb/scf
ADGAS	Amount of gas adsorbed in a block, scf
ADGASTOT	Total amount of gas adsorbed in reservoir, scf
BHP	Bottom-hole pressure, psi
WC	Well constant
RW	Well radius, ft
DR	Drainage radius, ft
PCONST	Pressure constant
H	Perforation length, ft
RHOG	Density of gas, lb/scf
RADSPH	Radius of sphere, ft
VOLSPH	Volume of a sphere, ft^3
CRITDESPR	Critical desorption pressure, psi
FRACX	Fracture width, ft
CUBESIZE	Length of side of a cube, ft
TIME	Time in days
TIMEYRS	Time in years
PERMCONST	Constant for permeability
TOTDES	Total desorbed volume at a given time step, scf

List of integers used in FSGP simulator	
STMAX	Number of time steps
MX	Number of numerical blocks in X-direction (columns)
NX	Number of Numerical blocks in Z-direction (rows)
IPE	trigger, not in use
ISKIP	trigger, not in use
IWRITE	trigger, if equal to 1, intermediate pressures are written
INJCONST	Injection constant
I,J,K	Loop counter
L	time step counter

Table D Variables and Integers defined in FSGP simulator.