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MASTER'S THESIS

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SHALE GAS PRODUCTION - MODELLING WITH NON-LINEAR FLOW MECHANISMS

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ABSTRACT

Unconventional shale gas reservoirs are well known as a low permeable reservoirs so production study from such reservoirs is very complex. In recent years, by introducing new techniques such as of massive fracture and horizontal drilling for extraction of gas from shale formations, production has resulted in oversaturated market and strong decline in oil price.

Because of the complexity of shale gas reservoirs, conventional simulator studies are not accepted and this project includes the study of mechanism used for shale gas production simulation. The modelling of diffusion, gas desorption and non-Darcy flow were done for a model that considers a porous cube containing a sphere inside where sphere represents matter where gas is adsorbed. By pressure decline, adsorbed gas fills the pore media and then goes toward the well through the fracture. All cells considered in the model are put together where well, fracture and reservoir are connected.

Due to the low matrix permeability, gas velocity is significantly higher in comparison with the conventional reservoir, and as a result of that many non-linear mechanism, such as non-Darcy flow, adsorption, Klinkenberg effect, geomechanics shall be taken into consideration for successful reservoir characterization study. Mathematical modelling of non-linear mechanism was done, and based on the numerical model, FSGP simulator, that is developed by Dhruvit Berawala 2015., is updated for a non-linear mechanisms. Also effects of viscosity and density variation with pressure are taken into account.

As a results of introducing non-linear mechanism in reservoir characterization study, smoother results are gotten when production moves from one block to another due to the inertial effect.

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Chapter 1 -   INTRODUCTION

First chapter of this thesis refers on a basics of an unconventional resources with main aim to explain the differences between conventional and unconventional resources and give an overview of unconventional gas through its history etc.

The main difference between conventional and unconventional resources are in their extraction technique, where unconventional oil or gas is extracted by technique different than it is used for standard oil or gas well. Conventional oil and gas are trapped within geological formations that are relatively well known and they don't need some specialized technologies in order to extract them from the ground. These formations represent rocks with relatively good connected pores containing hydrocarbons. The most common representatives, of these rocks, are sandstone and carbonate. For conventional oil and gas extraction purposes, wells are drilled and oil or gas naturally starts flowing up to the surface, or it is pumped if natural energy of the reservoir is not sufficient.

Many years of oil and gas production has resulted in a decline of conventional oil and gas reserves, and by introducing new technologies, oil and gas from unconventional resources became possible to extract in an economical manner. Unconventional resources are trapped within geological formations characterized with low permeability and with little or without ability to flow through the formations and into a well. Special stimulation technique such as hydraulic fracturing is necessary to be performed in order to create fractures in the rocks and allow oil or natural gas to flow, but this is general staff that is not true for each type of unconventional resource.

As it is noted by International Energy Agency (IEA), what is grouped by conventional or unconventional resource is changing over time and depends on technology development and economies change. Nowadays, following sources are considered as unconventional:

- Shale gas
- Tight gas
- Coalbed methane
- Synthetic natural gas
- Methane clathrate

Also on Figure 1, the difference between conventional natural gas and unconventional such as shale gas, tight gas and coalbed methane, can be seen. Conventional natural gas is trapped within the sandstone reservoir and can be extracted by vertical well, while shale gas reservoir is buried deeper and for gas extraction it is necessary to drill directional well in order to establish better contact with gas rich zone. Shallower formation is coalbed methane, which actually represents coal bed enriched with methane that is adsorbed into the solid matrix of the coal. This gas is known as a sweet gas because of its lack of hydrogen sulfide. Tight gas formation is contained within the sandstone and also can be contained within limestone but rarely. Tight gas formations characterize very low matrix permeability and for gas extraction from such formations it is necessary to perform massive hydraulic fracturing process in order to make production profitable.
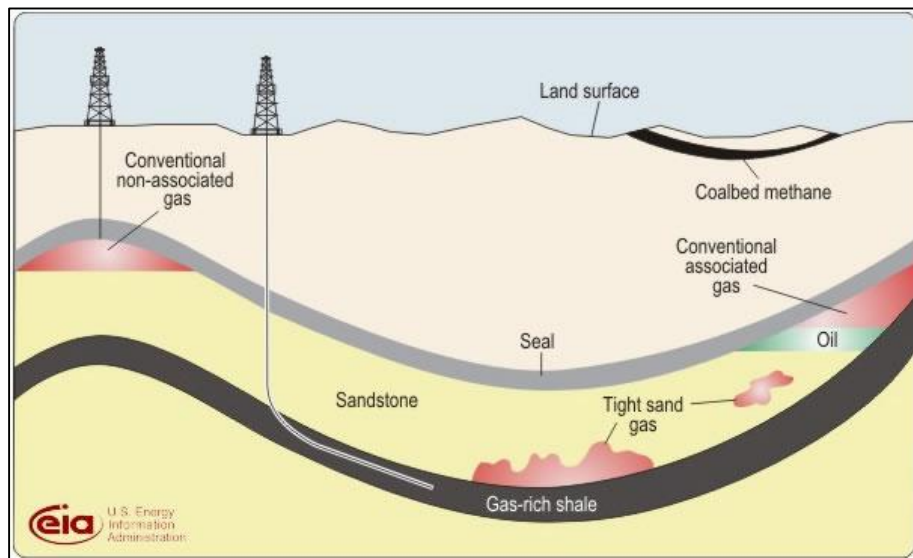
Figure 1 Conventional and Unconventional resources (source: EIA).

Shale gas reservoirs, in this thesis is of particular interest which according to me represents no.1 energy source in 21 century and it's not accidently called future of gas supply in North America. As a result of that, oil companies and governments, across the globe are investing more and more in projects, technology, development, and research in unconventional resources due to increasing scarcity of conventional resources. Also, production from unconventional resources within United States has caused glut on the market which resulted strong decline in oil price which is 46$ per barrel at the moment of writing this thesis.

Each Shale gas reservoir characterizes unique properties. Shale reservoir is well known as a low permeable reservoir so gas production in economical manner requires hydraulic fractures to provide permeability. In order to initiate gas production, it is necessary to determine number and complexity of fractures, their effective conductivity, and ability to reduce the pressure throughout the fracture. Good understanding of fractures complexity, their conductivity, permeability of matrix and recovery of gas is an essential for effective shale gas development. Almost all shale gas reservoirs have double porosity system, rock matrix porosity system and natural fractures system which in fact represent space for gas accumulation. Unstimulated conventional production from such reservoirs is impossible because of the very low matrix permeability, usually on the order of hundreds nanoDarcies (*nD*), so hydraulic fracturing process has to be performed and it represents the first key difference between conventional and shale gas reservoir. Second key difference is in adsorbed gas that exists within the shale and represent molecules that are attached to the surface of rock grains. Today, the only method to accurately determine adsorbed gas within the shale is through core sampling and its analysis. Amount of adsorbed gas, desorption time, desorption pressure are the parameters that significantly influence on how quantities of adsorbed gas can influence on total gas production (Sunjay et al.2011). Third key difference is in position of a well that shall be horizontal in order to establish better contact area which will drain shale resources with larger area that could be established with vertical well and with that make a well profitable.

1.1 Shale gas reserves

According to the U.S. Energy Information Administration (EIA), total reserves of conventional natural gas are around 6614 trillion cubic feet (Tcf) and only unconventional shale gas reserves are 7516 Tcf, which means that shale gas production will experience fullest potential in the future. Nowadays leader in shale gas production is North America, United States and Canada, which has significant level in total shale gas production around the globe. Beyond North America, shale gas is also produced in Argentina and China. When we talk about reserves, situation is a little bit different. Figure 2 represents the list of top 20 countries by unproved technically recoverable shale gas reserves (data are taken from EIA's report 2013).
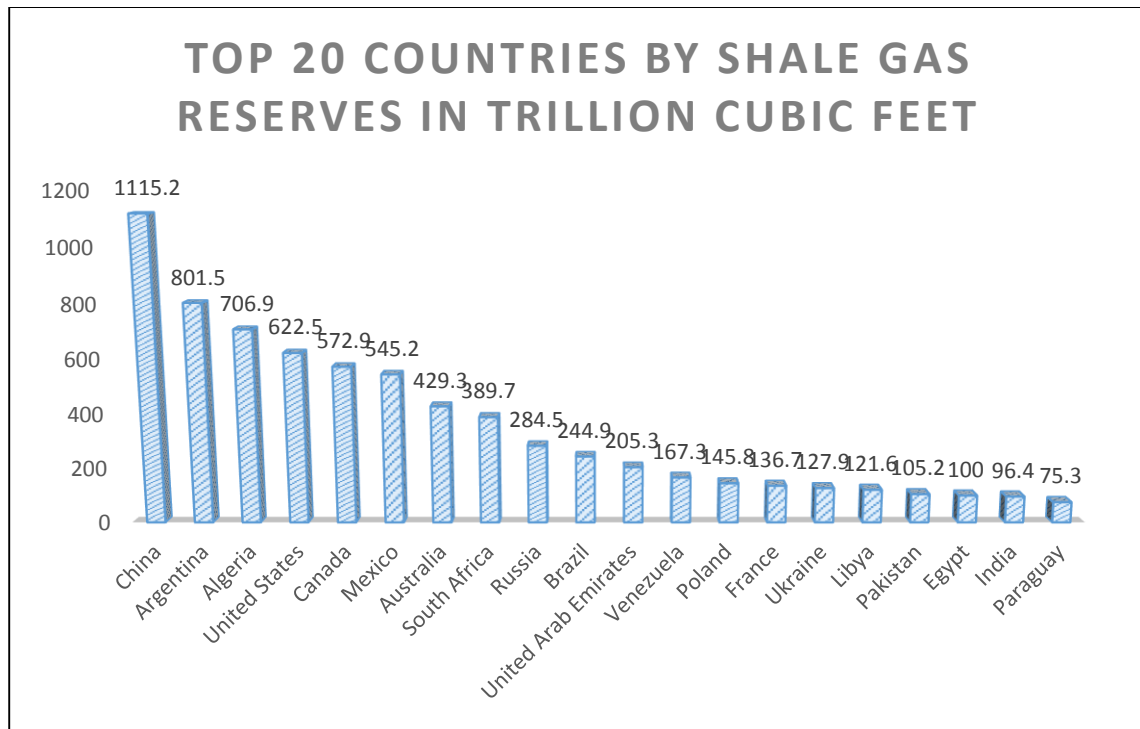
Figure 2 Top 20 countries by unproved technically recoverable shale gas reserves.

China is the leader in terms of shale gas resources, which has around 15% of total resources around the globe. Argentina is on the second place with 10.5% then Algeria, United States, and Canada with 9.3%, 8.2%, 7.6% of total resources which means that there is more than 50% of total resources in only 5 countries.

The largest basin in the world is The Sichuan Basin which accounts 40% of a total China's resources (James G. Speight).

1.1.1 United States

48 states, within the United States, have 482 trillion cubic feet of technically recoverable reserves. Marcellus Shale has largest amount of resources (141 trillion cubic feet), second is Haynesville Shale (75 trillion cubic feet) and third is Barnett Shale (44 trillion cubic feet). Shale gas activities in the United States have increase natural gas production from 388 to 4945 billion cubic feet from 2000 until 2010 which means that with shale gas expansion, production has increase over 10 times for period of 10 years. (Data taken from EIA report, 2011)

1.2 Key elements of Shale gas

In petroleum geology, organic shale formations are source rocks as well as seal rocks that trap oil and gas (Speight 2014). While in reservoir engineering they represents flow barriers.

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Another definition of shale, it represents fissile and terrigenous sedimentary rock composed of silt and clay size particles (Blatt and Tracy 2000). Fissile means that shale has ability to split into thin sheets along the bedding while terrigenous means to the origin of a sediment.

In general there are two types of shale and these are dark and light shale. Dark shale is enriched with organic matter while light shale is organic lean. Black shale formations are deposited in the water under certain conditions with little or no oxygen. Absence of oxygen preserve organic matter to decay. The presence of an organic material in sedimentary rock indicates that this rock can be a good candidate for oil and gas generation. Black shale is the source rock of a many oil and gas deposits around the world. In most of the cases, a black color in a shale indicates the presence of organic matter. Only 1% of organic material within the sedimentary rock can influence on dark gray or black color. Black shale formations get black color from tiny particles of organic material that are deposited with the mud from which the shale formed. If the mud is buried and warmer over the time, organic material is transformed into oil and/or natural gas. (James G. Speight)

1.2.1 Shale gas reservoirs

Conventional reservoirs characterizes mobile oil and gas that can flow through the permeable formation and migrate until they reach seal rocks which represent some kind of barriers (very low permeable rocks). When oil and gas reach traps, further movements is prevented and accumulations of oil and gas are made. Shale gas reservoir have different form, and once oil or gas have been generated, it is unable to migrate further due to the ultralow permeability and it remains in place where it was formed. Shale gas can be found in three different forms: free gas in pores and natural fractures, dissolved gas in oil or water, and adsorbed gas within the organic matter.

For successful shale gas reservoir development six most important parameters exist and these are: thermal maturity, reservoir thickness, total organic carbon content (TOC), adsorbed gas, free gas within the pores and natural fractures and permeability (Rick Lewis, et al. 2010). Thermal maturity is measured in core sample analysis, reservoir thickness by logs and for other four parameters it is necessary to perform more complex calculation.

1.2.2 Shale gas

Natural gas produces from shale formations typically is composed of methane with part of 60-95% which represents dry gas, but in another hand there are formations prone to produce wet gas.

Good example of a wet shale gas formations are The Antrim and New Albany formations that are located in Michigan and Illinois basins in the United States (James G. Speight).

1.3 Shale gas production technology

Introducing horizontal drilling, together with the hydraulic fracturing, has significantly impacted on economical natural gas production from a low permeability geological formations, especially shale formations. General overview of these techniques are given below.

1.3.1 Horizontal Drilling

After many years of oil and gas extraction, drilling technology has progressed to the point which allows the driller to turn the well into the certain direction and make it horizontal. One of the greatest advantage of horizontal drilling is because it provides better contact with the reservoir, as can be seen on figure 3. Vertical well exercises less contact area with the reservoir while horizontal well follows spreading of a shale layer and considering horizontal well with larger contact area with the reservoir, production rates and recovery factor can be also increased. It is good to mention that most of a horizontal wells begin at the surface as a vertical wells and then at the certain depth are being turned into desired direction.
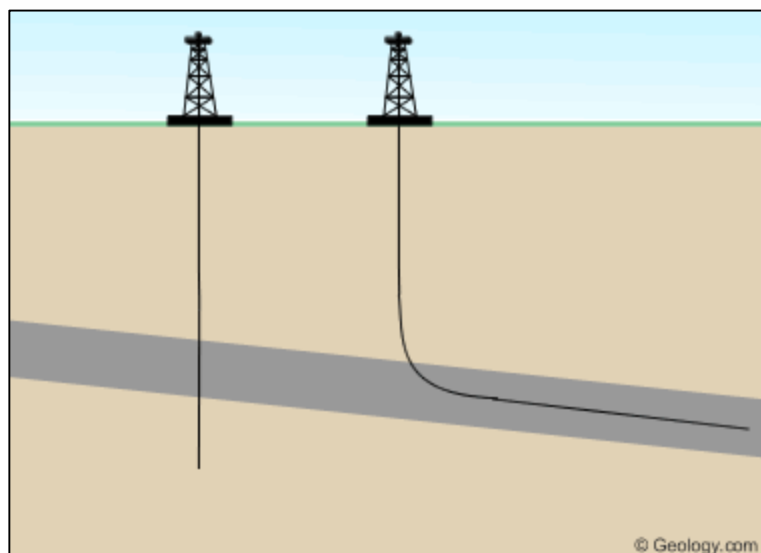
Figure 3 Vertical and Horizontal well (source: www.geology.com).

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The use of a horizontal drilling significantly influenced on environmental concerns, because the number of a drilling pads is significantly reduced as a result of a new technology which is capable to drill more than one well from the same pad, and with that the surface environmental disturbance, such as noise, traffic, dust, disturbed land area, wildlife etc., is significantly reduced. Beside the environmental concerns, horizontal drilling has significantly affect production rates.

Barnett shale had been previously drilled by vertical wells in 1980s and two decades later, in 2003, by introducing horizontal drilling, production has dramatically increased Figure 4. As of December 2011 had around 12600 wells where 9400 are horizontal wells and 3200 vertical wells which represent 35% of wells in total, while production from vertical wells contributions with less than 25%. (Z.Dong et al.2013).
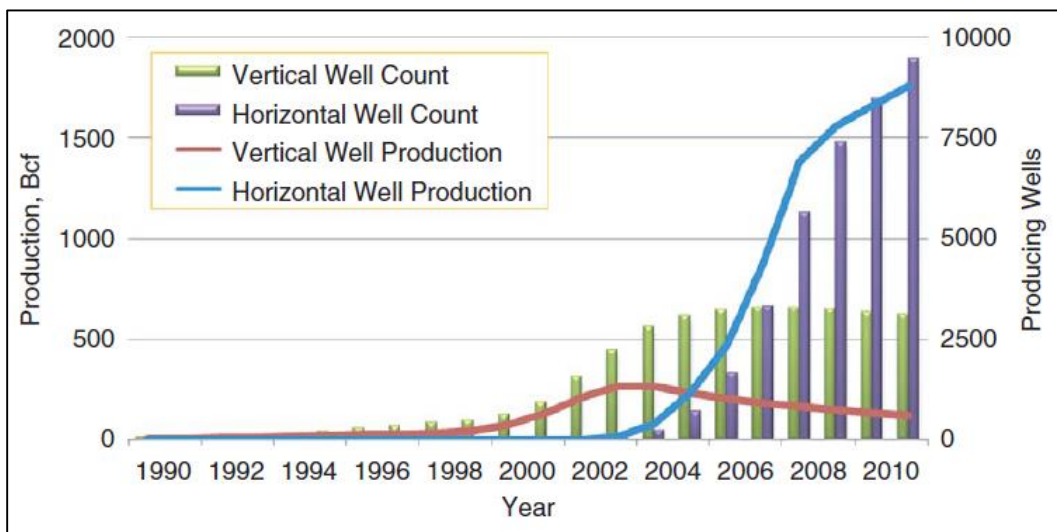
Figure 4 Vertical and Horizontal wells, comparison in terms of production (Z.Dong et al.2013).

1.3.2 Hydraulic fracturing

Hydraulic fracturing is a key technology in making gas from the shale deposits affordable, and this technique grow rapidly in 1950s, while experiments dates back to the 19th century. Hydraulic fracturing is a technology where large quantities of water (or water based fluid) together with proppants and additives are pumped down at sufficient high pressure in order to break a rock and make artificial channels (hydraulic fractures) within the rock which enable the gas flowing. Sand is a proppant that is usually used and it keeps fractures opened once the fluids have passed into the formation. Choice of a base fluid (water, carbon dioxide, nitrogen gas…) depends on many factors, such as presence of swelling clay that can cause plugging in

the presence of fresh water. Only water and proppants give more than 99% of total amount of hydraulic fracturing fluid, and rest are chemical additives.

There are generally two factors that influence on an ability of shale to fracture: the presence of a hard minerals and the internal pressure of the shale. The presence of hard material such as silica, which breaks like a glass, represents good candidate for hydraulic fracturing process because it breaks under the pressure. Clay adsorbs more pressure and bends under applied hydraulic pressure without breaking. In terms of the internal pressure, over pressured formations can be developed during natural gas generation process due to the low matrix permeability, and some amounts of gas cannot escape and being built into the place and with that increase internal rock pressure. As a result of that, hydraulic fractures can penetrate further into the formation because hydraulic fracturing pressure is below the over pressured zone with the formation. (James G. Speight)

1.4 Objective of the thesis

The purpose of this thesis is to make a model that will be used to simulate desorption of gas and diffusion processes in combination with the non-Darcy flow in shale gas reservoir. It is supposed to create a mathematical model that will explain well performance characteristics throughout production period. In order to represent the model, several ascertainments are given. First we will consider grid composed of 3 different layers where each layer contains 6 blocks where 5 out of 6 blocks, in 2 layers, are considered within the shale gas reservoir. Block within the reservoir is a cube that contains sphere which is treated as organic part of the reservoir. Free space within the sphere is treated as inorganic part composed of nano-pores that contain free gas.

Mathematical modeling of fluid behavior within the reservoir is done, and then model is run into the simulator, made in FORTRAN compiler, in order to describe non-linear behavior of fluid. The simulator is initially developed for linear flow by Berawala Dhruvit 2015., and the updated by me for non-linear flow. Moreover, production profile is tested on different input parameters.

1.5 Outline of the thesis

Chapter 2 presents the basics of the flow model as well as different factors that influence on the model and gives a theoretical overview of all non-linear mechanisms used in this project.

Theoretical overview of non-linear mechanism such as adsorption/desorption, non-Darcy flow, slippage (Klinkenberg) effect, geomechanics effect etc. will be given together with the description of simulator used for this project purposes. Theoretical overview of double and multi porous systems and pseudo pressure concept is also given but these effects are not covered in FSGP simulator.

Chapter 3 of this project is about mathematical modeling and it starts with forming the diffusivity equation that is used for this project, and it is diffusivity equation where effect of desorption and non-Darcy flow are taken into account. Desorption term in diffusivity equation is introduces through the Langmuir's isotherm, while non-Darcy flow is represented with Forchheimer equation. Such diffusivity equation is more expanded, where pseudo pressure is introduced, but it is not used for final simulation. Also, diffusivity equation discretization and forming the final simulation equation that is used in the simulator is also given in this chapter.

Chapter 4 is about results that are presented in this project. Almost all results are represented on the plots and brief comment for each of them is also given. Chapter 4 is composed of 3 parts, where first part is referred on a results from "VDP" program which is used to show how viscosity, density, and compressibility of gas vary with pressure, and also sensitivity analysis was done. Second part shows how slippage effect influence on apparent permeability and it is represented by program "Klinkenberg" that is made in FORTRAN 95 for this thesis purposes. While last, third part shows plots based on the results, made in FSGP similar for the non-Darcy fluid flow, and later plotted in Microsoft Excel.

Chapter 5 of the project is the conclusion part where results from the thesis are summed, pros and cons of the model are presented and good recommendation for future work is given.

Appendix A of this project contains 2 parts, where first is about programming code for "VDP" program that is used for calculation of viscosity, density, compressibility of gas at different pressures. While second part presents the results from the "VDP" program.

Appendix B contains programming code for "Klinkenberg" program, program used estimation of absolute permeability of core sample based on measured core plug air permeability at specific mean pressure.

Appendix C contains programming code for FSGP simulator. This program was presented in the thesis by Dhruvit Berawala, 2015. This simulator is updated by me to incorporate non-

Darcy flow mechanism for this project. Also, appendix C contains results from the FSGP simulator.

Chapter 2 - DESCRIPTION OF FLOW MODEL

In general, two differences exist between conventional and unconventional reservoirs, and these are low permeability and necessity for horizontal wells for shale gas reservoirs. Low permeability which can be measured with nano-Darcy withdraws itself other factors that are neglected in conventional reservoir characterization. These factors or in other words non-linear mechanisms are adsorption/desorption of gas within the solid matter, non-Darcy flow, slippage (Klinkenberg) effect, geomechanics effect etc. Because of a presence of these factors traditional reservoir simulators will not give proper results for unconventional reservoir study.

In this chapter, general overview of non-linear mechanism will be given and also in the first section, description of the flow model that is used in updated FSGP simulator.

2.1 Flow model

Shale gas reservoirs characterize extremely low permeability and heterogeneity in structure, hence forecasting of fluid flow and production is very difficult.

Gas in shale reservoirs can be stored in the natural micro fractures and adsorbed onto the surface of shale grains. Adsorbed gas depends on an actual reservoir pressure or more detailed when actual reservoir pressure reaches value of critical desorption pressure adsorbed gas starts filling natural micro fractures and with that maintains the reservoir pressure. Adsorbed gas that filled micro fractures later goes into the well and being produced. For this project, whole fluid path, from solid matter through micro fractures and well, is considered as flow that is not according to the Darcy's flow (flow is considered as non-Darcy) and is represented by Forchheimer term in diffusivity equation.

Model used for simulation is represented by the grid of 6x3 cells where there are generally three types of cells where each characterizes different properties and can be a cell within the reservoir, hydraulic fracture, or well. Figure 5 illustrates layer of 6x3 grid blocks.
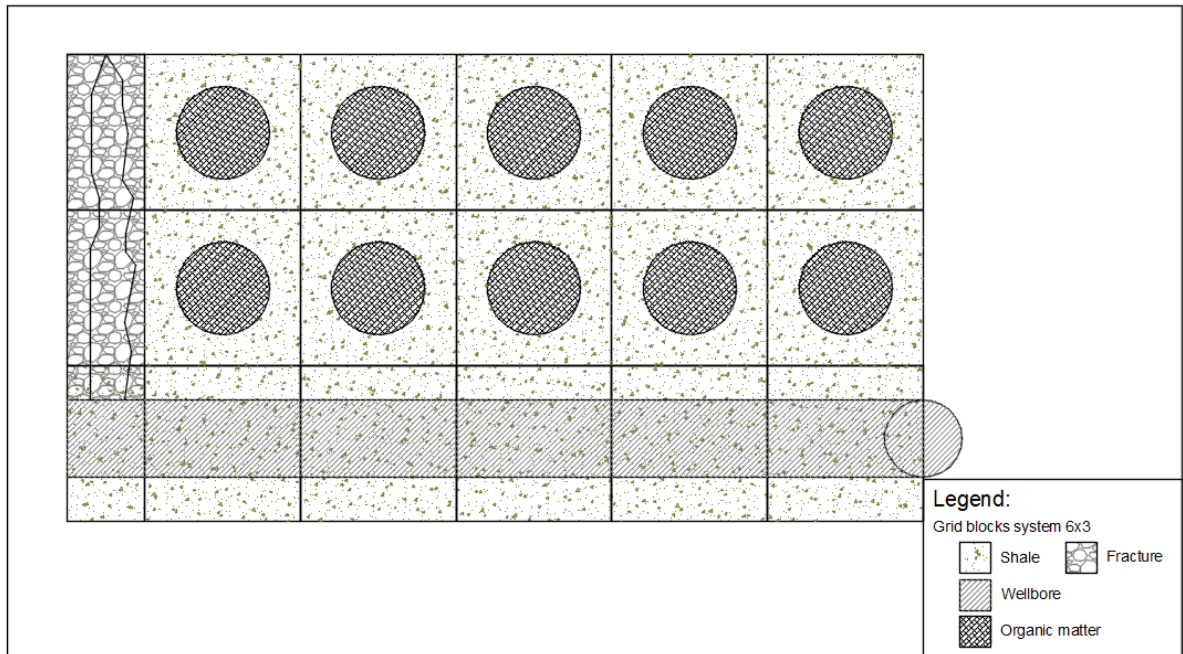
Figure 5 Layout of 6x3 grid blocks.

Cell located within the reservoir is actually a cube that contains sphere. Free gas, stored in natural micro fractures, is represented as a free space of the cube while adsorbed gas stored within organic matter is considered within the sphere. Cells within the hydraulically induced fracture and within the well do not contain sphere because they don't have the organic matter. Figure 6 illustrates cells within the shale gas reservoir, fracture and well respectively in 2D, while 3D representation of cell within the reservoir will be given in section 2.3.
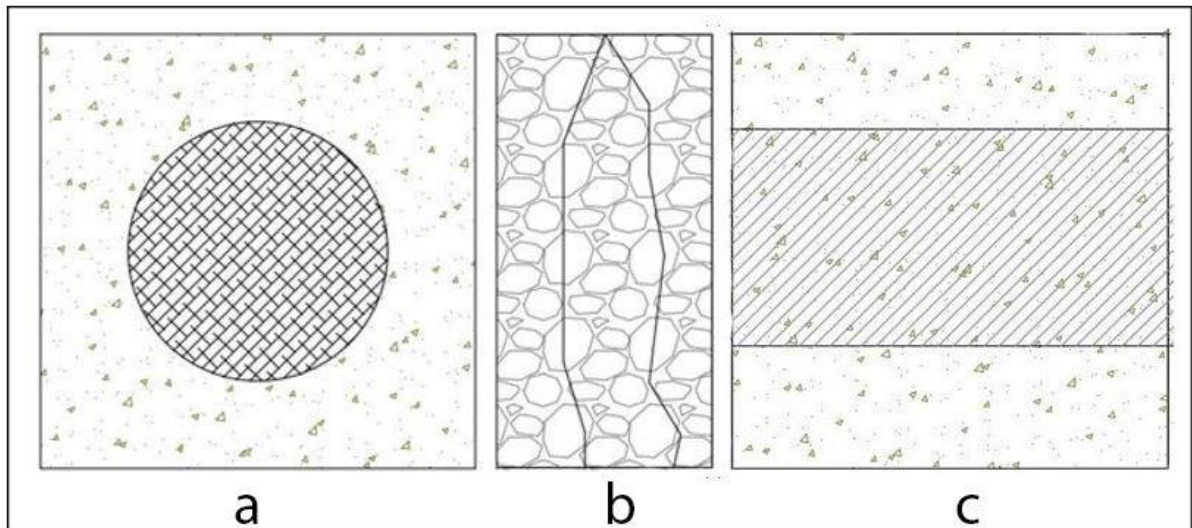
Figure 6 Cells within the reservoir (a), fracture (b), and well (c).

2.2 Adsorption/Desorption

There are two phases of natural gas storing mechanisms, free gas phase in natural fractures and adsorbed gas phase on the solid matter. Adsorbed gas is considered as higher density gas compared with surrounding free gas. During the production period reservoir pressure decreases and by reaching value of critical desorption pressure, adsorbed gas starts releasing and filling the natural fractures where free gas is stored and with that stimulate production. Amount of adsorbed gas within the organic matter should not be neglected during the reservoir study because in some reservoir can take part of up to the 80% of total amount of gas. For production simulation it is necessary to create an accurate model of gas adsorption because critical desorption pressure is some reservoirs can be very high and when pressure significantly drops the adsorbed gas, that are being released, significantly contributes in production. Amount of adsorbed gas depends on several factors and these are pore structure, mineral composition and organic matter as the most important factor because it influences on pore size and structure so that implies how large will be the surface area for adsorption.

In order to have proper data for the reservoir characterization and to assess amount of adsorbed gas it is necessary to analyze core samples. Core samples are tested on different pressures at constant temperature and based on the results, adsorption isotherm that describes the amount of adsorbed gas, are given. Langmuir's isotherm (equation 2.1) describes the relationship of pressure and gas capacity in the rock.

$$V_E = V_L \frac{P}{P + P_L} \quad (2.1)$$

Where V_E is the gas volume of adsorption at specific pressure in *scf/ton*, V_L is maximum amount of adsorbed gas; P is reservoir gas pressure in *psi*; and P_L is Langmuir's pressure is *psi*.

Value of P_L (Langmuir's pressure) is value at which 50% of gas is desorbed.

Then the gas volume of adsorption can be written in following form:

$$V_{des} = V_L V_b \rho_R \frac{P}{P + P_L} \quad (2.2)$$

Where V_b is bulk volume in *ft³* and ρ_R is density of shale at initial pressure in *lbm/ft³*.

Value of Langmuir volume V_L depends of the total organic matter (TOC) and thermal maturity of the shale, and how TOC effects on amount of the adsorbed gas is represented on figure 7 for the Marcellus Shale.
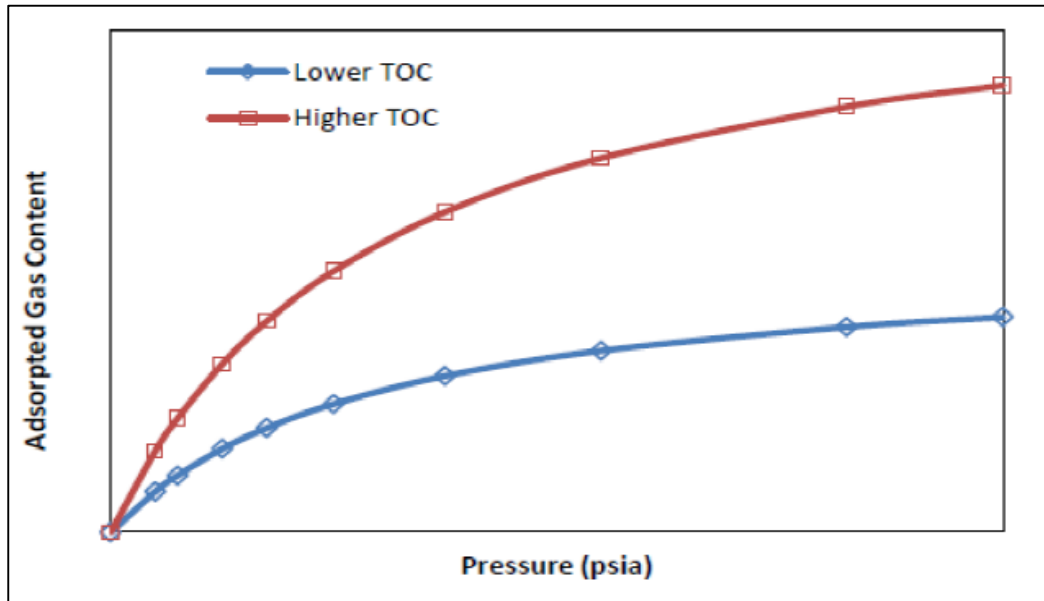
Figure 7 Effect of TOC on Adsorbed gas content for the Marcellus Shale (Berawala's project).

Differentiating the equation 2.2 in time, we can get gas rate from desorption into the matrix pore space in *scf/sec*.

$$\vartheta_{des} = -\frac{\partial V_{des}}{\partial t} = -V_L V_b \rho_R \frac{P}{(P + P_L)^2}\frac{\partial P}{\partial t} \quad (2.3)$$

Or in another form to get gas rate in kg/sec, equation 2.3 has following form:

$$m_{des} = -\frac{\partial V_{des}}{\partial t} = -V_L V_b \rho_R \rho_{ntp} \frac{P}{(P + P_L)^2}\frac{\partial P}{\partial t} \quad (2.4)$$

2.3 Gas in shale reservoirs

There are generally three forms of gas storing mechanism within the shale gas reservoir: free gas in pores and fractures, adsorbed gas within the organic matter, and amount of dissolved gas in oil and/or water.

Total amount of gas in place can be calculated as sum of these three forms. For this project's purposes only free and adsorbed gas are considered and it is represented by following equations:

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$$OGIP = free\ gas + adsorbed\ gas$$

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

Where, *Vc* is volume of cube in *ft³*; $\emptyset$ is matrix porosity; *Sg* is gas saturation; *Bgi* initial gas formation factor; *Vs* is volume of sphere in *ft³*; V_L is maximum amount of adsorbed gas (TOC dependent) in *rcf/scf*; p_i is initial reservoir pressure in *psi* and p_L is Langmuir pressure in *psi*.

Free gas is stored inside the cube, in the inorganic part, but not within the sphere, while the adsorbed gas is stored within the sphere (figure 8).
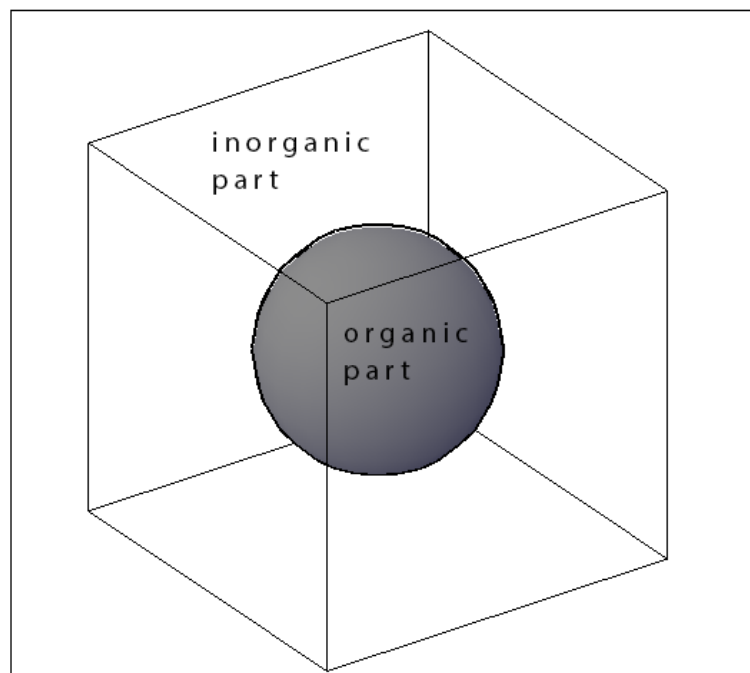
Figure 8 Cube within the reservoir presenting inorganic and organic parts.

2.4 Non-Darcy flow

Characteristic of shale gas reservoirs is nonlinear behavior of fluids (gas, gas condensate or brine) which flow through extremely low permeable rocks. Because of high velocities, Darcy's concept is not acceptable for such formations and in many cases Forchheimer equation is sufficient for application.

For this project purposes, conventional fluid flow according to the Darcy's law, where flow is laminar with zero inertia, is considered within fracture and flow that is not according Darcy's

law, which characterizes fluid flow with strong inertia effect, is considered within the reservoir and it is represented by Forchheimer equation.

Philip Forchheimer, Austrian scientist, (1901) investigated high velocities fluid flow within a porous medium where he concluded fact that with an increasing in fluid velocity, the inertial effect start dominating the flow. By introducing kinetic energy of the fluid into the Darcy equation the inertia effect, caused by high velocity, is accounted (H. Teng, T.S. Zhao). Later, it was seen that non-Darcy flow does not occur in gas reservoir only, it can also occur in fractured reservoirs and multi-permeability systems within oil reservoirs as well. As a result of non-Darcy flow behavior such reservoirs manifest non-linearity (Wang et.al. 2015).

Forchheimer's equation has following form:

$$-\frac{d^2 P}{dx^2} = \frac{\mu}{K}\frac{dv}{dx} + 2\beta\rho v\frac{dv}{dx} \quad (2.5)$$

Where μ is fluid (gas) viscosity in *cP*; K is permeability in *mD*; β is non-Darcy coefficient; ρ is density of fluid (gas) in *kg/m³*; v is fluid (gas) velocity in *m/s*.

2.5 The Klinkenberg effect (slippage effect)

Klinkenberg effect has not found significant application in conventional reservoir studies except cases when analyzing pressure responses or flow near gas production wells at very low pressure. This is due to the presence of relatively high pressure and larger pore size in conventional reservoirs. Nevertheless, Klinkenberg effect is considered as a significant in shale gas reservoirs because of nano-size pores and presence of high pressure conditions.

Kinkenberg (1941) found that there are a difference in permeability values measurements between air as the flowing fluid and a liquid as the flowing fluid. The permeability values for a core sample of an air, as the flowing fluid, are always greater than the permeability measured for a liquid as the flowing fluid. Based on Klinkenberg's laboratory experiments, he concluded that liquids have a zero velocity at the sand grain surface while gases have finite velocity at the sand grain surface (gases have slippage velocity at the sand grain surface). Gas slippage result in a higher flow rate at the certain pressure differential. Klinkenberg also found, for a given porous system, that the measured permeability decreases as the mean pressure (average pressure values of upstream and downstream flowing pressures) increases and vice versa. A good example is shown by Wang et al. (2009) which shows that gas permeability in the

Marcellus Shale increases from 19.6 µD at 1000 psi to 54 µD at 80psi, as a result of the strong slippage effect.

If a plot of the measured permeability versus inverse mean pressure ($1/p_m$), were extrapolated to the point where inverse mean pressure is equal to zero (mean pressure is infinity), this value of permeability would be approximately equal to the value of liquid permeability (figure 9). (Tarek Ahmed, 2001).
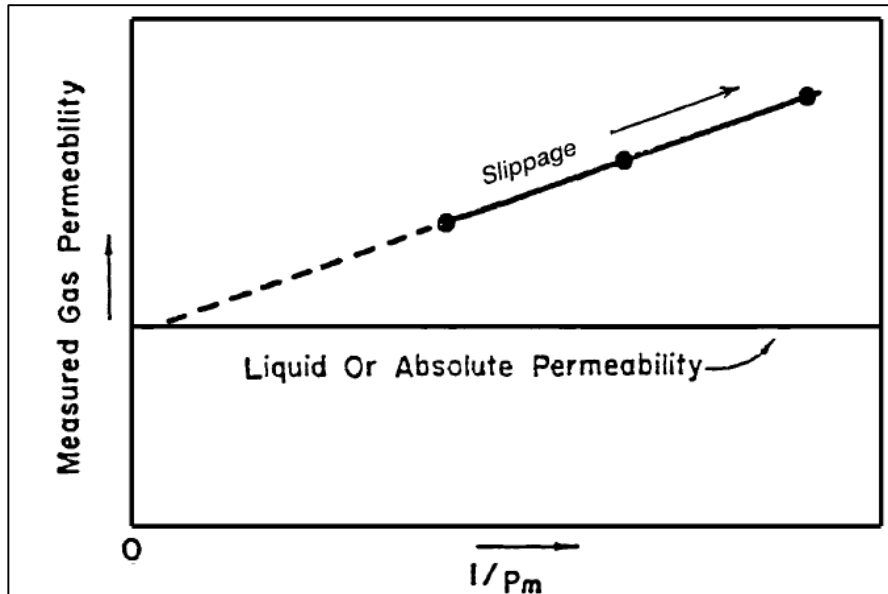
Figure 9 Klinkenberg effect in gas permeability measurements (Tarek Ahmed, 2001).

The type of gas and the core sample permeability influence on the magnitude of the Klinkenberg effect which can be seen on the figures 10 and 11. Straight line relationship has following expression:

$$k_g = k_L + c\frac{1}{p_m} \quad (2.6)$$

Where, *kg* is measured gas permeability in *mD*, p_m is mean pressure in *psi*, k_L is absolute permeability in *mD*; *c* is the slope of the line.

$$c = bk_L \quad (2.7)$$

In equation 2.7, *b* is a constant depending of the size of the pore openings and it is inversely proportional to the capillary radius.

Where *c* is expressed as the slope of the line which is a function of absolute permeability, type of gas, and average capillary radius of the rock. Combination of equations 2.6 and 2.7 gives equation 2.8 in which k_g represents gas permeability as measured at mean pressure.

$$k_g = k_L + (bk_L)\frac{1}{p_m} \quad (2.8)$$

Where, k_g is the permeability of gas, measured on average pressure p_m, in *mD*.
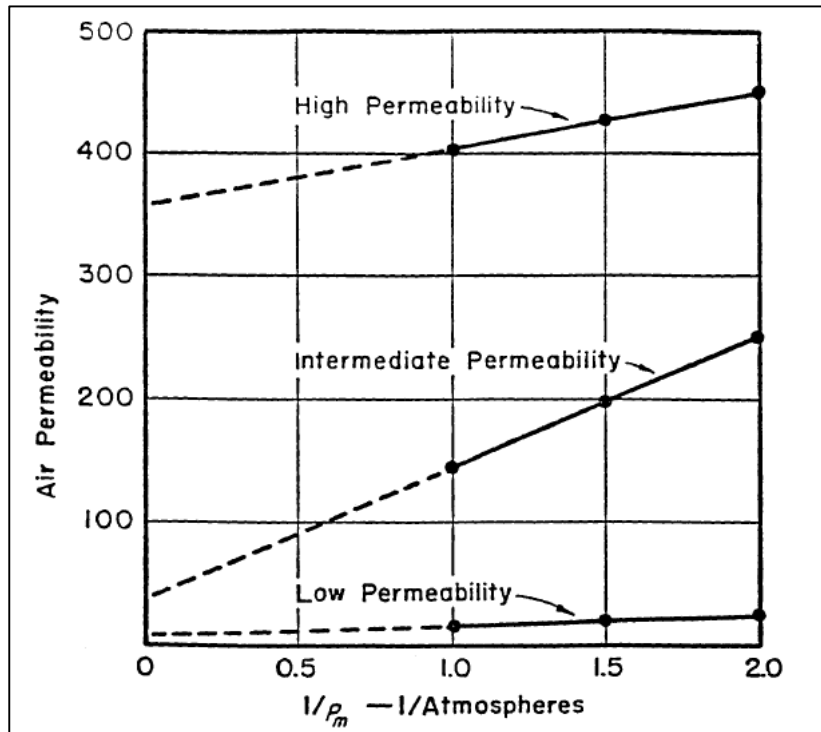
Figure 10 Effect of an air permeability on the Klinkenberg effect (Tarek Ahmed, 2001).
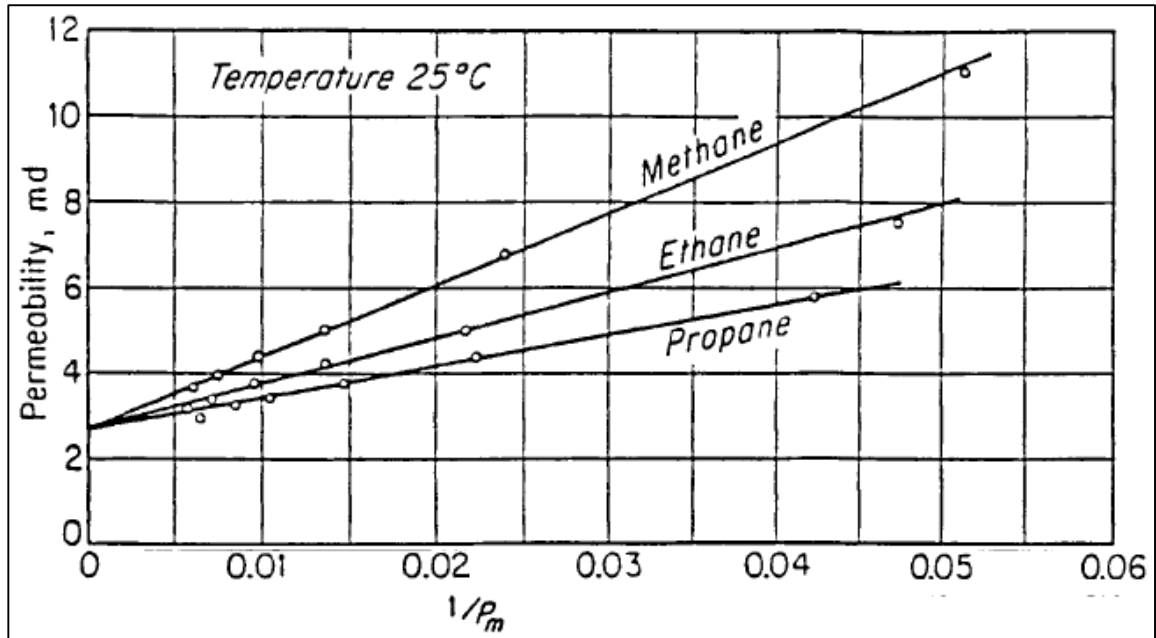
Figure 11 Effect of type of gas on Klinkenberg Effect (Tarek Ahmed, 2001).

Jones (1972). Based on an experiment made for a group of cores, where porosity, absolute permeability (liquid permeability), and air permeability were measured, Jones correlated the parameter *b* (eq. 2.9) with liquid permeability.

$$b = 6.9k_L^{-0.36} \quad (2.9)$$

The measurements of permeability were made at mean pressure just above atmospheric pressure of 1 atm. In order to determine Klinkenberg effect as well as slip phenomena it is necessary to measure gas permeability at two different pressure levels, otherwise equations 2.6 and 2.7 give relation 2.10 for calculating absolute permeability when measurement of gas permeability was done at the certain mean pressure (Tarek Ahmed, 2001).

$$6.9k_L^{0.64} + p_m k_L - p_m k_g \quad (2.10)$$

Nonlinear equation 2.10 is solved iteratively with Newton-Raphson method. The solution method can be written as:

$$k_{i+1} = k_i - \frac{f(k_i)}{f'(k_i)}$$

The iterative procedure is repeated until result converges is reached (when $f(k_i)$ approaches zero and when there is no changes in calculated k_i. Calculation was done by using FORTRAN 95 and will be presented later in the chapter 4.

2.6 Geomechanical effect

In conventional reservoir studies, geomechanical effect does not play an important role and in most cases is practically ignored, while for unconventional shale gas formations it play very important role in order to successfully optimize production from such reservoirs. Geomachanics study covers whole lifecycle of a shale reservoir, from drilling process, in terms of well stability issues, via hydraulic fracturing operation and until end of a reservoir's lifecycle.

Shale formations characterize extremely low permeability and presence of various scaled natural fractures. These natural fractures are generated as a result of tectonic activities and thermal maturity processes of hydrocarbon. Thermal maturity processes covers processes where kerogen had been transformed into bitumen and then was transformed into oil and gas (hydrocarbon volume increasing process), where amount of gas could be up to 10 times larger than original amount of kerogen.

Permeability decreases as confining pressure increases and this is significantly expressed for shale formations in comparison with carbonates or consolidated sandstones. Study (Soeder 1988 and Wang et al. 2009) shows that permeability in Marcellus Shale is very pressure dependent and with increasing in confining pressure (total stress), it significantly decreases. This effect is caused by reduction in porosity or pore volume (Wang et al. 2015).

2.6.1 Dual porosity systems

Dual porosity systems are very important issue when performing geomechanical study which includes matrix porosity system and porosity within a network of fractures. Term dual porosity model is first time mentioned 1963 by Warren and Root, and it found wide application in modeling hydraulically fractured shale gas reservoirs. Matrix system is considered as one system and hydraulically fractured system as another part. The differences between single and dual porosity systems are in their fluid flow path where fluid flows directly from a reservoir to a well for single porosity systems and from a reservoir through fractures to a well for dual porosity systems. Matrix systems have much more volume than fracture network systems and they contain both inorganic and organic matter that could also contain distinct porosities (see

2.6.2 Multi porosity systems). Fracture network system which mainly occupies smaller part of a system has high permeability and represent path for gas flow. Figure 12 illustrates how it looks like.

According to the study (Wang et al. 2015), it is necessary to perform the classic theory of elasticity, which is governed by Hook's law, for both systems (fracture network and rock matrix systems).
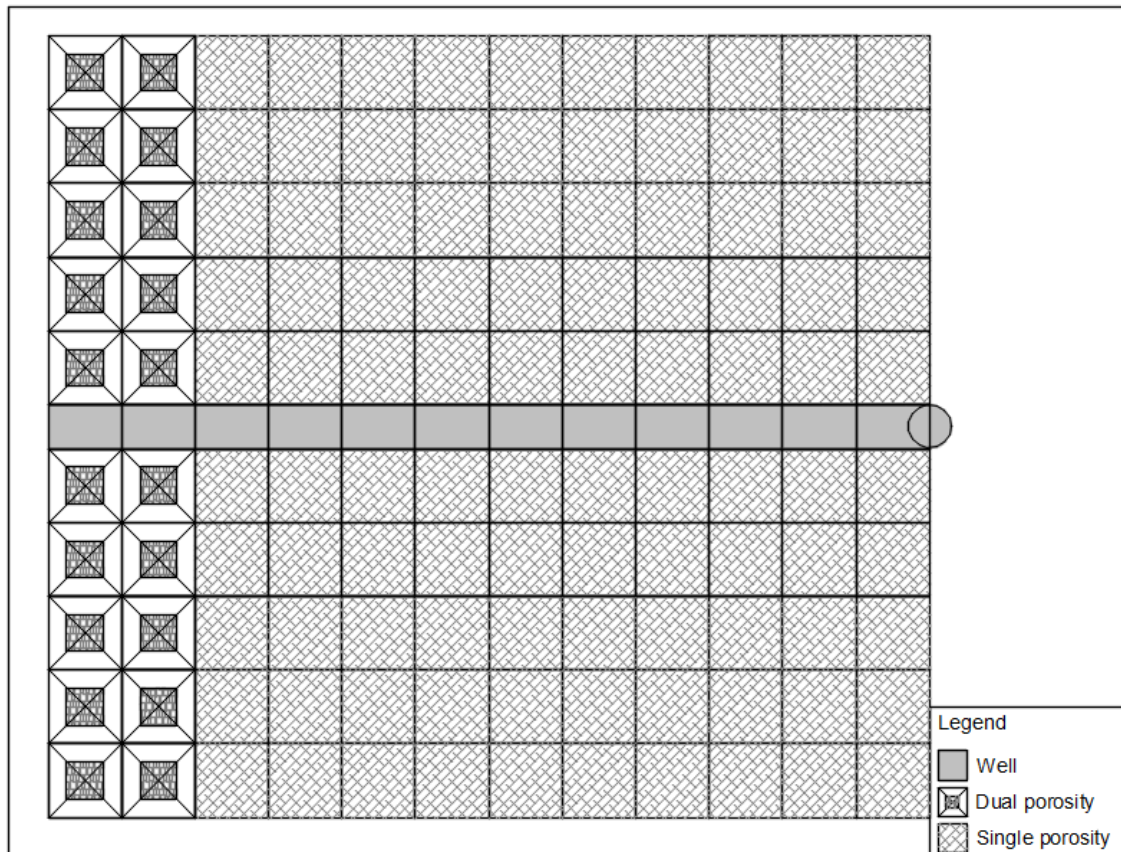
Figure 12 Dual Porosity system.

2.6.2 Multi porosity systems

Multi porosity systems (figure 13) are more complex systems where more than 2 porous systems are studied within the reservoir. Several studies were carried out for multi porous systems for shale gas reservoirs and exists a few distinctions of the systems.

According to the Dehghanpour et al. 2011, they divided matrix blocks in the dual porosity system into subsystems with nano-Darcy permeability pores and micro fractures that contain micro Darcy permeability. As a result of sensitivity analysis where micro fractures are took

into account for simulation was performed, the wellbore pressure drop rate has significantly decreased.

Another example of multi porous system is published by Yan et al. 2012. This model separates matrix into two sub-matrix inorganic and organic part and further organic part into organic with vugs and organic that contains nanopores. This model is made up of four different continua: nanopores within organic part, vugs within organic part, inorganic matrix and fractures. This system is more producible and results in faster pressure drop in comparison with dual porosity system.
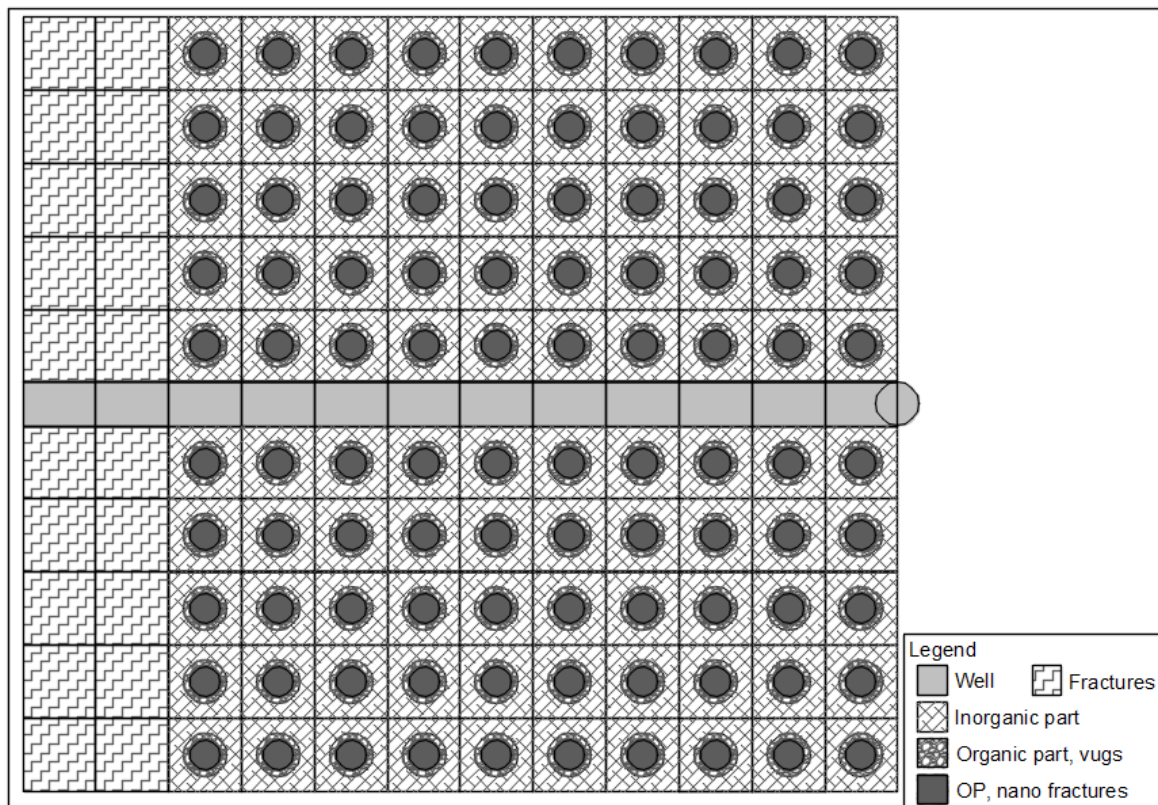
Figure 13 Multi porous system.

2.7 Viscosity

Program for calculation gas viscosity is based on Lee, Gonzales and Eakin correlation (Lee, et al. 1966). Existing work based correlation is used for calculation gas viscosity where data about temperature, pressure, density of gas at a specific temperature, and molecular weight of gas are known. Gas viscosity program (VDP program) is made in FORTRAN 95 and for program purposes following equation (2.11) is used:

$$\mu_g = 10^{-4} K exp(X\rho^Y) \quad (2.11)$$

Where, μ_g is viscosity of gas, at specific temperature and pressure, in *cP* and ρ is gas density in *kg/m³*.

And coefficients *K,X,Y* are:

$$K = \frac{(9.379 + 0.01607 M_w) T^{1.5}}{209.2 + 19.26 M_w + T}$$

Where, M_w is molecular weight of gas mixture in *lb/lbmole* and *T* is temperature in °R.

$$X = 3.448 + \frac{986.4}{T} + 0.01009 M_w$$

$$Y = 2.447 - 0.224X$$

2.8 The real gas pseudo-pressure concept

Viscosity, density and compressibility of gas vary significantly with pressure and because of that classic diffusivity equation (i.e. equation 3.11) is not sufficiently mathematically developed for describing the flow for compressible fluids within the reservoir. Variation of gas viscosity, density and compressibility with pressure can be seen on the plots in the first part of chapter 4.

In order to analyze fluid flow more accurately, it is necessary to add real density (2.12) and gas compressibility (2.13) equations into diffusivity equation.

$$\rho = \frac{pM}{zRT} \quad (2.12)$$

$$c_g = \frac{1}{p} - \frac{1}{z}\frac{dz}{dp} \quad (2.13)$$

Al-Hussainy, Crawford, and Ramey linearize such diffusivity equation where real gas potential *m(p)* was introduced and they got following equation:

$$m(p) = \int_0^p \frac{2p}{\mu z} dp \quad (2.14)$$

The real gas pseudo-pressure concept has wide application for all phases of gas well testing, analysis, and gas reservoir calculations. This concept is very useful for conventional reservoir analysis however when used directly for unconventional reservoirs, some problem may occur due to the non-linearity, non-Darcy flow, desorption, strong interaction between rock and fluid etc., and all because of the extremely low permeability.

In chapter 3, section 3.2, mathematical derivation for this model case was done.

2.9 Introduction to FSGP simulator

FSGP is the simulator that is initially developed to simulate single phase flow of gas form the linearly oriented porous cubes through the vertical fractures and finally to the well that is placed horizontally. As a source term, sphere is considered which will provide gas to the porous region after critical desorption pressure is reached. Fluid flow of gas according to the Darcy law, occurs under the pressure and viscous forces. Simulator is capable to simulate different porosity in matrix and the fracture. By using finite element method, the diffusivity equation is solved numerically. The final linear equation is solved by implicit formulation and pressure in each cell is calculated by Gauss elimination method. Implicit method is has proven to be efficient in modeling linear single phase flow in 2D reservoir, and it is capable to handling reservoir heterogeneity (Berawala 2015.).

Mathematical model used in this thesis, contains both first and second order derivatives which are solved fully implicitly and then run into the simulator. FSGP simulator, for this thesis purposes, is made to be capable to handle non-linear mechanisms such as non-Darcy flow.

In next chapter, detailed mathematical modelling has been done.

Chapter 3 - MATHEMATICAL MODELING

Third chapter of this thesis is about mathematical and numerical modeling of diffusivity equation for Non-Darcy flow within the shale reservoir. Diffusivity equation derivation has been done for a single phase linear flow for one and two dimensional cases. In order to get the final diffusivity equation, continuity equation (3.1) has been used in which Langmuir and non-Darcy terms are put together. As a Non-Darcy term, Forchheimer's equation (3.2) is used which in fact represents flow that is not according to the Darcy's model. Diffusivity equation is then more expanded for pseudo pressure term, this new equation is only mathematically derived and is not used in FSGP simulator. Diffusivity equation (3.12) is then discretize and further developed and the final simulation equation is formed.

3.1 Diffusivity equation derivation

Equation 3.1 represents continuity equation for one dimensional reservoir:

$$\rho_g \frac{dV}{dx} + v \frac{d\rho_g}{dx} = -\phi \frac{d\rho_g}{dt} \quad (3.1)$$

Equation 3.2 represents Forchheimer's term that is used for non-Darcy flow conditions:

$$-\frac{d^2P}{dx^2} = \frac{\mu}{K} \frac{dv}{dx} + 2\beta \rho v \frac{dv}{dx} \quad (3.2)$$

In order to bring equation 3.1 to be in compliance with β-models, density term is replaced by formation volume factor (b_g) in continuity equation 3.1.

$$\rho_g = \frac{\rho_{gs}}{B_g} = \frac{constant}{B_g} \quad (3.3)$$

More practical form of the equation 3.3 (for simulation purpose) is its inverse form:

$$b_g = \frac{1}{B_g} \quad (3.4)$$

Then continuity equation 3.1 has following form:

$$b_g \frac{dv}{dx} + \frac{vdb_g}{dx} = -\phi \frac{db_g}{dP_g} \frac{dP_g}{dt} \quad (3.5)$$

Further rearranging of equation 3.5 in order to bring the equation in suitable form:

$$b_g \frac{dv}{dx} + \frac{v d b_g}{d P_g} \frac{d P_g}{dx} = -\phi \frac{d b_g}{d P_g} \frac{d P_g}{dt}$$

Further,

$$b_g \frac{dv}{dx} = -\frac{v d b_g}{d P_g} \frac{d P_g}{dx} - \phi \frac{d b_g}{d P_g} \frac{d P_g}{dt}$$

Further,

$$b_g \frac{dv}{dx} = (-\phi \frac{d P_g}{dt} - \frac{v d P_g}{dx}) \frac{d b_g}{d P_g}$$

Divided equation by b_g we get:

$$\frac{dv}{dx} = -\frac{1}{b_g} \frac{d b_g}{d P_g} \left(\phi \frac{d P_g}{dt} + \frac{v d P_g}{dx} \right) \quad (3.6)$$

By introducing equation 3.6 into Forchheimer's equation 3.2 we get following equation:

$$-\frac{d^2 P}{dx^2} = \left(\frac{\mu}{K} + 2\beta b_g v \right) \left(\frac{-\phi}{b_g} \frac{d b_g}{d P_g} \frac{d P_g}{dt} - \frac{v}{b_g} \frac{d b_g}{d P_g} \frac{d P_g}{dx} \right) \quad (3.7)$$

For further simplification of equation (3.7), new term ($A2$) is introduced and then equation has following form:

$$-\frac{d^2 P}{dx^2} = (\frac{\mu}{K} + 2\beta b_g v)(\frac{-A_2}{b_g} \frac{d P_g}{dt} - \frac{v A_2}{b_g \phi} \frac{d P_g}{dx})$$

Where A2 is expressed as:

$$A2 = \phi \frac{d b_g}{d P_g} \quad (3.8)$$

Further rearranging:

$$-\frac{d^2 P}{dx^2} = \left(\frac{\mu}{K b_g} + 2\beta v \right) \left(-A_2 \frac{d P_g}{dt} - \frac{v A_2}{\phi} \frac{dP}{dx} \right) \quad (3.9)$$

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Multiplying the equation 3.9 by -1 and by introducing source/sink term q_g we get the final diffusivity equation 3.9 for one dimensional single phase linear fluid flow:

$$\frac{d^2P}{dx^2} \pm q_g = A_2 \left(\frac{\mu}{K * b_g} + 2\beta v\right)\left(\frac{dP_g}{dt} + \frac{v}{\phi}\frac{dP}{dx}\right) \quad (3.10)$$

Positive sing of q_g represents injection well while negative sing means that well is producer. Hence, we have adsorbed gas, whose amount is represent by Langmuir's isotherm within the organic matter, our case can be treated as injection well.

Replacing source/sink term with Langmuir term into the equation 3.10, we get another form of the final diffusivity equation which is only valid for pressure values at/below the critical desorption pressure (equation 3.11). For pressure values above the critical desorption pressure, equation 3.10 without source/sink term can be used.

$$\frac{d^2P}{dx^2} + V_L\rho_R \frac{P_L}{(P + P_L)^2}\frac{dP}{dt} = A_2 \left(\frac{\mu_g}{k_x b_g} + 2\beta v_g\right)\left(\frac{dP_g}{dt} + \frac{v}{\phi}\frac{dP}{dx}\right) \quad (3.11)$$

3.1.1 Two dimensional case of diffusivity equation

Equation 3.11 can also be extended for 2 dimensional case, where flow along the z axis represents a vertical flow within the fracture and flow along the x axis represents a horizontal flow within the reservoir.

Two dimensional case of the equation 3.11 has following form:

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2} + V_L\rho_R \frac{P_L}{(P + P_L)^2}\frac{dP}{dt} = A_2 \left(\frac{\mu_g}{k_x b_g} + 2\beta v_g\right)\left(\frac{dP}{dt} + \frac{v}{\phi}\left(\frac{dP}{dx} + \frac{dP}{dz}\right)\right) \quad (3.12)$$

3.1.2 Two phase case of diffusivity equation

Another extension of diffusivity equation 3.12 is for two phase flow, flow of gas and water in shale gas reservoir. Two phase diffusivity equations 3.13a and 3.13b have following form:

Diffusivity equation for gas phase:

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2} + V_L\rho_R \frac{P_L}{(P + P_L)^2}\frac{dP}{dt}$$
$$= A_2 \left(\frac{\mu_g}{k_x k_{rg} b_g S_g} + 2\beta v_g\right)\left(\frac{dP}{dt} + \frac{v_g}{\phi}\left(\frac{dP}{dx} + \frac{dP}{dz}\right)\right) \quad (3.13a)$$

Diffusivity equation for water phase:

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2} + V_L \rho_R \frac{P_L}{(P+P_L)^2} \frac{dP}{dt}$$

$$= A_2 \left(\frac{\mu_w}{k_x k_{rw} b_w S_w} + 2\beta v_w \right) \left(\frac{dP}{dt} + \frac{v_w}{\phi} \left(\frac{dP}{dx} + \frac{dP}{dz} \right) \right) \quad (3.13b)$$

Constraining equations for saturation 3.14 and gas-water capillary pressure 3.15 are:

$$S_g + S_w = 1 \quad (3.14)$$

$$p_{cgw} = p_g - p_w \quad (3.15)$$

Terms K_{rg} and K_{rw} represent relative permeability for gas and water respectively.

3.2 Diffusivity equation with pseudo pressure

Once when diffusivity equation 3.11 had been derived, where Langmuir and Non Darcy terms are included we got diffusivity equation that is more convenient for unconventional shale gas reservoirs. This diffusivity equation can be more accurate if we put into account Al-Hussainy (1966) term 3.16 for pseudo pressure.

$$m(p) = \int_0^p \frac{2p}{\mu z} dp \quad (3.16)$$

Differentiating equation 3.16 with respect to pressure p we get:

$$\frac{dm(p)}{dp} = \frac{2p}{\mu z} \quad (3.17)$$

Then following relations are obtained by applying the rule of chain:

$$\frac{dm(p)}{dx} = \frac{dm(p)}{dp} \frac{dp}{dx} \quad (3.18)$$

$$\frac{dm(p)}{dt} = \frac{dm(p)}{dp} \frac{dp}{dt} \quad (3.19)$$

If we include equation 3.17 into the equations 3.18 and 3.19, we get following terms that will be included later into diffusivity equation 3.11.

$$\frac{dm(p)}{dx} = \frac{2p}{\mu z}\frac{dp}{dx}$$

$$\frac{dp}{dx} = \frac{\mu z}{2p}\frac{dm(p)}{dx} \quad (3.20)$$

$$\frac{dm(p)}{dt} = \frac{2p}{\mu z}\frac{dp}{dt}$$

$$\frac{dp}{dt} = \frac{\mu z}{2p}\frac{dm(p)}{dt} \quad (3.21)$$

When we include terms 3.20 and 3.21 into diffusivity equation 3.11, we get diffusivity equation (3.22) where pseudo pressure is included together with non-Darcy and adsorption terms.

$$\frac{d^2m(p)}{dx^2} + V_L\rho_R\frac{P_L}{(P+P_L)^2}\frac{d^2m(p)}{dt} = A_2\left(\frac{\mu}{kb} + 2\beta v\right)\left(\frac{d^2m(p)}{dt} + \frac{v}{\phi}\frac{d^2m(p)}{dx}\right) \quad (3.22)$$

3.3 Diffusivity equation discretization

Once when diffusivity equation 3.12 had been derived, discretization in space and time was done in order to get the final simulation equation. Diffusivity equation 3.12 is represented in 2 dimensions, one for the vertical flow in fracture (along z axis) and one for the horizontal flow within the reservoir (along x axis). Disposition of blocks is represented on figure 14.
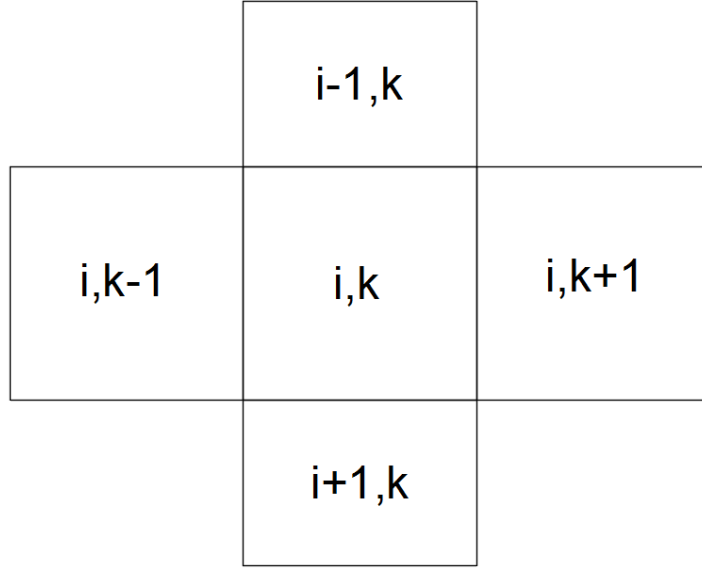
Figure 14 Disposition of blocks.

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2} + V_L\rho_R \frac{P_L}{(P+P_L)^2}\frac{dP}{dt} = A_2\left(\frac{\mu_g}{k_xb_g} + 2\beta v_g\right)\left(\frac{dP}{dt} + \frac{v}{\phi}\left(\frac{dP}{dx} + \frac{dP}{dz}\right)\right) \quad (3.12)$$

Equation 3.12 has to be arranged into another form suitable for discretization and also to be in compliance with FORTRAN program that is used as a foundation.

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2} = \left(\frac{A_2\mu + 2A_2\beta vkb}{kb}\right)\left(\frac{dP}{dt} + \frac{v}{\phi}\left(\frac{dP}{dx} + \frac{dP}{dz}\right)\right)$$

Introducing unit conversion constant "*C*" into the equation and rearranging, we get another form that is represent as equation 3.23.

$$\left(\frac{Ckb}{A_2\mu + 2A_2\beta vkb}\right)\left(\frac{d^2P}{dx^2} + \frac{d^2P}{dz^2}\right) - \frac{v}{\phi}\left(\frac{dP}{dx} + \frac{dP}{dz}\right) = \frac{dP}{dt} \quad (3.23)$$

Form of final diffusivity equation represented as equation 3.23 is composed of both first and second order derivatives, and using the implicit formulation method these derivatives take new form of weighted approximation between the new and old values as follows:

First order derivatives have following forms:

$$\frac{dP}{dx} = \frac{P_{i,k+1}^{t+1} - P_{i,k}^{t+1}}{\Delta x}$$

$$\frac{dP}{dx} = \frac{\Delta x P_{i,k}^+}{\Delta x}$$

$$\frac{dP}{dz} = \frac{P_{i+1,k}^{t+1} - P_{i,k}^{t+1}}{\Delta z}$$

$$\frac{dP}{dz} = \frac{\Delta z P_{i,k}^+}{\Delta z}$$

$$\frac{dP}{dt} = \frac{P_{i,k}^{t+1} - P_{i,k}^t}{\Delta t}$$

$$\frac{dP}{dt} = \frac{P_{i,k}(t + \Delta t) - P_{i,k}(t)}{\Delta t}$$

Second order derivatives have following forms:

$$\frac{d^2 P}{dx^2} = \frac{P_{i,k+1}^{t+1} - 2P_{i,k}^{t+1} + P_{i,k-1}^{t+1}}{(\Delta x)^2}$$

$$\frac{d^2 P}{dx^2} = \frac{P_{i,k+1}^{t+1} - P_{i,k}^{t+1} + P_{i,k-1}^{t+1} - P_{i,k}^{t+1}}{(\Delta x)^2}$$

$$\frac{d^2 P}{dx^2} = \frac{\Delta x P_{i,k}^+ + \Delta x P_{i,k}^-}{\Delta x^2}$$

$$\frac{d^2 P}{dz^2} = \frac{P_{i+1,k}^{t+1} - 2P_{i,k}^{t+1} + P_{i-1,k}^{t+1}}{(\Delta z)^2}$$

$$\frac{d^2 P}{dz^2} = \frac{P_{i+1,k}^{t+1} - P_{i,k}^{t+1} + P_{i-1,k}^{t+1} - P_{i,k}^{t+1}}{(\Delta z)^2}$$

$$\frac{d^2 P}{dz^2} = \frac{\Delta z P_{i,k}^+ + \Delta z P_{i,k}^-}{\Delta z^2}$$

Where *dx, dz* represent derivatives in space and *dt* derivative in time.

By introducing derivatives into equation 3.23, following form was obtained:

$$\left(\frac{Ckb}{A_2\mu + 2A_2\beta vkb}\right)\left(\frac{\Delta xP_{i,k}^+ + \Delta xP_{i,k}^-}{\Delta x^2} + \frac{\Delta zP_{i,k}^+ + \Delta zP_{i,k}^-}{\Delta z^2}\right) - \frac{v}{\phi}\left(\frac{\Delta xP_{i,k}^+}{\Delta x} + \frac{\Delta zP_{i,k}^+}{\Delta z}\right) = \frac{dP}{dt}$$

Multiplying both sides of the equation with A_2, we get:

$$\left(\frac{Ckb}{\mu + 2\beta vkb}\right)\left(\frac{\Delta xP_{i,k}^+ + \Delta xP_{i,k}^-}{\Delta x^2} + \frac{\Delta zP_{i,k}^+ + \Delta zP_{i,k}^-}{\Delta z^2}\right) - \frac{vA_2}{\phi}\left(\frac{\Delta xP_{i,k}^+}{\Delta x} + \frac{\Delta zP_{i,k}^+}{\Delta z}\right) = A_2\frac{dP}{dt}$$

In order to simplify the equation new terms are introduced:

$$Ox_{i,k}^+ = \left[\frac{Ck_xb}{\mu\Delta x^2 + 2\Delta x^2\beta vk_xb}\right]^+$$

$$Ox_{i,k}^- = \left[\frac{Ck_xb}{\mu\Delta x^2 + 2\Delta x^2\beta vk_xb}\right]^-$$

$$Oz_{i,k}^+ = \left[\frac{Ck_zb}{\mu\Delta z^2 + 2\Delta z^2\beta vk_zb}\right]^+$$

$$Oz_{i,k}^- = \left[\frac{Ck_zb}{\mu\Delta z^2 + 2\Delta z^2\beta vk_zb}\right]^-$$

Notation of the terms has to be same as it is in a foundation project in order to bring all terms at the same reference level and to be suitable for initially developed programming code.

Introducing new terms into equation, following form is obtained:

$$Ox_{i,k}^+ \Delta x P_{i,k}^+ + Ox_{i,k}^- \Delta x P_{i,k}^- + Oz_{i,k}^+ \Delta z P_{i,k}^+ + Oz_{i,k}^- \Delta z P_{i,k}^- - \frac{vA_2}{\phi}\left(\frac{\Delta P_{i,k}^+}{\Delta x}\right) - \frac{vA_2}{\phi}\left(\frac{\Delta P_{i,k}^+}{\Delta z}\right) = A_2 \frac{dP}{dt} \quad (3.24)$$

Equation 3.24 is then more expanded by adding Langmuir (desorption) term and by further developing:

$$Ox_{i,k}^+\left(P_{i,k+1} - P_{i,k}\right) + Ox_{i,k}^-\left(P_{i,k-1} - P_{i,k}\right) + Oz_{i,k}^+\left(P_{i-1,k} - P_{i,k}\right) + Oz_{i,k}^-\left(P_{i+1,k} - P_{i,k}\right) - \frac{vA_2}{\phi \Delta x}\left(P_{i,k+1} - P_{i,k}\right) - \frac{vA_2}{\phi \Delta z}\left(P_{i-1,k} - P_{i,k}\right)$$

$$- V_L \rho_R \frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2} \frac{P_{i,k}(t + \Delta t) - P_{i,k}(t)}{\Delta t} = A_2 \frac{P_{i,k}(t + \Delta t) - P_{i,k}(t)}{\Delta t}$$

Next step is rearranging:

$$Ox_{i,k}^+ P_{i,k+1} + Ox_{i,k}^- P_{i,k-1} + Oz_{i,k}^+ P_{i-1,k} + Oz_{i,k}^- P_{i+1,k} + \left(-Ox_{i,k}^+ - Ox_{i,k}^- - Oz_{i,k}^+ - Oz_{i,k}^- + \frac{vA_2}{\phi \Delta x} + \frac{vA_2}{\phi \Delta z}\right)P_{i,k} - \frac{vA_2}{\phi \Delta x} P_{i,k+1} - \frac{vA_2}{\phi \Delta z} P_{i-1,k}$$

$$- V_L \rho_R \frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2} \frac{P_{i,k} - P_{i,k}(t)}{\Delta t} = \frac{A_2{}_{i,k}}{\Delta t}\left(P_{i,k} - P_{i,k}(t)\right)$$

Further:

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$$Ox_{i,k}^{+}P_{i,k+1} + Ox_{i,k}^{-}P_{i,k-1} + Oz_{i,k}^{+}P_{i-1,k} + Oz_{i,k}^{-}P_{i+1,k} + \left(-Ox_{i,k}^{+} - Ox_{i,k}^{-} - Oz_{i,k}^{+} - Oz_{i,k}^{-} + \frac{vA_2}{\phi\Delta x} + \frac{vA_2}{\phi\Delta z} - V_L\rho_R\frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2} - \frac{A_{2\,i,k}}{\Delta t}\right)P_{i,k}$$

$$- \frac{vA_2}{\phi\Delta x}P_{i,k+1} - \frac{vA_2}{\phi\Delta z}P_{i-1,k} = \left(-\frac{A_{2\,i,k}}{\Delta t} - V_L\rho_R\frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2}\right)P_{i,k}(t)$$

Next step is further rearranging:

$$\left(Ox_{i,k}^{+} - \frac{vA_2}{\phi\Delta x}\right)P_{i,k+1} + Ox_{i,k}^{-}P_{i,k-1} + \left(Oz_{i,k}^{+} - \frac{vA_2}{\phi\Delta z}\right)P_{i-1,k} + Oz_{i,k}^{-}P_{i+1,k}$$

$$+ \left(-Ox_{i,k}^{+} - Ox_{i,k}^{-} - Oz_{i,k}^{+} - Oz_{i,k}^{-} + \frac{vA_2}{\phi\Delta x} + \frac{vA_2}{\phi\Delta z} - V_L\rho_R\frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2} - \frac{A_{2\,i,k}}{\Delta t}\right)P_{i,k}$$

$$= \left(-\frac{A_{2\,i,k}}{\Delta t} - V_L\rho_R\frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2}\right)P_{i,k}(t) \quad (3.25)$$

Now, it is necessary to define following coefficients:

$$b_{i,k} = Ox_{i,k}^+ + Ox_{i,k}^- + Oz_{i,k}^+ + Oz_{i,k}^- - \frac{vA_2}{\phi \Delta x} - \frac{vA_2}{\phi \Delta z} + V_L \rho_R \frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2} + \frac{A_{2\,i,k}}{\Delta t}$$

$$a_{i,k} = \frac{Ox_{i,k}^-}{b_{i,k}}$$

$$c_{i,k} = \frac{Ox_{i,k}^+ - \frac{vA_2}{\phi \Delta x}}{b_{i,k}}$$

$$e_{i,k} = \frac{Oz_{i,k}^-}{b_{i,k}}$$

$$f_{i,k} = \frac{Oz_{i,k}^+ - \frac{vA_2}{\phi \Delta z}}{b_{i,k}}$$

$$d_{i,k} = \frac{\left(A_{2\,i,k} + V_L \rho_R \frac{P_L}{\left(P_{i,k}(t) + P_L\right)^2}\right) \frac{P_{i,k}(t)}{\Delta t}}{b_{i,k}}$$

Then we get the final simulation equation 3.26 by introduction these coefficients into equation 3.25.

$$-a_{i,k}P_{i,k-1} - c_{i,k}P_{i,k+1} + P_{i,k} - e_{i,k}P_{i+1,k} - f_{i,k}P_{i-1,k} = d_{i,k} \quad (3.26)$$

The final simulation equation 3.26 is used to calculate pressure in each block that contains adsorbed gas or in other words it is used for calculating pressure in each block when the value of actual reservoir pressure is below the value of critical desorption pressure. Also it is necessary to say that each block contains one equation with 5 unknowns, hence, there is a same number of equations and unknowns.

Another case, where we have flow within the fracture, there is no source term (desorption term is neglected) and coefficients get following forms:

$$Ox_{i,k}^+ P_{i,k+1} + Ox_{i,k}^- P_{i,k-1} + Oz_{i,k}^+ P_{i-1,k} + Oz_{i,k}^- P_{i+1,k}$$

$$+ \left(-Ox_{i,k}^+ - Ox_{i,k}^- - Oz_{i,k}^+ - Oz_{i,k}^- + \frac{vA_2}{\phi\Delta x} + \frac{vA_2}{\phi\Delta z} - \frac{A_{2_{i,k}}}{\Delta t} \right) P_{i,k} - \frac{vA_2}{\phi\Delta x} P_{i,k+1}$$

$$- \frac{vA_2}{\phi\Delta z} P_{i-1,k} = -\frac{A_{2_{i,k}}}{\Delta t} P_{i,k}(t)$$

Further,

$$\left(Ox_{i,k}^+ - \frac{vA_2}{\phi\Delta x} \right) P_{i,k+1} + Ox_{i,k}^- P_{i,k-1} + \left(Oz_{i,k}^+ - \frac{vA_2}{\phi\Delta z} \right) P_{i-1,k} + Oz_{i,k}^- P_{i+1,k}$$

$$+ \left(-Ox_{i,k}^+ - Ox_{i,k}^- - Oz_{i,k}^+ - Oz_{i,k}^- + \frac{vA_2}{\phi\Delta x} + \frac{vA_2}{\phi\Delta z} - \frac{A_{2_{i,k}}}{\Delta t} \right) P_{i,k}$$

$$= -\frac{A_{2_{i,k}}}{\Delta t} P_{i,k}(t)$$

And coefficients are:

$$b_{i,k} = Ox_{i,k}^+ + Ox_{i,k}^- + Oz_{i,k}^+ + Oz_{i,k}^- - \frac{vA_2}{\phi\Delta x} - \frac{vA_2}{\phi\Delta z} + \frac{A_{2_{i,k}}}{\Delta t}$$

$$a_{i,k} = \frac{Ox_{i,k}^-}{b_{i,k}}$$

$$c_{i,k} = \frac{Ox_{i,k}^+ - \frac{vA_2}{\phi\Delta x}}{b_{i,k}}$$

$$e_{i,k} = \frac{Oz_{i,k}^-}{b_{i,k}}$$

$$f_{i,k} = \frac{Oz_{i,k}^+ - \frac{vA_2}{\phi\Delta z}}{b_{i,k}}$$

$$d_{i,k} = \frac{A_{2_{i,k}} \frac{P_{i,k}(t)}{\Delta t}}{b_{i,k}}$$

If we assume that the flow within the reservoir (among blocks) is in a horizontal direction and within the fracture in vertical, for the system 6x3 represented on figure 15, we get a matrix of form $AX=B$.
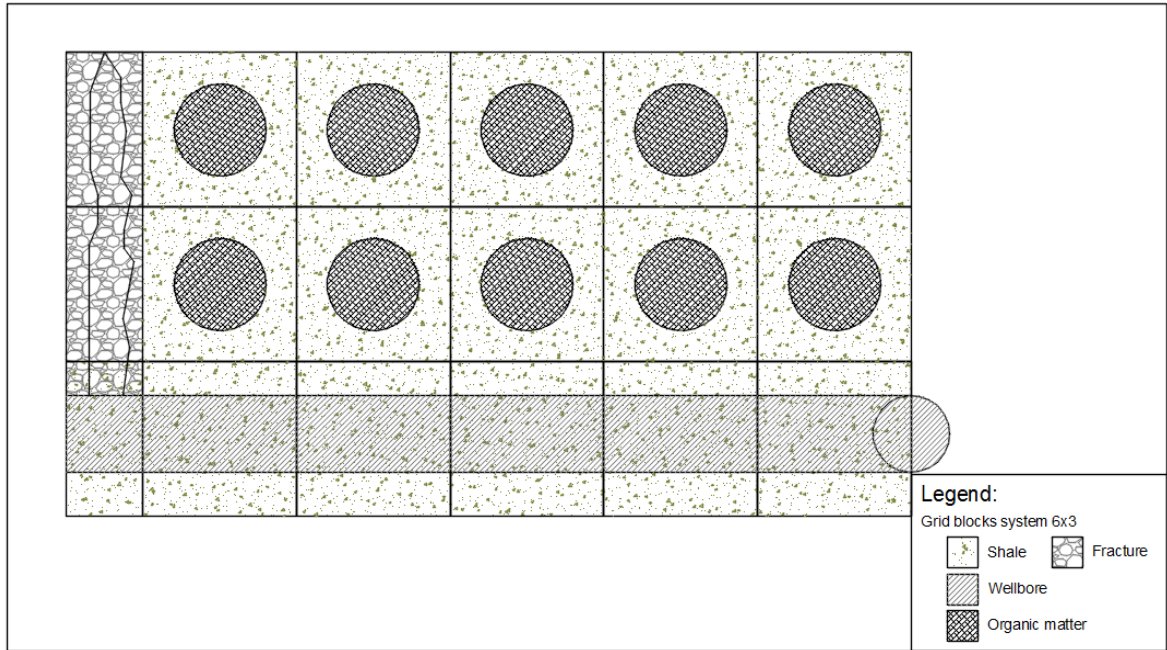
Figure 15 Grid blocks system 6x3.

Matrix of AX=B has following form:

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

3.4 FSGP simulator flow chart

In this section on figure 16, flow chart for FSGP simulator is presented.
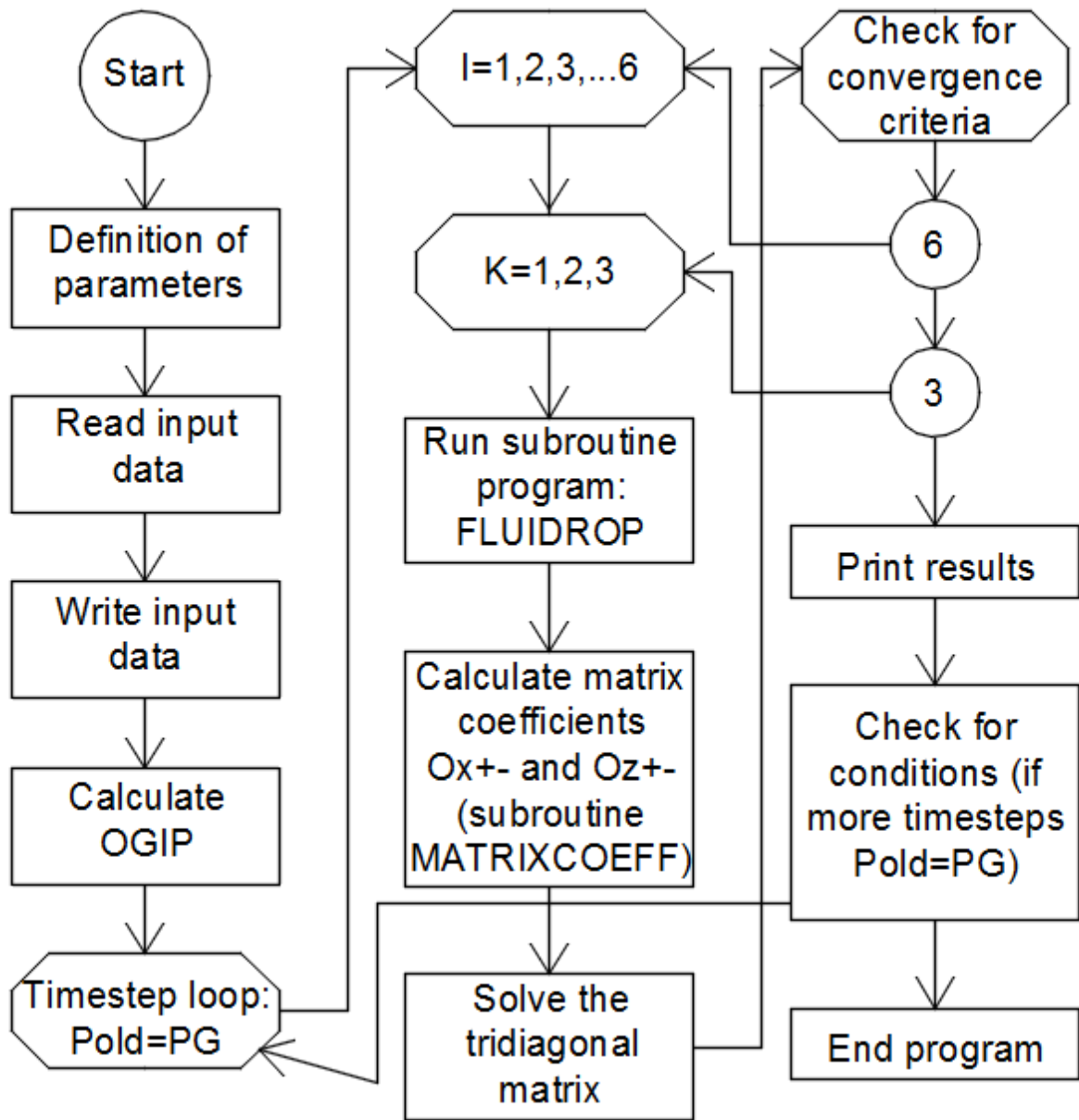
Figure 16 Flow chart for FSGP simulator.

Chapter 4 - Results

This chapter is composed of three parts, first part of this chapter is referred on a results from VDP program, second part is about "Klinkenberg" program and third part on results from the FSGP simulator.

PART A – VDP PROGRAM RESULTS

VDP program is made for the purposes to analyze how will viscosity, compressibility and density of gas vary on different pressures. All simulation results from VDP program are represented on diagrams that are plotted in Microsoft Excel program.

Simulation study was done on different pressures for different gas properties, natural gas and pure methane. Mole fracture of each component in natural gas composition is assumed but again to be realistic as a wet gas that can be found in the shale reservoirs. According to the U.S energy development corporation, the difference between dry and wet natural gas is in methane content which reference is 85% where dry gas has more than 85% while wet gas contains less than 85% of methane content and has higher amounts of ethane and butane (liquid natural gases). Another study is with purpose to analyze how will natural gas composition, on different temperatures, behave on different pressures.

4.1 Natural gas and pure methane

This part is referred on an analysis of plots where natural gas and pure methane are compared. Natural gas used for simulation has following composition:

Table 1 Natural gas composition.

Component	Molecular weight (g/mol)	Mole fraction yi	Molecular weight of fraction
Methan (CH4)	16.04	0.701	11.24404
Ethan (C2H6)	16	0.162	2.592
Propan (C3H8)	44.1	0.0237	1.04517

i-Butan (C4H10)	58.12	0.0582	3.382584
n-Butan (C4H10)	58.12	0.0482	2.801384
i-Pentane (C5H12)	72.15	0.0037	0.266955
n-Pentane (C5H12)	72.15	0.0032	0.23088
	Σ Mole fraction	**1**	
	Total molecular weight of natural gas		**21.563013**

Mole fracture of methane in natural gas is 70% and natural gas has total molecular weight of 21.563013.
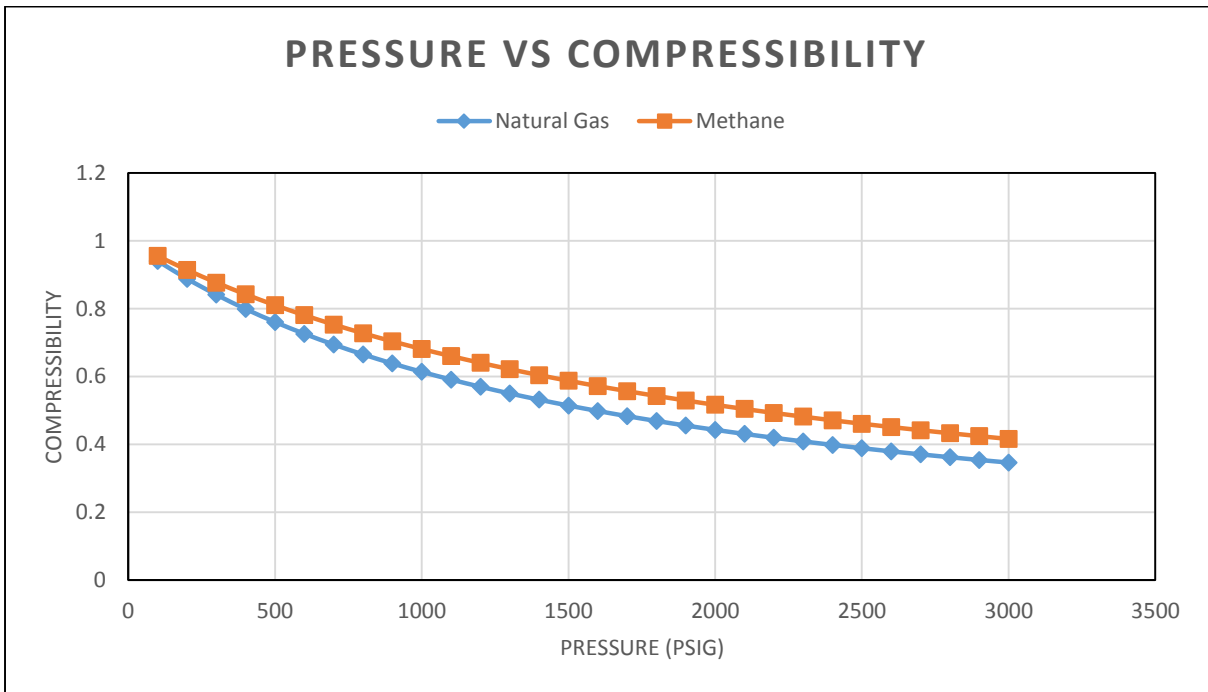
Figure 17 Pressure versus compressibility diagram for different gas composition.

Compressibility of gas changes with pressure is much more significant for Natural gas compared to pure gas methane. Thus, while modelling of shale gas, it is important to consider such effect and variation of compressibility if natural gas properties are used, which is the case in this thesis.
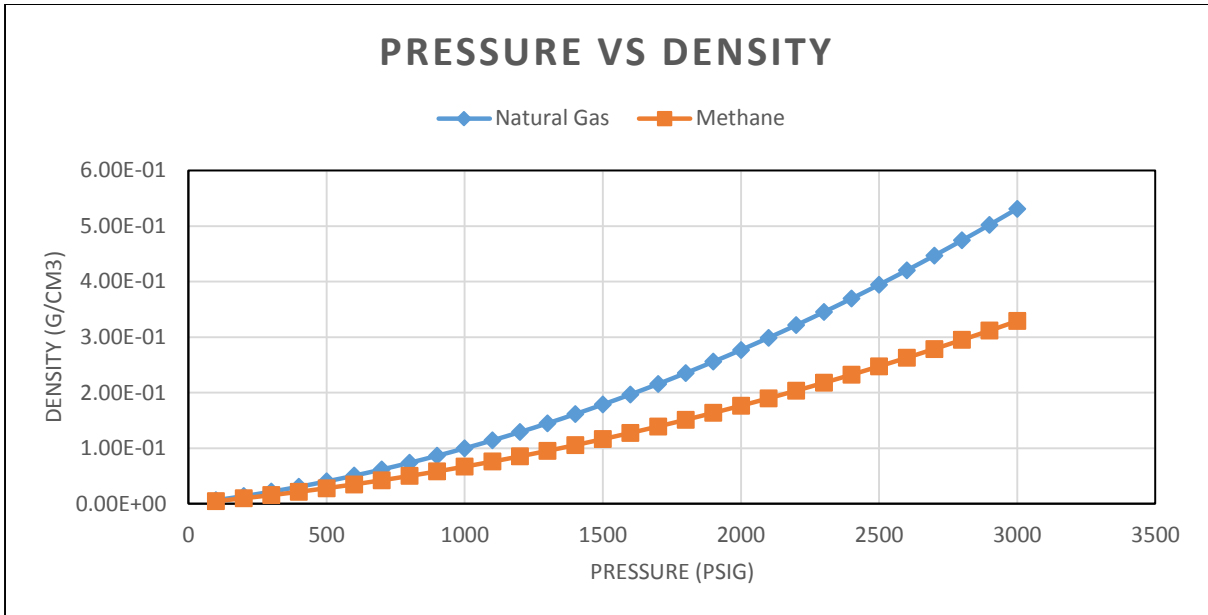
Figure 18 Pressure versus density for different natural gas compositions.

As pressure increases as volume decreases which results in higher molecule concentration or in other words higher density. This effect is more expressed for higher molecular weight components which is shown on figure 18 (blue trend).
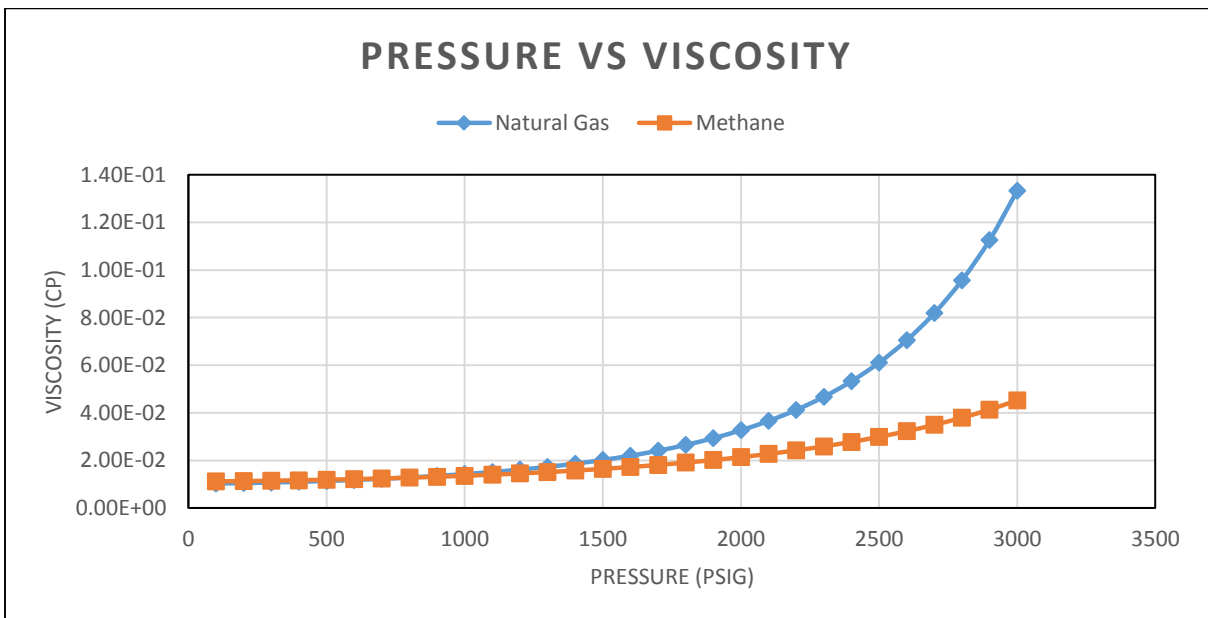
Figure 19 Pressure versus viscosity for different natural gas compositions.

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4.2 Natural gas on different temperatures

Composition of Natural gas used here is same as defined in previous section. The temperatures are considered in sensitivity study and these are 525R and 550R. Results are represented on the following plots. Compressibility and density changes become less significant with increase in temperature.
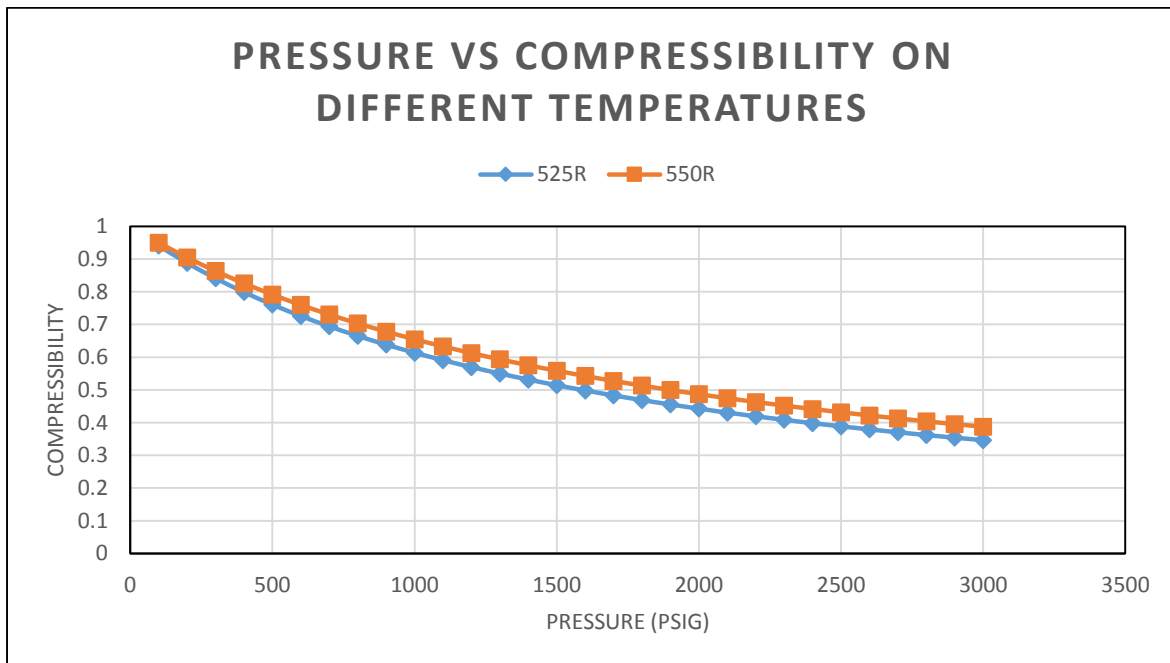
Figure 20 Pressure versus compressibility for different temperatures.
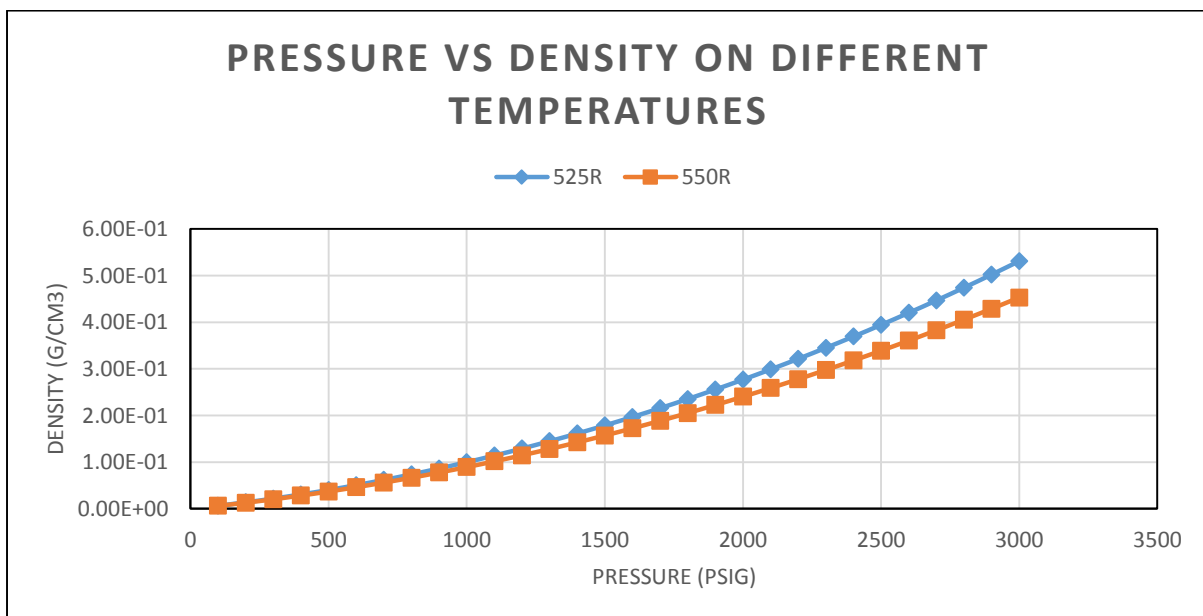
Figure 21 Pressure versus density for different temperatures.
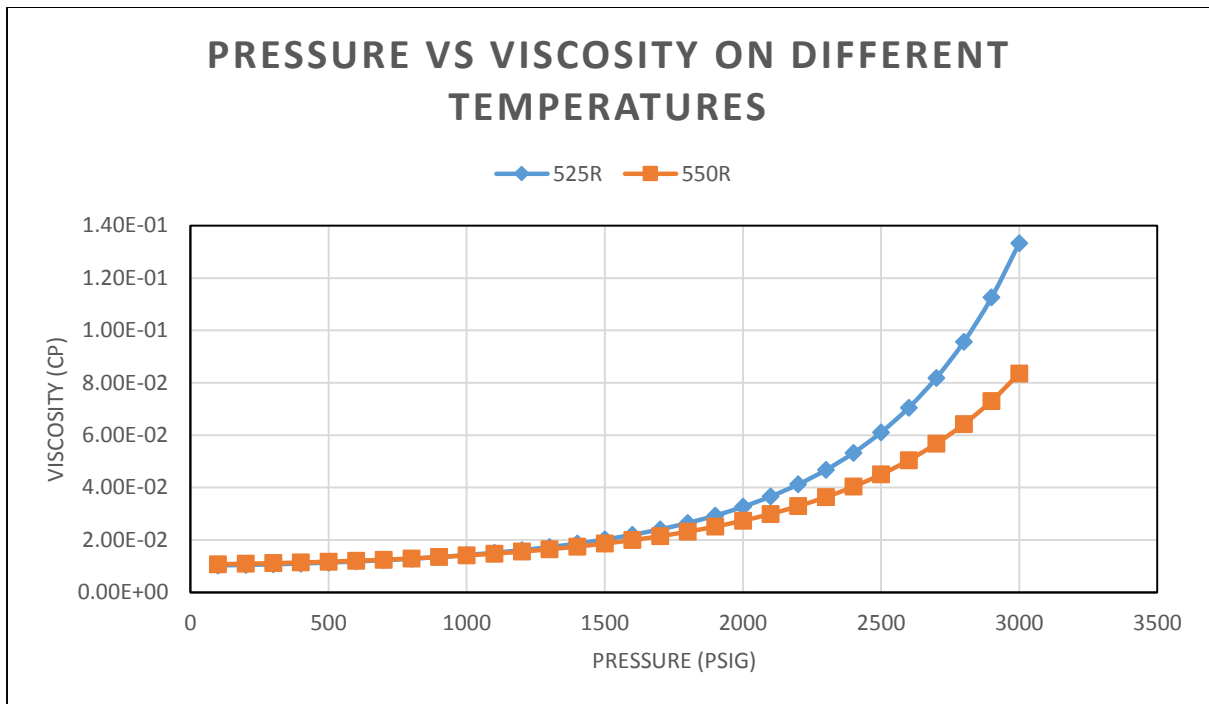
Figure 22 – Pressure versus viscosity for different temperatures.

Similar results can be observed for viscosity of natural gas as well when exposed to varying temperature. Higher the temperature, less change in viscosity is observed for natural gas.

PART B – "KLINKENBERG" PROGRAM RESULTS

"Klinkenberg" program was made for estimation of absolute permeability of core sample based on measured core plug air permeability at specific mean pressure. Data for "Klinkenberg" program are taken from "Tarek Ahmed, Reservoir Engineering 2001" book. Program is made in FORTRAN 95 and it represent Newton-Raphson method to find required solution after specific number of iteration.

In order to evaluate slippage phenomena and the Klinkenberg effect, it is necessary to have at least two measurements of a gas permeability at different mean pressure levels. In case that only one measurement was done, Newton-Raphson iteration method can be used for estimation of the absolute permeability. Program functions on iteration principle where initial value is guessed and run through equation (equation is given in Chapter 2) until result converges to the true value. Number of iteration directly depends on difference between true and guessed value.

Data used for calculation:

Table 2 Data used for "Klinkenberg" program.

Name:	Value:
Permeability of a core plug measured by air	46.6 (mD)
Mean pressure	2152 (psi)
Guess value of absolute permeability	30 (mD)

Number of iteration	Guess value of absolute permeability	Main equation	First derivative of the main equation	New absolute value used for next iteration
1	30	25.12635	3.46528	22.71952
2	22.71987	-0.46627	3.29857	22.86118
3	22.86135	0.41472	3.29658	**22.8490009**

Value of 22.85 mD represents the estimated value for absolute permeability for a core sample, it is very close to the actual absolute permeability which is 23.66 mD.

PART C – FSGP PROGRAM RESULTS

In this part, results produced from the FSGP simulator are presented. Production profile is given and its well performance characteristics. Almost all results plotted here are compared with the Darcy flow behavior. Pressure behavior study was also done for each cell at different time step. Sensitivity analysis in terms of velocity, non-Darcy constant (Beta) and size of sphere is given later in this part.

Data used for the simulation are taken from Berawala, 2015, while additional data for non-Darcy flow are assumed (table 3).

Table 3 Shale gas characteristics and reservoir properties data used for the simulation.

Parameter	Value	Unit
Initial reservoir pressure	3100	psi
Gas viscosity	0.0184	cP
Gas formation volume factor (b_g)	1.35	scf/rcf
Initial dbg/dp, compressibility	6.30E-05	1/psi
Density of gas	6.42	lb/ft^3
Matrix permeability	0.001	mD
Porosity	0.05	fraction
Cell length	100	ft
Cell width	100	ft
Cell height	100	ft
Fracture length	20	ft
Fracture permeability	500	mD
Well radius	0.3	ft
Bottom-hole pressure	2550	psi
Perforation length	20	ft
Langmuir's volume	0.09914	scf/lb
Langmuir's pressure	2695.57	psi
Critical desorption pressure	2800	psi
Density of shale rock	168.55	lb/ft^3
Velocity	0.0001	m/s

Beta (non-Darcy constant)	0.00001	atm-sec^2/gm

4.3 Production profile

Plot on figure 23 represents production profile after 6802 days for non-Darcy flow and homogeneous reservoir properties.
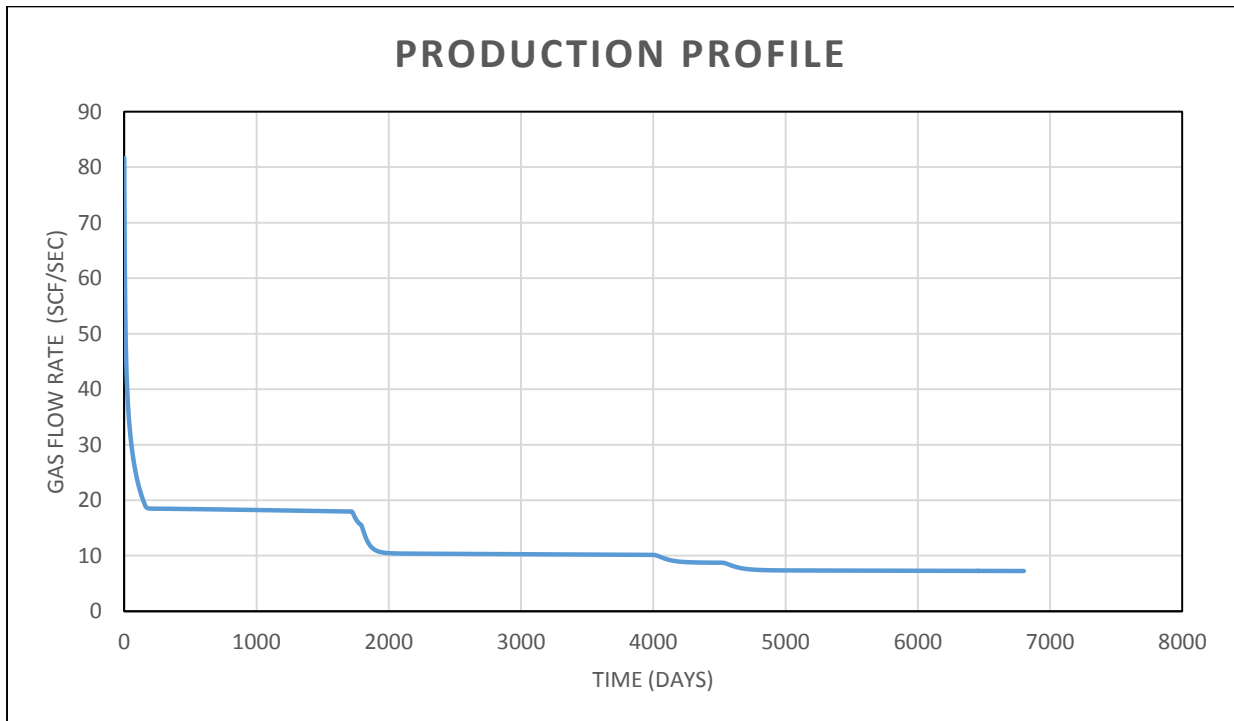
Figure 23 Production profile for non-Darcy flow.

Initial reservoir pressure is 3100 psi and production is at constant bottom hole pressure of 2550 psi. Initial production period characterizes production of free gas stored within the pore space and natural fractures. When critical desorption pressure is reached, adsorbed gas are being released and it starts filling the pore space, at a rate which is pressure dependent.

Figure 24 illustrates the difference between the Darcy and non-Darcy flow results.

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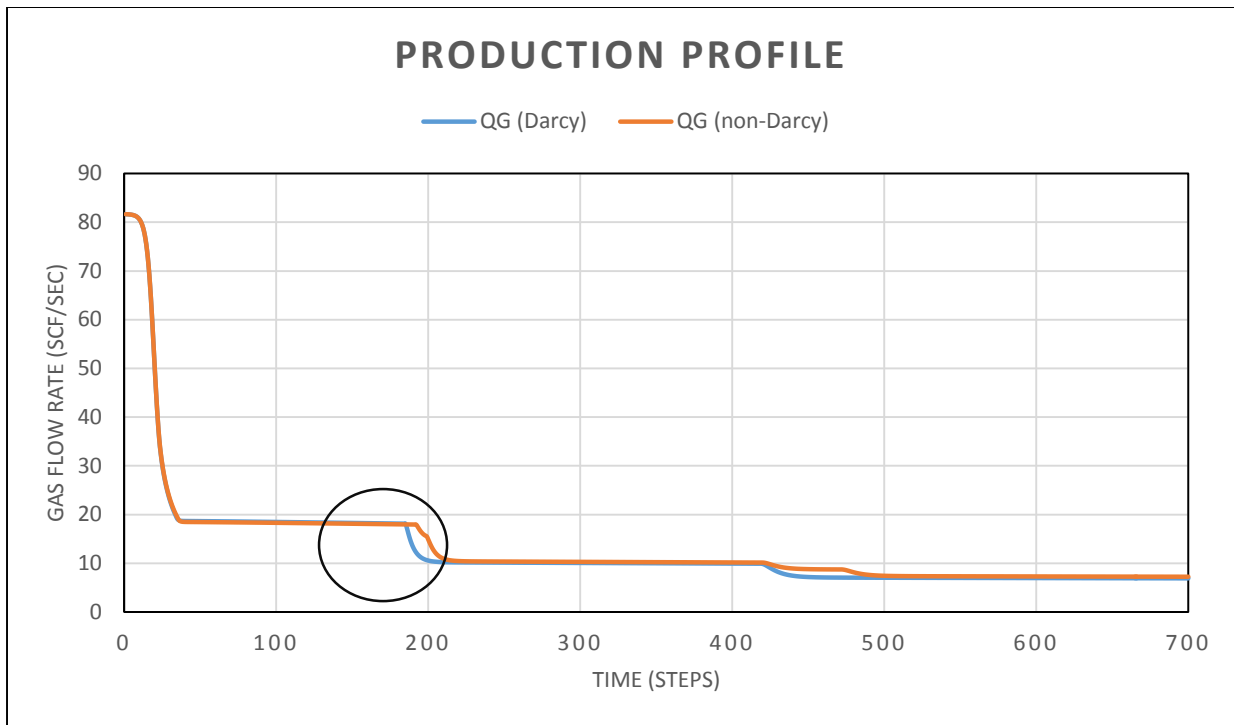
Figure 24 Production profile for Darcy and non-Darcy flow.

Until around 30 time step, during the initial production period, we will have production of free gas from the first cell near the fracture so in that cell critical desorption pressure will be reached faster. After that, when critical desorption pressure is reached, adsorbed gas starts filling the pore space and this is represented on plot when production is stabilized. During the stabilized production period (from 30 to 190 time step) we will also have production from the second cell which will be explained later. Next drop on around 190 time step is when the critical desorption pressure, in second cell, is reached.

If we consider model of 6x3 grid cells where there are 5 cells, in two layers, within the reservoir, we can conclude that there will be 5 dumps during the production period which is correct and can be seen on figure 23 where production profile is represented for 6802 days.

Figure 25 illustrates cumulative production for the period in 700 time steps.
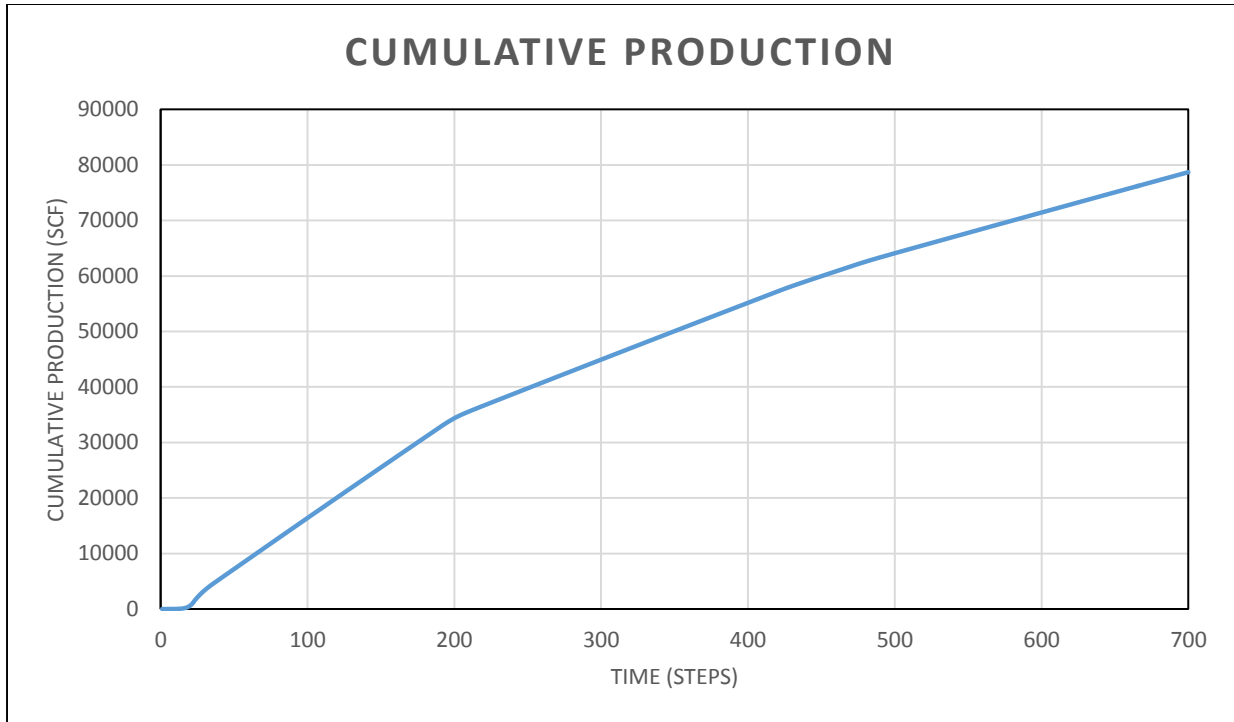
Figure 25 Cumulative production for non-Darcy flow.

The curve trend is very similar to the trend that describes cumulative production for a conventional reservoir.

At the beginning of the production period, production rates are very low and this is because of the time step length. In that period, the time step length is very low, which starts with 10E-04 at the beginning of the production period and up to the 10 days later.

4.4 Fracture pressure

In this section, the variation of the fracture pressure versus time steps is presented. Both linear and non-linear effect on pressure drop are considered. For linear flow which is according to the Darcy law, flow rate only depends on pressure, while in non-Darcy case, inertia effect has to be taken into consideration.
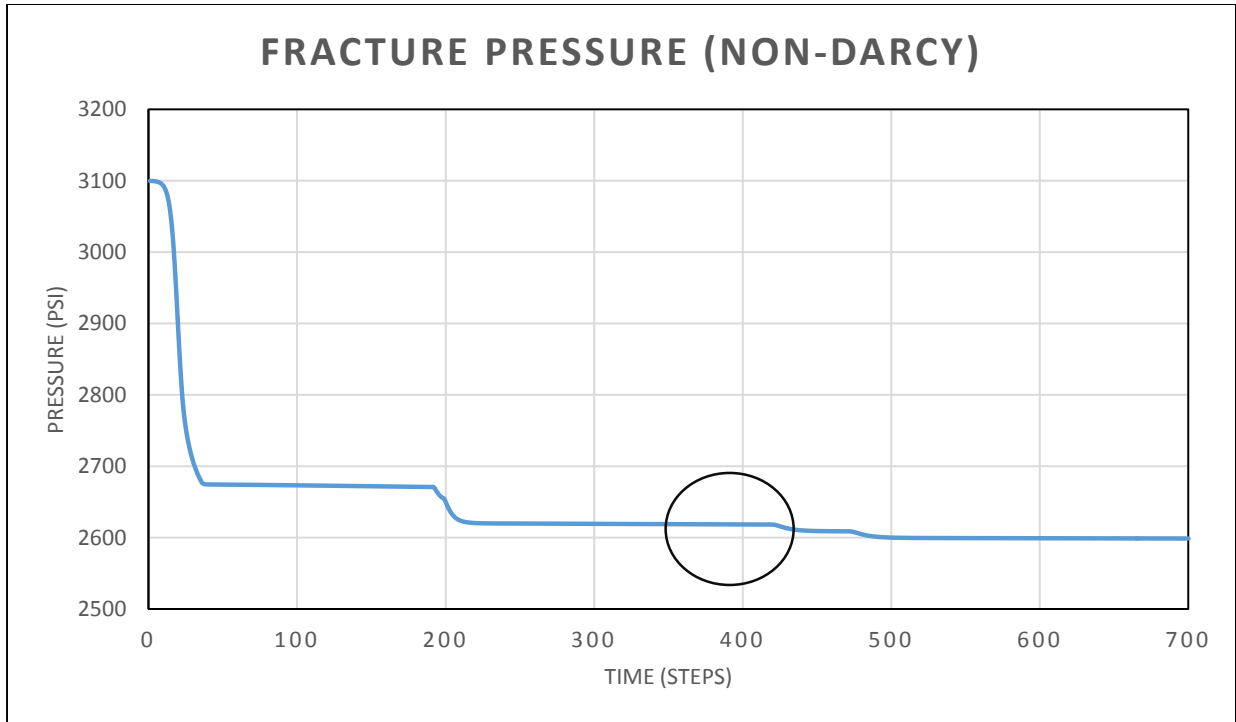
Figure 26 Fracture pressure for the non-Darcy flow.

Calculated pressure drop is considered at the center of first cell (fracture cell). The inflow from the reservoir to the fracture is considered as non-linear and thus we have an inertial effect in the flow due to higher velocity of gas. Comparison between the Darcy and non-Darcy flow is described in figure 27.
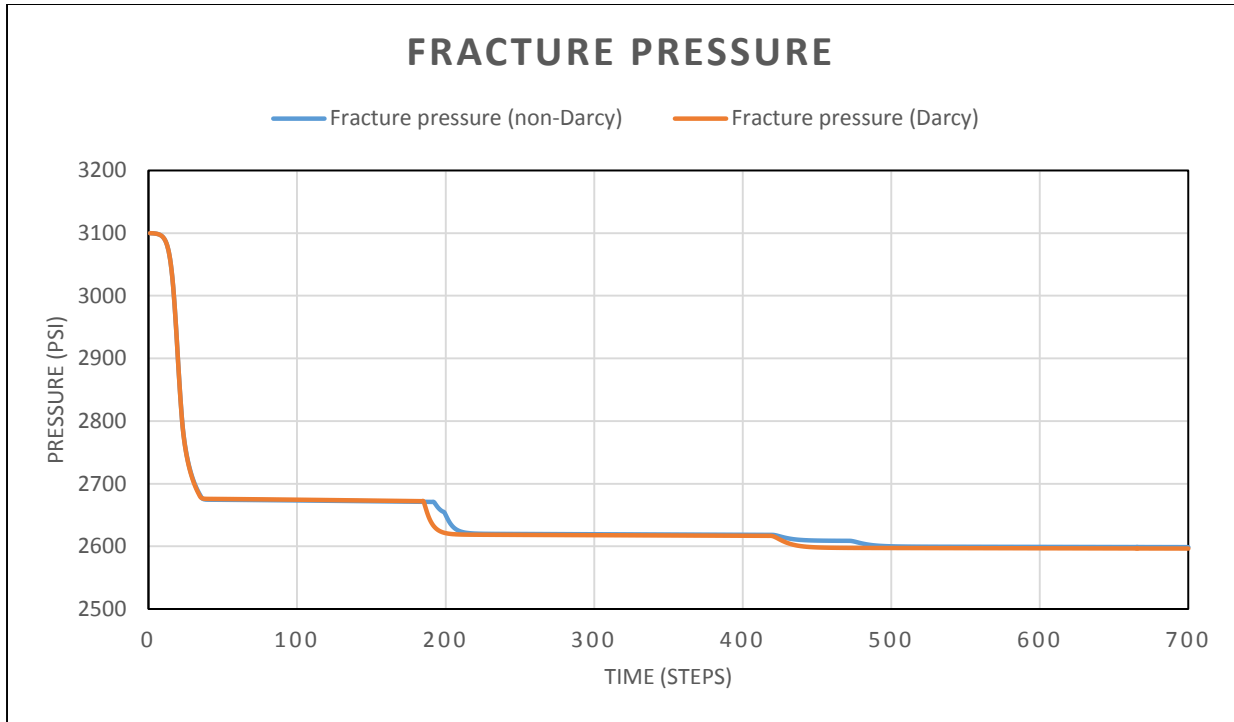
Figure 27 Comparison between fracture pressure for Darcy and non-Darcy flow.

The difference between the Darcy and non-Darcy flow is actually expressed in these drops, where for drop is steeper for the linear flow, while for the non-linear flow where inertial effect is taken into consideration, drop will be smoother. Inertial effect will prolong the time for stabilization.

4.5 Pressure in cells

This section represent how pressure in different layers varies, for non-Darcy flow model. It is good to mention that two layers within the reservoir exist. Each layer has 6 cells where 5 out of 6 are considered within the reservoir and first column cells are considered within the fracture. Figure 28 illustrates layout of our model where different layers are shown.
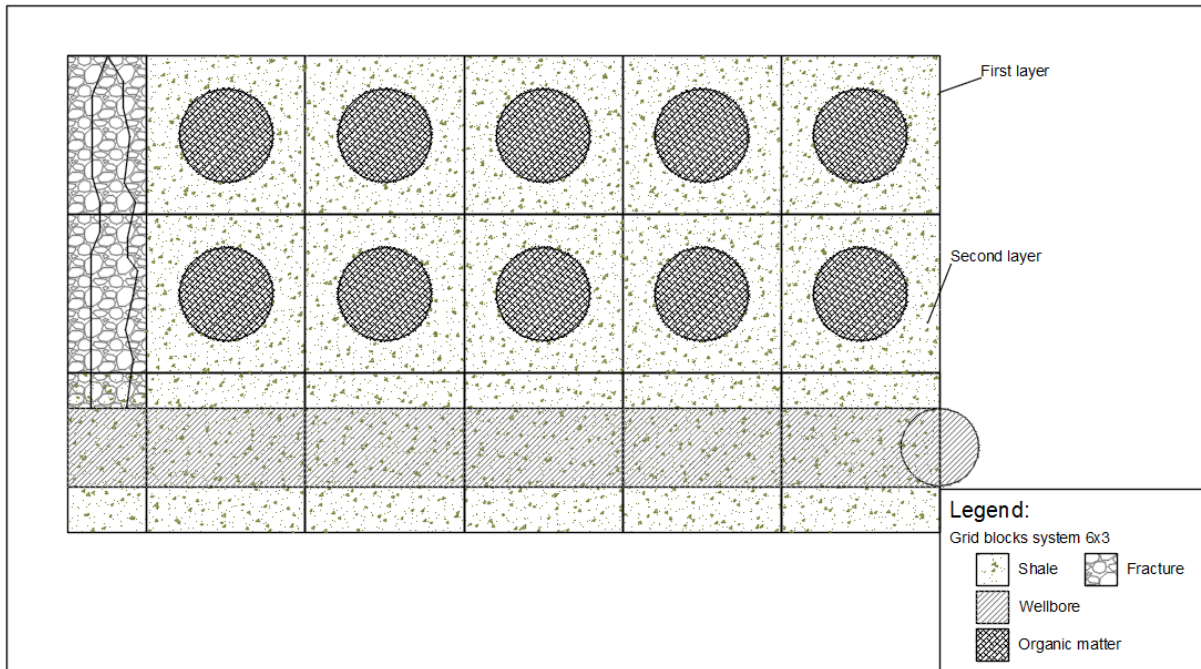
Figure 28 Layout of the model showing different layers within the reservoir.

Flow within the model is treated as non-Darcy flow in all direction for a whole fluid path. Flow direction among the cells within the reservoir is considered as horizontal, which means that the only flow that exists is the flow among the cells within one layer. Flow within the first column of cells or in other words flow within the fracture is considered as vertical flow. There is no transmissibility among the layers.

Once we know how flow functioning in our model, we can observe how will be the pressure change in this model.
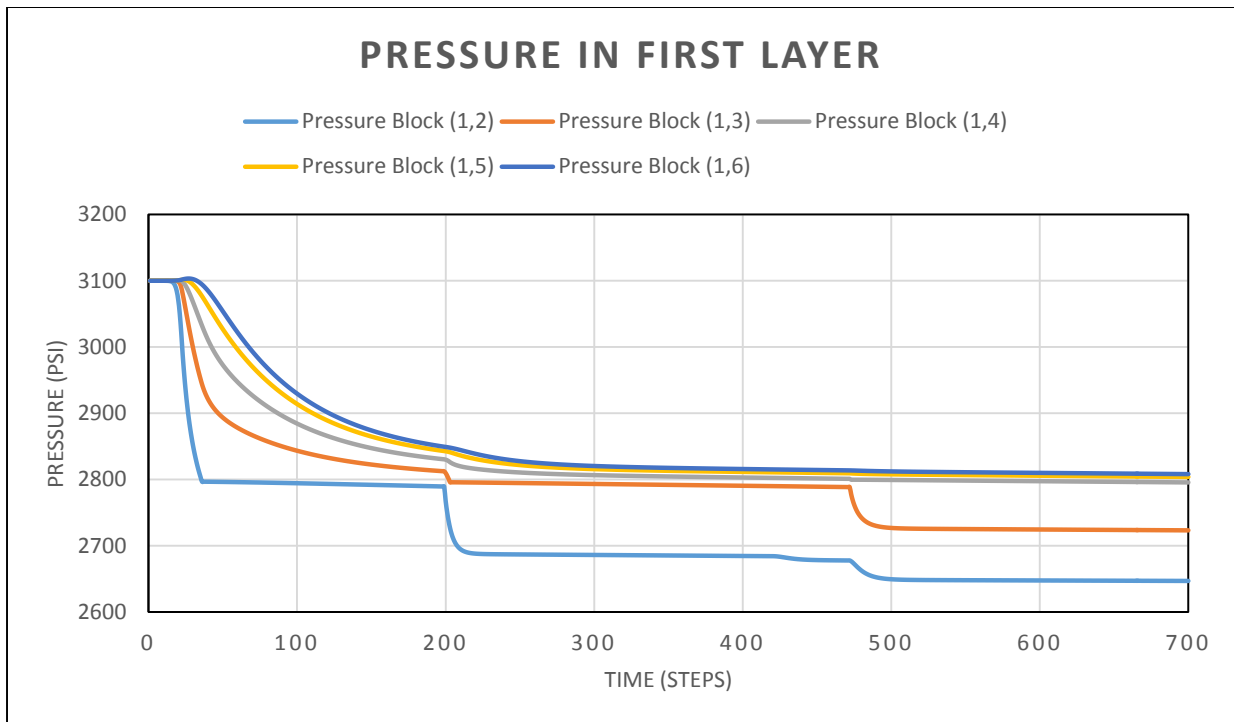
Figure 29 Pressures change in first layer.

From figure 29 we can conclude that each cell has different behavior over time. If we compare pressures in blocks 1,2 (blue trend) and 1,4 (gray trend), we see that pressure drops significantly faster in block 1,2, and this is because this block is closer to the fracture. From block 1,2 free gas will be produced until critical desorption pressure is reached, then adsorbed gas from block 1,2 will start filling pore space and will be produced as well.

Second layer shown on figure 30 has very similar pressure respond as it is in first layer but with the one difference in time of pressure respond.
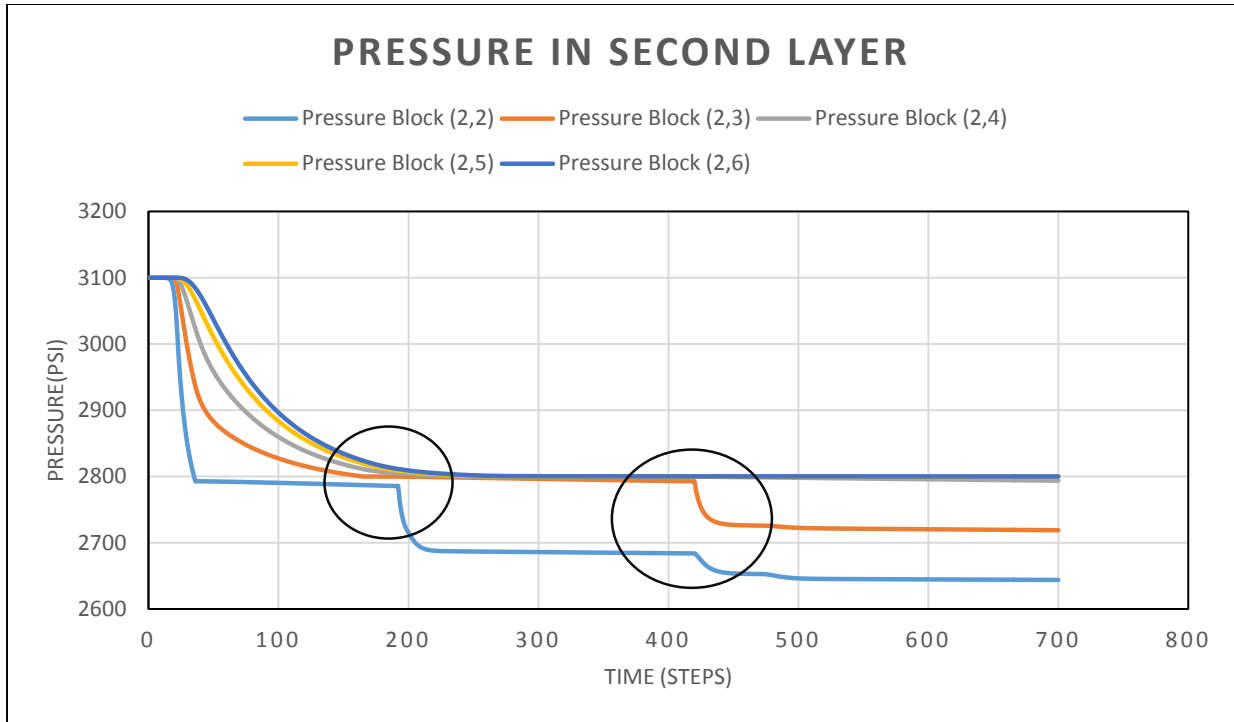
Figure 30 Pressures change in second layer.

As can be seen on figure 30, pressure drop is very similar as it is in first layer, but if we look deeply we can see that critical desorption pressure is reached faster (for 10 time steps in second block and 50 time steps for third block). This offset is created as a result of distance between the layer and the well. Well is closer to the second layer and it logic that production will start from a block that is closer to the well.

4.6 Volume of desorbed gas

In this section, focus will be on a volume of the desorbed gas being produced. The desorbed gas will be first produced from the nearest block 2,2, and almost at the same time production will start from above block 1,2 which can be seen on figure 31.

Figure 31 illustrates volume of the desorbed gas for first three blocks in both reservoir layers.

Figure 31 Volume of desorbed gas for first three blocks in different layers.

As can be seen, until 30th time steps, volume of the desorbed gas being produced is 0 and this is the period until critical desorption pressure is reached (this period is around 200, 420, 480 etc. for other blocks). Production from nearest block will start earlier (from block 2,2; then 1,2; 2,2; 1,2 etc.). If we consider block 2,2 (yellow line), desorbed gas production period starts at 30th time step and lasts until 190. At the end of 190 time step, all the adsorbed gas from the sphere of block 2,2 has been produced. It is similar for other blocks, where trend will be the same which means that when pressure is depleted in previous block, production from adjacent block will start. That trend is "continuous" because of the reservoir which is considered as homogenous. If we have heterogeneous reservoir, where values of permeability and porosity varies for each block, trend will change.

4.7 Sensitivity analysis

All plots presented in the previous sections are plots based on the results for the homogeneous reservoir properties and input data used for these plots are from the table 3. These plots are presented for constant parameters such as velocity, non-Darcy coefficient, porosity and permeability (homogeneous reservoir properties), etc.

In this section we will try to analyze what effect will be if some of the parameters, mentioned above, is changed. All results from sensitivity analysis are plotted below.

55

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55

4.7.1 Different velocities of gas

Velocity term represents the velocity of gas within the shale reservoir. Shale gas reservoirs are well known as extremely low permeable reservoirs which characterize nano scale pores and as a result of that the velocity of gas is higher in comparison with the conventional reservoirs. Value of velocity chosen for this master's project is 0.0001 *m/s* and this value is assumed but again to be realistic. Following plots represent how the different velocities influence on the production profile.

Figure 32 illustrates effect of different velocities on the production profile.
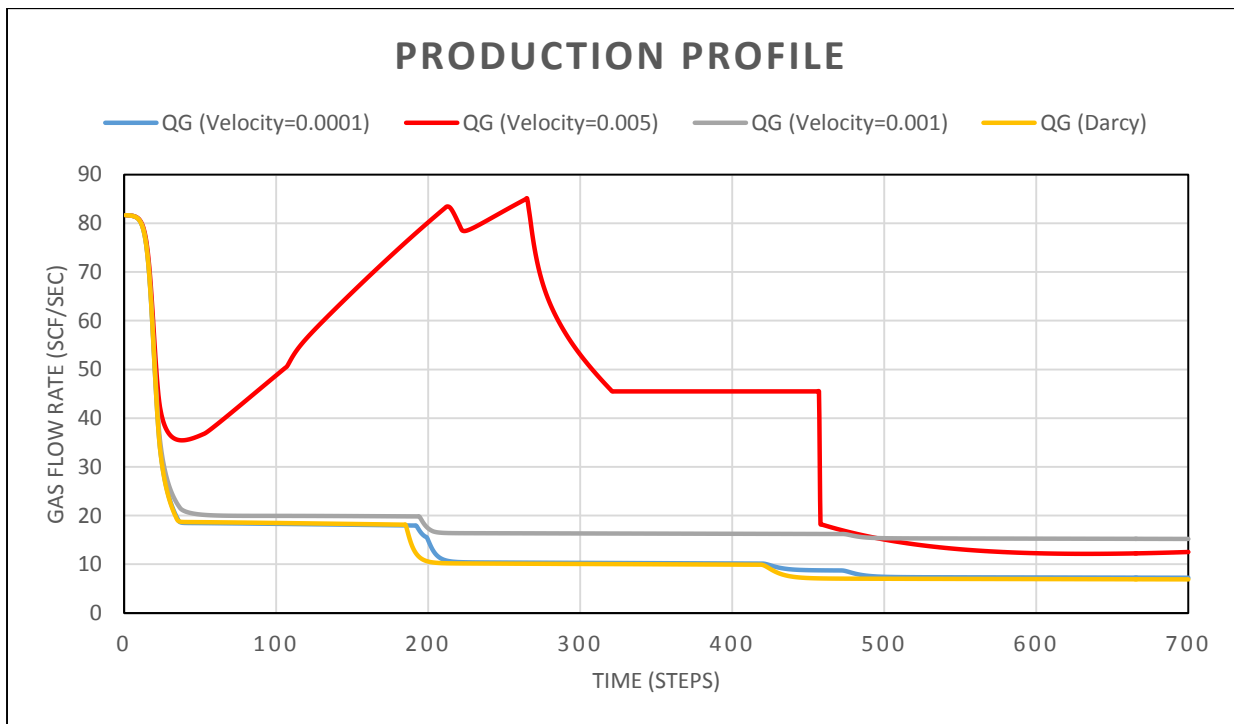
Figure 32 Production profile for different velocities.

Figure 33 illustrate effect of different velocities on the cumulative production.
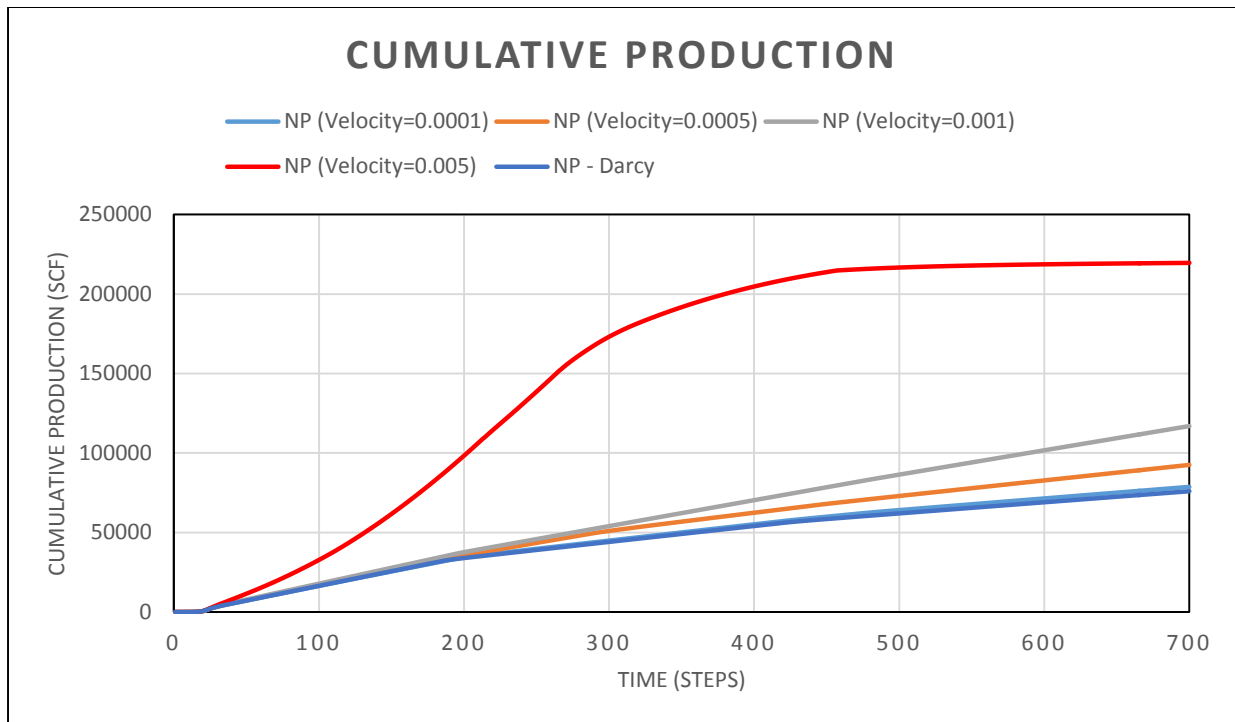
Figure 33 Cumulative production for different velocities.

Production profile during the first 150 time steps is almost same for velocity values of 0.0001, 0.001, and for Darcy flow. As velocity approaching value of zero, results are becoming closer to the flow that is according to Darcy, which is correct. In case where value of velocity is significantly higher (here 0.005, which is 50 times larger than basic value of 0.0001), plot is becoming disturbed (red plot).

4.7.2 Different values of Forchheimer's constant

In this section, sensitivity analysis on non-Darcy coefficient beta is checked. Figures 34 and 35 illustrate how different values of non-Darcy coefficient influence on production profile.
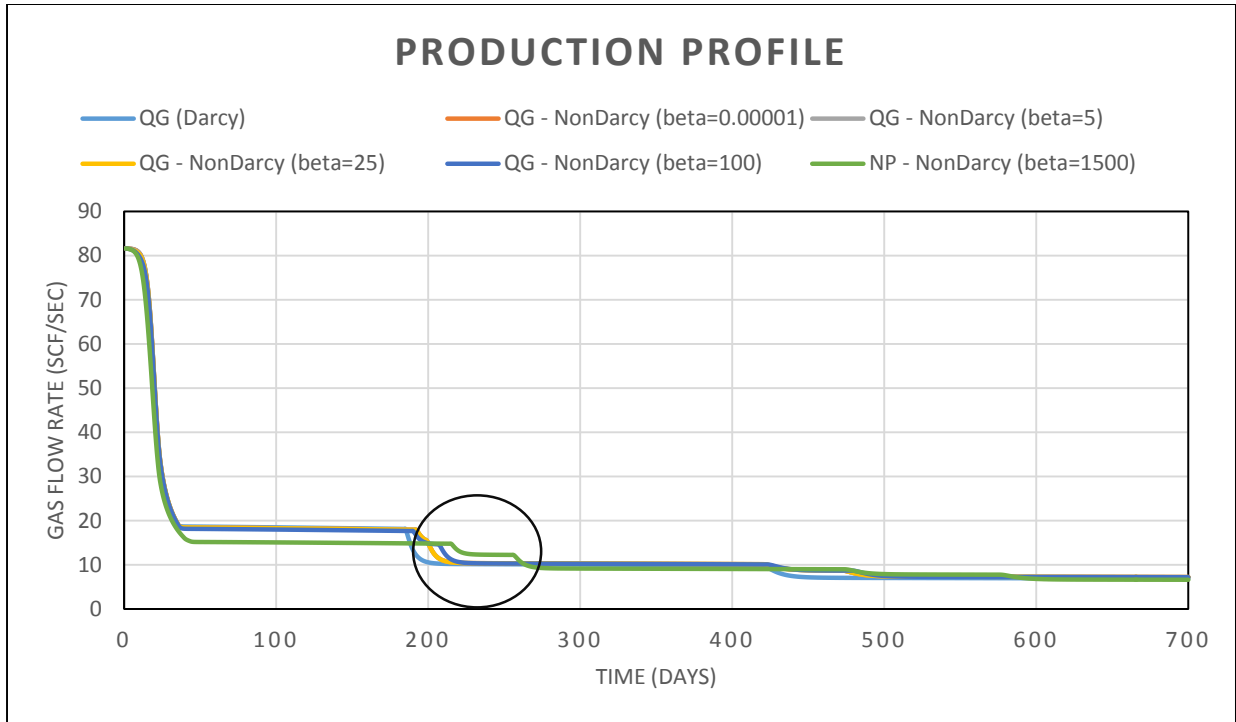
Figure 34 Production profile versus different velocities.
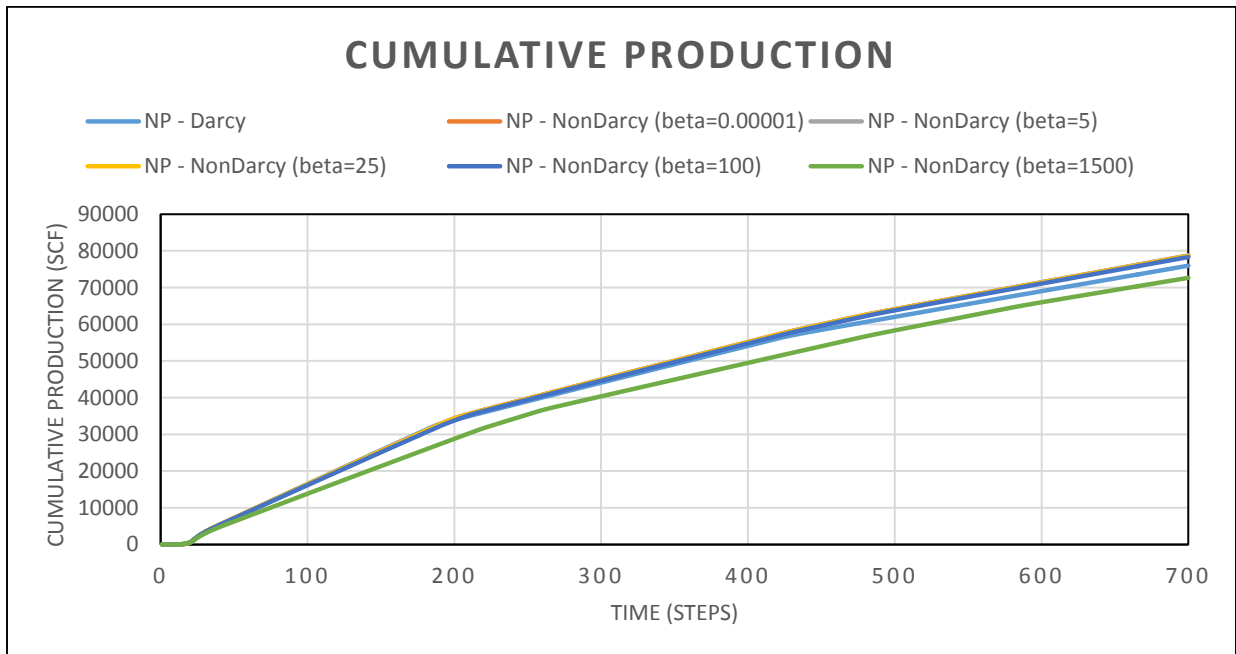
Figure 35 Cumulative production versus different velocities.

As can be seen from figure 34 and 35, different values of beta do not have such impact on the production profile as it is expressed for different values of velocities. Values of beta of 5, 25, and 100 give almost same trend for cumulative production, and as value of non-Darcy coefficient) approaches zero as trend becomes closer to the trend that is according to the Darcy

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flow. We can also see, on figure 35 that trend (green) for a valued of beta=1500, becomes prolonged during the transitional period, and it is caused as a result of increased inertial effect (as beta increases as inertial effect increases and vice versa).

Also it is good to mention, that value of 1500 for beta is no realistic because it is very high, but it is chosen only to show its impact on the production profile. In many papers (example Wang et al. 2013.) value of beta is assumed to be zero.

4.7.3 Heterogeneous reservoir

Heterogeneous reservoir, where permeability values range from 10^{-7} mD to 10^{-1} mD and porosity ranges from 0.3% to 5% is plotted on figure 36.
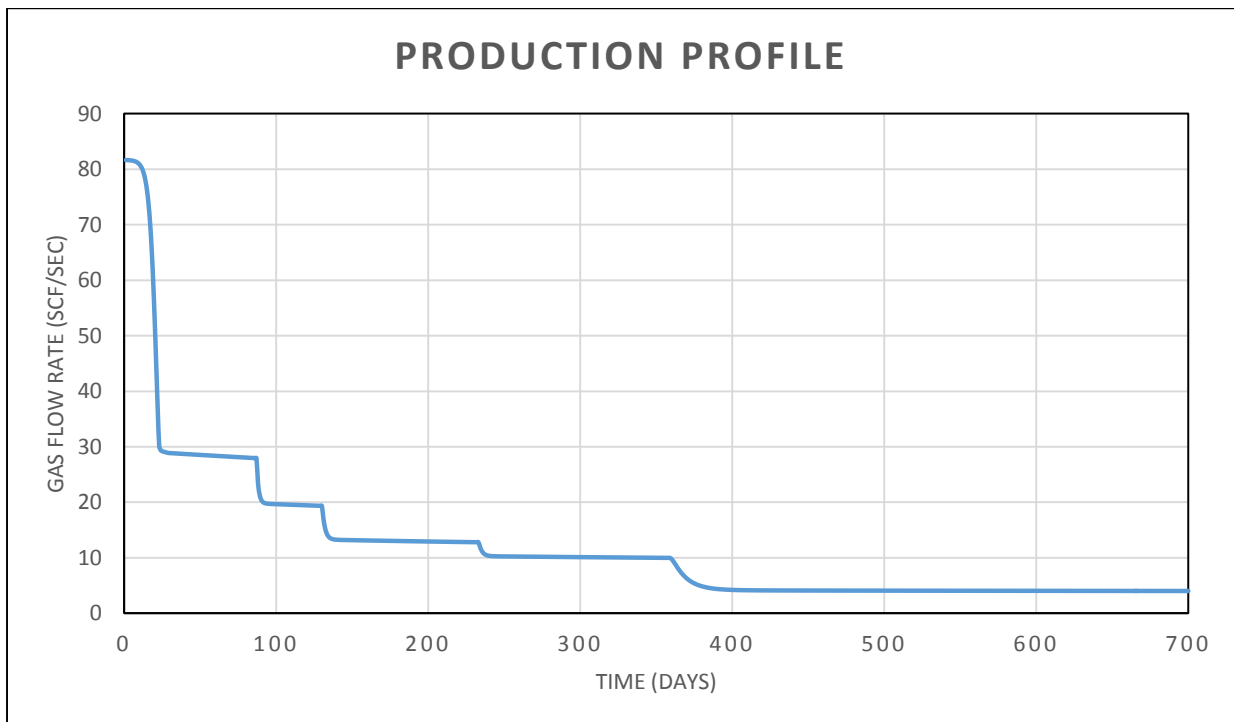
Figure 36 Production profile for heterogeneous reservoir.

Production profile shown on figure 36 does not have same "continuous" trend as it is shown in section 4.3.

4.7.4 Different permeability

On figure 37, production profile for different values of permeability, which vary from 10^{-7} mD to 10^{-1} mD, is shown.
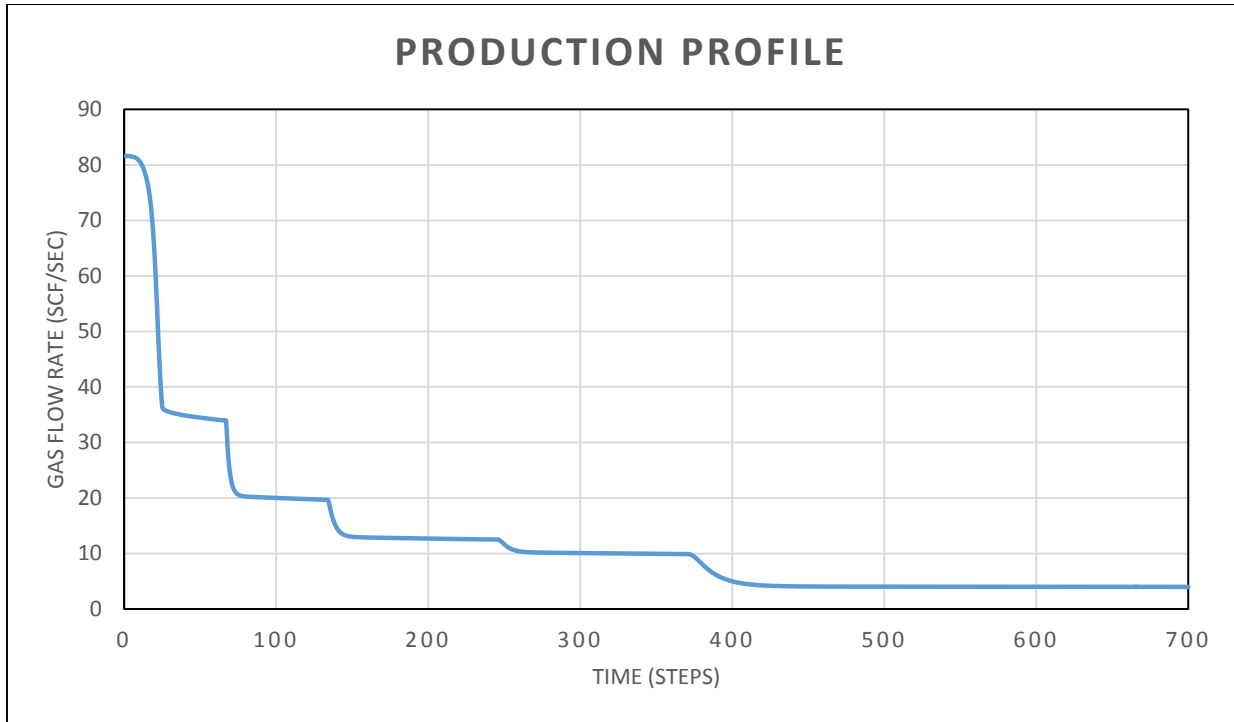
Figure 37 Production profile for heterogeneous reservoir.

The production plot shows long term well performance characteristics for flow of gas in shale reservoirs with non-Darcy flow mechanism. This validates the applicability of the updated FSGP simulator. The steepness in the plot and the duration of the gas desorption from individual cells depends on its and its adjacent cells porosity and permeability. The cell with a lower porosity and permeability value will take longer time to produce free and adsorbed gas.

4.8 Sphere size

In this section, comparison between different sizes of spheres are presented. As size of sphere increases as amount of organic matter increases, and with that total amount of adsorbed gas will also increase. Comparison is shown for 4 different sizes: 10ft, 20ft, 30ft, and 50ft.
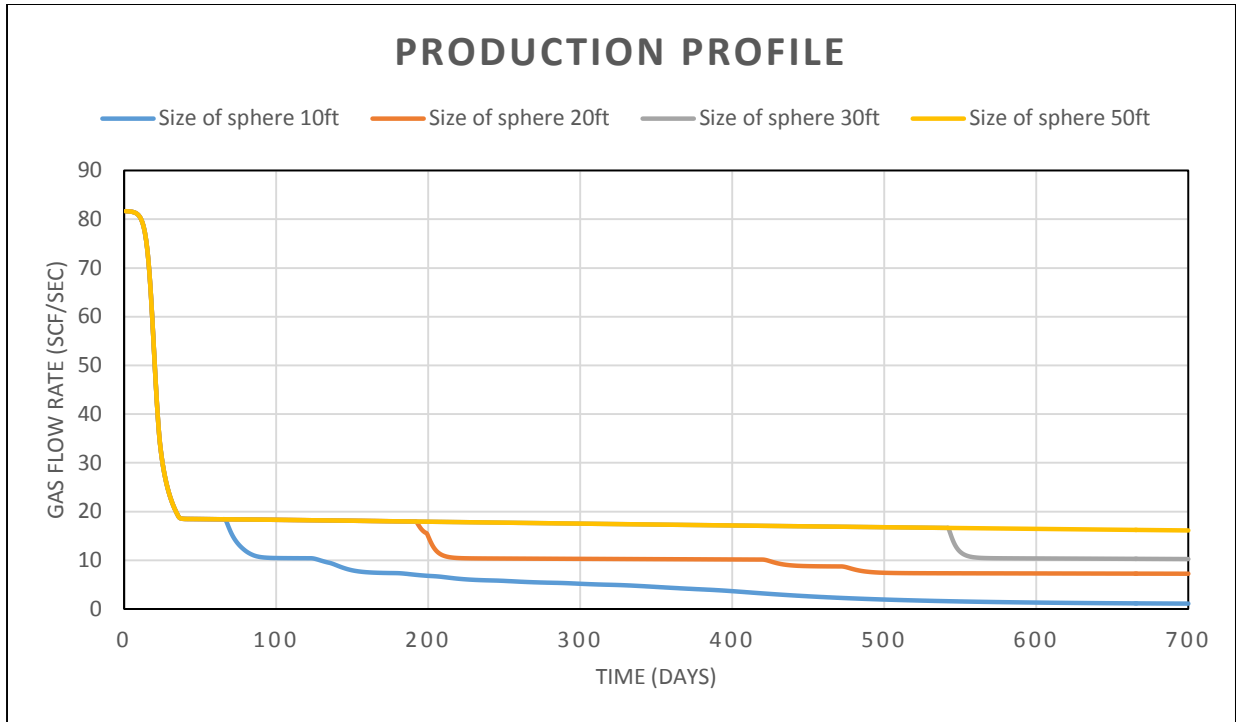
Figure 38 Production profile for different sizes of sphere.

Chapter 5 - Conclusions and future work

This thesis covers the simulation for unconventional shale gas reservoir. In order to make more accurate model for the simulation several non-linear factors such as non-Darcy flow, adsorption/desorption, slippage (Klinkenberg effect), effect of geomechanics, are described. For the simulation purposes, desorption effect and non-Darcy effect are taken into consideration, while theoretical overview of Klinkenberg and geomechanical effect are described. Mathematical modelling of diffusivity equation, where non-Darcy flow is included through the Forchheimer's equation and desorption term through the Langmuir's isotherm, is also given. Final mathematical model is tested in FSGP simulator that is changed for the non-Darcy flow. FSGP simulator considers three types of grid blocks, within the reservoir, fracture and the horizontal well. On the end two different models (Darcy and non-Darcy) are compared and discussed along with sensitivity analysis of various parameters.

5.1 Conclusions

1 Mathematical model for gas production from unconventional shale gas reservoir is discussed. This model incorporates several non-linear flow mechanisms such as non-Darcy flow, adsorption and pseudo pressure effect.

2 Adsorption is represented through a porous cube containing the sphere which is the organic matter that contains adsorbed gas. Adsorbed gas significantly influence on the production and cannot be neglected. The adsorbed gas is represented through the Langmuir's isotherm and it is coupled in the FSGP simulator. As a result of that, simulator presented the results about produced amount of the desorbed gas at each time step.

3 Slippage (Klinkenberg) effect is discussed only through the theoretical way. Effect is not coupled in the FSGP simulator. Deep shale gas reservoirs makes Klinkenberg effect more significant due to the presence of very low permeability under the high pressure conditions.

4 For modeling hydraulically fractured shale gas reservoirs, dual porosity study is very important due to the presence of matrix porosity system and porosity within the network of fractures. The difference between single and dual porosity system is in fluid path, where fluid flows directly from a reservoir to a well, while in dual porosity system fluid flows from reservoir to a well through the fracture, which is considered and tested, during the sensitivity analysis, in this model. Also, more complex effect of multi porous system is given but not coupled into the simulator.

5   Due to the presence of very low matrix permeability, gas velocity within the shale gas reservoir is very high and non-linear fluid behavior is considered. This non-linear flow that is not according to the Darcy flow is expressed by Forchheimer's equation and it is coupled into the simulator. As a result of that, we got smoother results due to the inertial effect.

6   The FSGP simulator generated the results, where non-linear mechanism are taken into account, which presented smoother transition when production moves from one block to another due to the inertial effect.

7   Beside the comparison between the Darcy and non-Darcy flow, results for non-Darcy flow for a heterogeneous reservoir are presented and discussed.

5.2 Suggestion for further work

1   Dual porosity effect in this simulator is only simplified version that is tested. A full derived model which will take into account dual and multi porous system should be developed.

2   Complete set of field data which including the parameters about gas desorption, gas velocity, Klinkenberg effect, effect of geomechanics will be helpful for complete understanding and modeling of fluid behavior in shale gas reservoirs.

3   Pseudo pressure effect will also be coupled into the simulator, since mathematical model is developed in this project.

4   We also wish to upgrade the present model for two phase fluid flow in 3D reservoir with PVT data.

NOMENCLATURE

Parameter   **Description**

μ_g Viscosity of gas (cP)

β non-Darcy coefficient (atm-sec^2/gm)

θ Matrix porosity (fraction)

ρ_g Density of gas (lbm/ft^3)

ρ_R Density of shale rock (lbm/ft^3)

ρ_{ntp} Density at normal temperature and pressure conditions (lbm/ft^3)

A2   Ødb/dp

ϑ_{des} Gas desorption rate (scf/sec)

m_{des} Mass desorption rate (kg/sec)

A_f Cross section area of fracture (ft^2)

$a_{i,k}$ Coefficient of pressure in simulation equation

b   Klinkenberg constant

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   Slope of the line (for Klinkenberg effect)

$c_{i,k}$ Coefficient of pressure in simulation equation

$C_{i,m}$ Concentration of gas within matrix

D_a Diffusion Constant

$D_{e,m}$ Effective Diffusion coeffecient 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_L Absolute 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)

OGIP   Original gas in place

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)

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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)
re	Drainage radius (ft)
rw	Well radius (ft)
S_g	Saturation of gas
S_w	Saturation of water
TOC	Total Organic Carbon
V_g	Non-Darcy's velocity of gas (m/sec)
V_b	Bulk volume (ft^3)
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 (ft^3)
W_C	Well constant
W_c	Well constant per volume basis
Z_0	Total fracture length (ft)
ΔV	Volume of cell (ft^3)
ΔX	Block length in x-direction
ΔY	Block length in y-direction
ΔZ	Block length in z-direction

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APPENDIX A – "VDP" PROGRAM

Appendix A contains two parts, first part is FORTRAN code for VDP program while second part contains results.

PART A – VDP CODE

```
! NAME OF THE PROGRAM: VDP program

! INFO: Program for calculation how Viscosity and Density vary with
pressure.

! The program is made for the master's thesis purpose.

! AUTHOR: Obrad Slijepcevic

! INSTITUTION: University of Stavanger, Norway

! DATE: 25.03.2016


_____

program ViscosityDensityVSPressure


! Define all parameters used in the program


    real p1, p2, step, t, mw, sg, z, ro, mi, k, x, y, p

    integer roh


! Define input parameters


    write(*,*) 'Give initial test pressure (lower) in psig'
```

```fortran
      read (*,*) p1


      write(*,*) 'Give end test pressure (upper) in psig'

      read (*,*) p2


      write(*,*) 'Give step'

      read (*,*) step


      write(*,*) 'Give temperature in R'

      read (*,*) t


      write (*,*) 'Give molar weight in lb/lbmol'

      read (*,*) mw


! Make calculation


      roh = ((p2-p1)/step)+1

      k = (9.379+0.01607*mw)*t**1.5/(209.2+19.26*mw+t)

      x = 3.448 + 986.4/t + 0.01009*mw

      y = 2.447-0.2224*x

      sg = mw/28.9
```

! Open and save calculated values of compressibility in compressibility text file

```fortran
open (10, file='compressibility.txt')


        do      p=p1,p2,step

            z = 1/(1+(p*344400*10**1.78*sg/(t**3.82)))

            write (10,*) z

            print *, 'Compressibility is ', z

        end do

    close (10)



! Open and save calculated values of density in density text file


    open (12, file='compressibility.txt')

    open (14, file='density.txt')

        do p=p1,p2,step

            read (12,*) z

            ro = p*mw/(10.7316*t*z)*0.0160185

            print *, 'Density is ', ro

            write (14,*) ro
```

```fortran
        end do

    close (12)

    close (14)


    ! Open and save calculated values of viscosity in viscosity text
file


    ! Plot the results


    open (16, file='density.txt')

    open (15, file='viscosity.txt')

        do p=p1,p2,step

            read (16,*) ro

            mi = 0.0001 * k * exp(x*ro**y)

            print *, 'Viscosity is ', mi

            write (15,*) mi

        end do


    end program
```

PART B - VDP RESULTS

Table 4 VDP program results

Pressure	Compressibility (Natural Gas)	Compressibility (Methane)	Density (Natural Gas)	Density (Methane)	Viscosity (Natural Gas)	Viscosity (Methane)
100	0.940794647	0.95528096	6.52E-03	4.77E-03	1.03E-02	1.12E-02
200	0.888207912	0.914390326	1.38E-02	9.97E-03	1.05E-02	1.13E-02
300	0.841188788	0.876856625	2.19E-02	1.56E-02	1.07E-02	1.15E-02
400	0.798897505	0.842282772	3.07E-02	2.17E-02	1.10E-02	1.17E-02
500	0.760655105	0.810331941	4.03E-02	2.81E-02	1.14E-02	1.19E-02
600	0.72590673	0.780716538	5.07E-02	3.50E-02	1.18E-02	1.22E-02
700	0.694194376	0.753189504	6.18E-02	4.24E-02	1.23E-02	1.25E-02
800	0.665136874	0.727537513	7.37E-02	5.01E-02	1.29E-02	1.28E-02
900	0.638414204	0.703575313	8.64E-02	5.83E-02	1.35E-02	1.32E-02
1000	0.613755822	0.681141198	9.99E-02	6.70E-02	1.43E-02	1.36E-02
1100	0.590931416	0.660093486	1.14E-01	7.60E-02	1.51E-02	1.40E-02
1200	0.569743752	0.640307605	0.129124671	8.55E-02	1.62E-02	1.45E-02
1300	0.55002284	0.621673346	0.14490059	9.54E-02	1.73E-02	1.51E-02
1400	0.531621516	0.604093015	0.161448136	0.105688252	1.87E-02	1.58E-02
1500	0.514411569	0.587479651	0.178767294	0.116439655	2.02E-02	1.65E-02
1600	0.498280913	0.571755588	0.196858093	0.12761803	2.20E-02	1.72E-02
1700	0.48313117	0.556851327	0.21572049	0.139223367	2.41E-02	1.81E-02
1800	0.468875468	0.542704344	0.235354513	0.151255682	2.65E-02	1.91E-02
1900	0.455436915	0.529258311	0.255760163	0.163714975	2.94E-02	2.02E-02
2000	0.442747235	0.516462564	0.276937425	0.176601186	3.27E-02	2.14E-02
2100	0.430745542	0.504270852	0.298886329	0.189914405	3.66E-02	2.27E-02
2200	0.419377327	0.492641479	0.321606845	0.203654587	4.12E-02	2.42E-02
2300	0.408593744	0.481536388	0.345098972	0.217821732	4.67E-02	2.59E-02
2400	0.398350835	0.47092095	0.369362712	0.232415825	5.33E-02	2.78E-02
2500	0.388608903	0.460763425	0.394398093	0.247436911	6.11E-02	2.99E-02
2600	0.379332095	0.451034844	0.420205086	0.262884945	7.05E-02	3.23E-02
2700	0.370487869	0.441708595	0.446783692	0.278759956	8.19E-02	3.50E-02
2800	0.362046659	0.432760239	0.474133909	0.295061916	9.57E-02	3.80E-02
2900	0.353981525	0.424167216	0.502255797	0.311790854	1.13E-01	4.14E-02
3000	0.346267879	0.415908813	0.531149268	0.328946769	1.33E-01	4.52E-02

Pressure	Compressibility (525R)	Compressibility (550R)	Density (525R)	Density (550R)	Viscosity (525R)	Viscosity (550R)
100	0.940794647	0.94995153	6.52E-03	6.16E-03	1.03E-02	1.08E-02
200	0.888207912	0.904673994	1.38E-02	1.29E-02	1.05E-02	1.10E-02
300	0.841188788	0.863516212	2.19E-02	2.03E-02	1.07E-02	1.12E-02
400	0.798897505	0.825940371	3.07E-02	2.83E-02	1.10E-02	1.14E-02
500	0.760655105	0.791498363	4.03E-02	3.70E-02	1.14E-02	1.17E-02
600	0.72590673	0.759813905	5.07E-02	4.62E-02	1.18E-02	1.21E-02
700	0.694194376	0.730568469	6.18E-02	5.61E-02	1.23E-02	1.25E-02
800	0.665136874	0.703490973	7.37E-02	6.65E-02	1.29E-02	1.30E-02
900	0.638414204	0.678348899	8.64E-02	7.76E-02	1.35E-02	1.35E-02
1000	0.613755822	0.654941916	9.99E-02	8.94E-02	1.43E-02	1.41E-02
1100	0.590931416	0.633096397	1.14E-01	1.02E-01	1.51E-02	1.48E-02
1200	0.569743752	0.612661183	0.129124671	1.15E-01	1.62E-02	1.56E-02
1300	0.55002284	0.593503892	0.14490059	0.128181085	1.73E-02	1.65E-02
1400	0.531621516	0.575508416	0.161448136	0.142357543	1.87E-02	1.75E-02
1500	0.514411569	0.558571994	0.178767294	0.157150671	2.02E-02	1.87E-02
1600	0.498280913	0.54260397	0.196858093	0.172560409	2.20E-02	2.00E-02
1700	0.48313117	0.527523518	0.21572049	0.188586786	2.41E-02	2.15E-02
1800	0.468875468	0.513258696	0.235354513	0.205229759	2.65E-02	2.32E-02
1900	0.455436915	0.499744982	0.255760163	0.222489387	2.94E-02	2.51E-02
2000	0.442747235	0.486924648	0.276937425	0.240365639	3.27E-02	2.74E-02
2100	0.430745542	0.474745631	0.298886329	0.258858532	3.66E-02	3.00E-02
2200	0.419377327	0.463160992	0.321606845	0.277968019	4.12E-02	3.29E-02
2300	0.408593744	0.452128261	0.345098972	0.297694176	4.67E-02	3.64E-02
2400	0.398350835	0.441608906	0.369362712	0.318036944	5.33E-02	4.04E-02
2500	0.388608903	0.431567907	0.394398093	0.338996351	6.11E-02	4.50E-02
2600	0.379332095	0.421973377	0.420205086	0.360572368	7.05E-02	5.04E-02
2700	0.370487869	0.412796199	0.446783692	0.382764995	8.19E-02	5.68E-02
2800	0.362046659	0.40400967	0.474133909	0.405574292	9.57E-02	6.42E-02
2900	0.353981525	0.395589411	0.502255797	0.429000199	1.13E-01	7.31E-02
3000	0.346267879	0.387512952	0.531149268	0.453042746	1.33E-01	8.35E-02

APPENDIX B – "KLINKENBERG" CODE

```
! NAME OF THE PROGRAM: Klinkenberg

! INFO: Program for calculation absolute permeability of core sample

! The program is made for the master's thesis purpose.

! AUTHOR: Obrad Slijepcevic

! INSTITUTION: University of Stavanger, Norway

! DATE: 30.05.2016


_____

program CoreSamplePermeability

real, parameter::error =0.0001

integer i

real xo,x1,f,f1,kg,pm

write (*,*), 'Guess initial absolute permeability of core sample in
mD'

read*,xo

kg=46.6

pm=2.152



i=1

22 x1=xo-(f(xo)/f1(xo))

if(abs((x1-xo)/x1)<error) then
```

```fortran
      print*,"Absolute permeability of core sample ", x1 ,"Number of
iteration = ", i

      else

      xo=x1

      i=i+1

      go to 22

      endif

      end


      real function f(x)

      real x,kg,pm

      kg=46.6

      pm=2.152

      f=6.9*x**0.64 + pm*x - pm*kg

      end


      real function f1(x)

      real x,kg,pm

      kg=46.6

      pm=2.152

      f1=4.416*(1/(x**0.36)) + pm

      end
```

APPENDIX C – FSGP SIMULATOR

Appendix C is composed of four parts. Part A contains programming code for FSGP simulator, second part is input file where data used in similar are listed, third part presents results from the output file, and last one, fourth part contains variables and integers used in the FSGP simulator.

PART A – FORTRAN CODE

```
C NAME OF THE PROGRAM: FORTRAN CODE FOR SHALE GAS PRODUCTION (FSGP)

C INFO: Program for 2D reservoir at constant bottom hole pressure

C The program is made for the master's thesis purpose.

C AUTHOR: Obrad Slijepcevic

C INSTITUTION: University of Stavanger, Norway

C DATE: 27.05.2016

C     * All real variables are defined using DOUBLE PRECISION



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,VELOCITY,

      +TIME,TIMEYRS,PERMCONST,TOTDES,DHRUVIT


       INTEGER STMAX,

      +L,MX,NX,ISOL,IPE,ISKIP,IWRITE,IFLAG,LCYSW,

      +IM,KCY,MXP1,II,IWC,

      +ICRN,G,INJCONST,J


C      CHARACTER PFILE*6


C      * Present dimensioning allows the simulation of a 20 block

C      * linear system.


       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)
```

```fortran
C     * Common storage area is used between this, the main program

C     * and the subroutines.


      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     * Open files for READING and WRITING:

C     * Simnagdata.dat is your SOURCE file,

C     * Simnagout.dat is your OUTPUT file.


      OPEN (5,FILE='FSGP_data.dat')

      OPEN (6,FILE='FSGP_output.dat')

      OPEN (7,FILE='FSGP_plotdata.dat')


C     * Read form source file.


      WRITE (6,3000)

      READ  (5,*) MX,NX,STMAX,IWC,IPE,ISKIP,IWRITE,IFLAG
```

```fortran
      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,VELOCITY   !Non-Darcy velocity



C    Source term definition of the blocks

      QG(1:NX,1:MX) = 0



C    Matrix permeability in X-direction

      DO 656 I = 1,NX

         READ (5,*) (KX(I,K), K = 1,MX)

  656    CONTINUE



C    Block length in x-direction

      DEX(1:NX,1) = FRACX        ! DEFINITION OF FRACTURE WIDTH


      DO 655 I = 1,NX

         READ (5,*) (DEX(I,K), K = 2,MX) ! WIDTH OF MAIN MATRIX CELLS

  655    CONTINUE
```

```fortran
C   Block length in z-direction

        DEZ(1:NX,2:MX) = DEX(1:NX,2:MX)     ! BLOCK LENGTH = BLOCK HEIGHT
SINCE ITS A CUBE

        DEZ(1:NX,1) = DEX(1:NX,2)




C   Defining porosity in each block

      DO 658 I = 1,NX

          READ (5,*) (PHI(I,K), K = 1,MX)     ! POROSITY OF EACH CELL

  658   CONTINUE




C     * Write to output file.


      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


      DO 972 I = 1,NX

        WRITE (6,3035) (I,K,DEX(I,K), K = 1,MX)    !Print block length
in X-direction

  972   CONTINUE
```

```fortran
      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


      WRITE (6,3080)

      DO 971 I = 1,NX

         WRITE (6,3036) (I,K,PHI(I,K), K = 1,MX)    !Print Porosity

  971    CONTINUE


      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    * Define constants.


      PI  =3.1415926D0

      PERMCONST = 1.06235D-14

      CKBAK =  0.00632827        ! constant
```

```fortran
      CKZ = 0.00632827*KF/(DEZ(NX,1)**2)/

     +  (VISORG+(2*0.00001*VELOCITY*KF*BORIG))   !Non-Darcy constant for
flow within the fracture

   ! BETA VALUE IS 0.0001 AND IT IS CHANGED MANUALLY



   C     * Initializing variables.


      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
```

```fortran
      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



      IM = 1

      DO 989 I = 1,NX

         DO 988 K = 1,MX

          IF(K .GT. 1) IM = K-1

  C        Non-Darcy constant for flow within the reservoir

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

     +           /DEX(I,K)/(VISORG+(2*0.00001*VELOCITY*KX(I,K)*BORIG))

  ! BETA VALUE IS 0.0001 AND IT IS CHANGED MANUALLY

           A2(I,K) = PHI(I,K)*DBDP

           VOL(I,K) = (DEX(I,K)*DEY*DEZ(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)
```

84

```fortran
      988    CONTINUE

      989    CONTINUE


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        Drainage Radius = DR

        DR = sqrt(DEZ(NX,1)*DEY/PI)


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
```

```fortran
      ENDIF

      PCONST= 6.89475E06*WC*BORIG/VISORG/VOL(NX,1)          ! Pressure
constant

   C     * Reservoir boundary conditions.



   C     * Define center of position in cells (pressure points).



      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     * Initializing rates and pressures.



      DO 10 I = 1,NX

         DO 986 K = 1,MX
```

```fortran
          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

    986  CONTINUE

    10   CONTINUE



    C       * Define original GIP.

          OGIP = FGIP + ADGASTOT



          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       * Start time step loop.
```

```fortran
      DO 6070 L = 1,STMAX              ! Main loop.


          POLD(1:NX,1:MX)=PG(1:NX,1:MX)



      LCYSW=0
```

C   * Time step calculation.


```fortran
      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


      TIMEINC = DELT                  ! DELT increases with time.

      WRITE (6,3070)
```

C   * Start iteration procedure.

```fortran
 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



      CALL  FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX) ! Parameters used  in
FLUIDPROP

      CALL MATRIXCOEFF(MX,BGIJ,DELT,ICRN,VL,PL,G,RHOR,NX,CKZ,

     +BHP,PCONST,INJCONST,CRITDESPR,VELOCITY,PHI)  ! Parameters  used  in
MATRIXCOEFF



      CALL MATRIX(NX,MX)              ! Direct solution.



  C     * Check on pressure change in all blocks.



      DPMX = DABS( PG(NX,1)-POLD(NX,1) )

      II = 1

      J = NX-1

      DO 33 I = 1,J
```

```fortran
          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     * 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)


      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 //)
```

90

```fortran
      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     * End iteration procedure.


      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


      TOTDES = 0.

      J = NX-1

      DO 889 I = 1,J

        DO 980 K = 2,MX
```

```fortran
      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)


      ENDIF

      TOTDES = TOTDES + VOLDES(I,K)

 980  CONTINUE

 889  CONTINUE


C     Well Flow rate calculation
      QG(NX,1) = (6.89475D06)*WC*(PG(NX,1)-BHP)*BORIG/VISORG


C     * Start mass balance calculation.


 6071 CONTINUE


      CTIM = CTIM + TIMEINC            ! Sum time increment.


      CALL FLUIDPROP(MX,BGIJ,PORIG,DBDP,BORIG,NX) ! New volume factors.
```

```fortran
      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


      NP = NP+(QG(NX,1)*TIMEINC)


      NPC = NP/(OGIP)*100.                    ! Mass balance.


      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


       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


       WRITE (6,3080)

       WRITE (6,3120) QG(NX,1)

  3120 FORMAT(' Gas Production Rate ; QG (scf/sec) ..........',F15.4/)   !
Print Gas production rate


       WRITE (6,3060)L,CTIM,NP,DELT,KCY,TOTDES,NT,NPC

   401 CONTINUE


       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.


  6070  CONTINUE                  ! End time step loop



   C     * Close files.


      CLOSE(5)
```

```fortran
      CLOSE(6)

      CLOSE(7)


C     * Format statements.


 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                              '/
     + '  - WHOLE FLOW PATH IS CONSIDETED AS NON DARCY FLOW  '/
     + '  - 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         '//)



 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  //)



 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/

/)


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 /

/)


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 /)


3035 FORMAT (

+ ' BLOCK NO. :', I3, I3, '   BLOCK LENGTH, DEX, (FT) .', F10.3)
```

```
3038 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  BLOCK HEIGHT, DEZ, (FT) .', F10.3)


3036 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  POROSITY, PHI, ......... ', F10.4)


3037 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  PERMEABILITY, KX, (mD).. ', F12.4)


3040 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  PRESSURE POINT, X(I), FT ', F8.1)


3050 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  GAS PRESSURE, PSIA ..... ', F15.6)


3030 FORMAT (

    + ' BLOCK NO. :', I3, I3, '  GAS DESORBED, SCF ...... ', F15.6)


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)
```

```
 3070 FORMAT (18('****')/)


 3080 FORMAT (/)

      STOP

      END



C     ************************************************************

C     *                END OF MAIN PROGRAM

C     ************************************************************



C     ************************************************************

C     *                SUBROUTINE MATRIX

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)
```

```fortran
      C

            N = (NX*MX) - MX + 1        ! No. of equations

            lda= size(a_full,1)

            ldb = size(b,1)

            nrhs = 1



      C        Defining coefficients of matrix A for equation AX = B

             a_full(1:N,1:N) = 0.0d0



             DO 501 I = 1,N

              a_full(I,I) = 1.0d0      ! Defining main diagonal as unit
        501  CONTINUE



             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


      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


      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
```

```fortran
        IF (L.LT.MX) THEN

            L = L + 1

        ELSE

            L = 1

            J = J + 1

        ENDIF

    504 CONTINUE


    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
```

```fortran
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     Matrix is solved by linking the compiler with NAG library

C     Factorize

C     The NAG name equivalent of dgetrf is f07adf

      Call dgetrf(n,n,a_full,lda,ipiv,info)


      If (info==0) Then

C       Compute solution
```

```fortran
C        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


           PG(J,K) = b(I,1)


           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


       DIMENSION BGIJ(20,20)


       COMMON /BLK1/A(20,20),C(20,20),D(20,20),AL(20,20),S(20,20),
```

105

```fortran
     +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     * Volume factors


      DO 20 I = 1,NX

          DO 977 K = 1,MX

  977     BGIJ(I,K) = BORIG+(PG(I,K)-PORIG)*DBDP

   20     CONTINUE


      RETURN

      END
C     ************************************************************
C     *            END OF SUBROUTINE FLUIDPROP
C     ************************************************************



C     ************************************************************
C     *            SUBROUTINE MATRIXCOEFF
C     ************************************************************
```

```fortran
      SUBROUTINE MATRIXCOEFF(MX,BGIJ,DELT,ICRN,VL,PL,G,RHOR,NX,CKZ,
     +BHP,PCONST,INJCONST,CRITDESPR,VELOCITY,PHI)
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,VELOCITY,PHI
      INTEGER  MX,I,IM,ICRN,G,NX,INJCONST,J


      DIMENSION BGIJ(20,20),G(20,20),INJCONST(20,20),PHI(20,20)


      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     * Matrix coefficients.


C    Defining matrix coefficients for non-Darcy flow within the fracture.


      J = NX-1
```
107

```fortran
      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     Defining matrix coefficients for non-Darcy flow within the reservoir.


      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.


      J = NX-1

      DO 975 I = 1,J

         K = 1

         B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)-
```

```
+      (VELOCITY*A2(I,K))/(PHI(I,K)*DEX(I,K))-(VELOCITY*A2(I,K))

+    /(PHI(I,K)*DEZ(I,K))+(A2(I,K)/DELT)

     A(I,K) = OXMIN(I,K)/B

     C(I,K) = (OXPLUS(I,K)-(VELOCITY*A2(I,K)/PHI(I,K)/DEX(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)-(VELOCITY*A2(I,K)/PHI(I,K)/DEZ(I,K)))/B

975    CONTINUE


     B = OXMIN(NX,1)+OXPLUS(NX,1)+OZMIN(NX,1)+OZPLUS(NX,1)+PCONST-

+    (VELOCITY*A2(NX,1))/(PHI(NX,1)*DEX(NX,1))-(VELOCITY*A2(NX,1))

+    /(PHI(NX,1)*DEZ(NX,1))+(A2(NX,1)/DELT)

     A(NX,1) = OXMIN(NX,1)/B

     C(NX,1) = (OXPLUS(NX,1)-(VELOCITY*A2(NX,1)/PHI(NX,1)

+    /DEX(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)-(VELOCITY*A2(NX,1)/PHI(NX,1)

+    /DEZ(NX,1)))/B



C    Defining matrix coefficients for non-Darcy flow within the reservoir.
```

```fortran
      DO 51 I = 1,J

        DO 974 K = 2,MX

        IF ((POLD(I,K).LT.CRITDESPR).AND.(INJCONST(I,K).EQ.0))THEN
```

C   Defining matrix coefficients for non-Darcy flow when

C   actual reservoir pressure is below the critical desorption pressure.

C   Desorption term is included into coefficients.

```fortran
        B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)-
     +    (VELOCITY*A2(I,K))/(PHI(I,K)*DEX(I,K))-(VELOCITY*A2(I,K))
     +    /(PHI(I,K)*DEZ(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)-(VELOCITY*A2(I,K)/PHI(I,K)/DEX(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)-(VELOCITY*A2(I,K)/PHI(I,K)/DEZ(I,K)))/B
        G(I,K) = 1
      ELSE
```

C   Defining matrix coefficients for non-Darcy flow when

```fortran
C    actual reservoir pressure is above the critical desorption pressure

C      Without desorption term.


         B = OXMIN(I,K)+OXPLUS(I,K)+OZMIN(I,K)+OZPLUS(I,K)-

   +     (VELOCITY*A2(I,K))/(PHI(I,K)*DEX(I,K))-(VELOCITY*A2(I,K))

   +     /(PHI(I,K)*DEZ(I,K))+(A2(I,K)/DELT)

         A(I,K) = OXMIN(I,K)/B

         C(I,K) = (OXPLUS(I,K)-(VELOCITY*A2(I,K)/PHI(I,K)/DEX(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)-(VELOCITY*A2(I,K)/PHI(I,K)/DEZ(I,K)))/B

         G(I,K) = 0

       ENDIF

  974      CONTINUE

  51     CONTINUE


      RETURN

      END

C    ***********************************************************

C    *              END OF SUBROUTINE MATRIXCOEFF

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     * Data is written to file.


      WRITE(7,4000) NP

 4000 FORMAT(F20.6,2X,F15.4)




      RETURN

      END



C     ************************************************************

C     *                END SUBROUTINE PLOTFILES

C     ************************************************************
```

PART B – INPUT DATA FILE

```
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

0.09914,2695.57,168.55,2800,0.00001***     VL,PL,RHOR,CRITDESPR,BETA***

6.42,20                                    RHOG,RADSPH

20,100,0.0001                              FRACX,CUBESIZE,VELOCITY

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)
```

*** BETA value is manually changed in lines 128 and 164.

PART B – FSGP SIMULATOR OUTPUT


```
***** 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 3099.942497
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.000091
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000093
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000093
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000093
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000093
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.937286
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 3099.926400

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```
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= 0.3275-301
  NT= 0.8213D+06  NPC= 0.1021D-04
 *************************************************************************


BLOCK NO. : 1 1  GAS PRESSURE, PSIA .....   3099.846282
BLOCK NO. : 1 2  GAS PRESSURE, PSIA .....   3100.000222
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....   3100.000232
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....   3100.000233
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....   3100.000233
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....   3100.000233
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....   3099.840469
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 .....   3099.828813
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
```

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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) 81.6321

 STEPS= 2   TIME= 0.3750D-02 NP= 0.3061D+00

 DELT= 0.2250D-02 CUM CYCLE= 4   TOTDES= 0.3275-301

 NT= 0.8213D+06 NPC= 0.2553D-04

 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.701089

 BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.000406

 BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000442

 BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000442

 BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000442

 BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000442

 BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.695238

 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 3099.683543

 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) 81.6105

 STEPS= 3   TIME= 0.7125D-02 NP= 0.5816D+00

 DELT= 0.3375D-02 CUM CYCLE= 6   TOTDES= 0.3275-301

 NT= 0.8213D+06 NPC= 0.4849D-04

 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.483419

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.000656
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.000756
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.000756
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.000756
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.000756
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.477568
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.999899
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 3099.465873
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) 81.5782
 STEPS= 4   TIME= 0.1219D-01 NP= 0.9946D+00
 DELT= 0.5063D-02 CUM CYCLE= 8   TOTDES= 0.3275-301
 NT= 0.8213D+06 NPC= 0.8293D-04
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3099.157309
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.000969
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.001226
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.001226
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.001226
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.001227
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3099.151459
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 3099.139767
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) 81.5298

STEPS= 5   TIME= 0.1978D-01 NP= 0.1614D+01
DELT= 0.7594D-02 CUM CYCLE= 10   TOTDES= 0.3275-301
NT= 0.8213D+06 NPC= 0.1346D-03
****
BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3098.669036
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.001303
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.001933
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.001933
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.001933
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.001933
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3098.663188
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.999367
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 3100.000001
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3098.651501
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

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Gas Production Rate ; QG (scf/sec) 81.4573

STEPS= 6   TIME= 0.3117D-01   NP= 0.2542D+01
DELT= 0.1139D-01 CUM CYCLE= 12   TOTDES= 0.3275-301
NT= 0.8213D+06   NPC= 0.2119D-03
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3097.938625
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.001497
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.002991
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.002992
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.002992
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.002993
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3097.932781
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.998500
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 3100.000001
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3097.921101
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) 81.3489

STEPS= 7   TIME= 0.4826D-01   NP= 0.3931D+01
DELT= 0.1709D-01 CUM CYCLE= 14   TOTDES= 0.3275-301
NT= 0.8213D+06   NPC= 0.3278D-03
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3096.847491
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3100.001102

```
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....    3100.004579
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....    3100.004581
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....    3100.004581
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....    3100.004584
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....    3096.841653
BLOCK NO. : 2 2  GAS PRESSURE, PSIA .....    3099.996515
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 .....    3100.000003
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....    3096.829983
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) ..........    81.1869


 STEPS=  8     TIME= 0.7389D-01  NP= 0.6012D+01
 DELT= 0.2563D-01 CUM CYCLE= 16     TOTDES= 0.3275-301
 NT= 0.8213D+06  NPC= 0.5013D-03
 *************************************************************************


BLOCK NO. : 1 1  GAS PRESSURE, PSIA .....    3095.220806
BLOCK NO. : 1 2  GAS PRESSURE, PSIA .....    3099.998977
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....    3100.006958
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....    3100.006964
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....    3100.006964
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....    3100.006971
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....    3095.214975
BLOCK NO. : 2 2  GAS PRESSURE, PSIA .....    3099.992009
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 .....    3100.000007
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....    3095.203321
```

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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) 80.9454

 STEPS= 9   TIME= 0.1123D+00   NP= 0.9124D+01
 DELT= 0.3844D-01 CUM CYCLE= 18   TOTDES= 0.3275-301
 NT= 0.8213D+06   NPC= 0.7608D-03
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3092.803088
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.992385
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.010518
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.010540
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.010540
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.010555
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3092.797269
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.981848
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 3100.000015
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3092.785640
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

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```
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) 80.5864

```
STEPS=  10      TIME=  0.1700D+00   NP=  0.1377D+02
DELT=  0.5767D-01 CUM CYCLE=  20      TOTDES=  0.3275-301
NT=  0.8213D+06  NPC=  0.1148D-02
**************************************************************************

BLOCK NO. : 1 1  GAS PRESSURE, PSIA .....    3089.225971
BLOCK NO. : 1 2  GAS PRESSURE, PSIA .....    3099.974964
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....    3100.015829
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....    3100.015902
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....    3100.015903
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....    3100.015936
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....    3089.220169
BLOCK NO. : 2 2  GAS PRESSURE, PSIA .....    3099.959085
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 .....    3100.000033
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....    3089.208575
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) 80.0553

```
STEPS=  11      TIME=  0.2565D+00   NP=  0.2070D+02
```

DELT= 0.8650D-01 CUM CYCLE= 22   TOTDES= 0.3275-301

NT= 0.8213D+06   NPC= 0.1726D-02

****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3083.969128

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.932318

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.023699

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.023946

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.023947

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.024022

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3083.963352

BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.908452

BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.999752

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 3100.000075

BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3083.951809

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) 79.2749

STEPS= 12   TIME= 0.3862D+00   NP= 0.3098D+02

DELT= 0.1297D+00 CUM CYCLE= 24   TOTDES= 0.3275-301

NT= 0.8213D+06   NPC= 0.2583D-02

****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3076.320748

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.832604

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.035187

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.036011

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.036014

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.036180

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3076.315010

BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.796816
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.999174
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 3100.000166
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3076.303544
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) 78.1393

 STEPS= 13   TIME= 0.5809D+00 NP= 0.4619D+02
 DELT= 0.1946D+00 CUM CYCLE= 26   TOTDES= 0.3275-301
 NT= 0.8213D+06 NPC= 0.3851D-02
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3065.355524
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.607140
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.051387
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.054099
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.054116
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.054481
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3065.349841
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.553595
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.997276
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999985
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000002
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000367
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3065.338484
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) 76.5114

 STEPS= 14   TIME= 0.8728D+00   NP= 0.6852D+02

 DELT= 0.2919D+00 CUM CYCLE= 28   TOTDES= 0.3275-301

 NT= 0.8213D+06   NPC= 0.5714D-02
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3049.968857
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3099.112343
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.072397
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.081193
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.081270
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.082065
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3049.963252
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3099.032446
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.991144
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999928
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000006
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.000799
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3049.952051
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

128

BLOCK NO. : 2 6 GAS DESORBED, SCF 0.000000

 Gas Production Rate ; QG (scf/sec) 74.2270

 STEPS= 15   TIME= 0.1311D+01   NP= 0.1010D+03
 DELT= 0.4379D+00 CUM CYCLE= 30   TOTDES= 0.3275-301
 NT= 0.8213D+06   NPC= 0.8424D-02
 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3029.033377
 BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3098.060478
 BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.093708
 BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.121651
 BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.122009
 BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.123709
 BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3029.027881
 BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3097.941679
 BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.971758
 BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.999660
 BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000017
 BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.001714
 BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3029.016897
 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) 71.1188

 STEPS= 16   TIME= 0.1968D+01   NP= 0.1477D+03
 DELT= 0.6568D+00 CUM CYCLE= 32   TOTDES= 0.3275-301
 NT= 0.8213D+06   NPC= 0.1232D-01
 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 3001.755920

129

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3095.907991

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.095242

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.181512

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.183127

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.186686

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 3001.750570

BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3095.732204

BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.912303

BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.998429

BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000041

BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.003595

BLOCK NO. : 3 1 GAS PRESSURE, PSIA 3001.739879

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) 67.0690

 STEPS= 17   TIME= 0.2953D+01 NP= 0.2138D+03

 DELT= 0.9853D+00 CUM CYCLE= 35   TOTDES= 0.3275-301

 NT= 0.8213D+06 NPC= 0.1783D-01
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2968.248107

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3091.710168

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3100.011631

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.267724

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.274770

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.282068

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2968.242945

BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3091.451830

BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.737392

BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.993005

BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3100.000039

BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.007323

BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2968.232631
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) 62.0943

 STEPS= 18   TIME= 0.4431D+01   NP= 0.3056D+03
 DELT= 0.1478D+01 CUM CYCLE= 38   TOTDES= 0.3275-301
 NT= 0.8213D+06   NPC= 0.2548D-01
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2930.096261
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3084.007513
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3099.661249
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.382567
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.411762
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.426598
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2930.091329
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3083.631484
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3099.250649
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.970419
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.999551
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.014355
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2930.081480
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

131

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) 56.4300

 STEPS= 19   TIME= 0.6648D+01 NP= 0.4307D+03
 DELT= 0.2217D+01 CUM CYCLE= 41   TOTDES= 0.3275-301
 NT= 0.8212D+06 NPC= 0.3591D-01
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2890.372808
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3070.893735
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3098.602862
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.501240
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.613974
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.645258
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2890.368146
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3070.353522
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3097.989523
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.883076
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.995526
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.026729
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2890.358840
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) 50.5325

STEPS= 20   TIME= 0.9973D+01   NP= 0.5987D+03

DELT= 0.3325D+01 CUM CYCLE= 44   TOTDES= 0.3275-301

NT= 0.8211D+06   NPC= 0.4992D-01
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2852.522517

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3050.434253

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3095.908894

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3100.502052

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.899549

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.973921

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2852.518158

BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3049.671334

BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3094.996638

BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3099.575470

BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.971743

BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.045879

BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2852.509460

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) 44.9130

STEPS= 21   TIME= 0.1496D+02   NP= 0.8227D+03

DELT= 0.4988D+01 CUM CYCLE= 47   TOTDES= 0.3275-301

NT= 0.8209D+06   NPC= 0.6860D-01
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2818.504271

BLOCK NO. : 1 2 GAS PRESSURE, PSIA 3021.411727

BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3089.934794

BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3099.994751

BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3101.248368

BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3101.457310

133

BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2818.500243
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 3020.356609
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3088.587985
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3098.608008
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.856746
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.064854
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2818.492213
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) 39.8626

 STEPS= 22   TIME= 0.2244D+02   NP= 0.1121D+04
 DELT= 0.7482D+01 CUM CYCLE= 50   TOTDES= 0.3275-301
 NT= 0.8206D+06   NPC= 0.9347D-01
 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2790.260311
 BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2987.527576
 BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3079.732558
 BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3098.337002
 BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3101.487898
 BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3102.056295
 BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2790.256614
 BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2986.137569
 BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3077.831431
 BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3096.341943
 BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3099.477459
 BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3100.043045
 BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2790.249250
 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

134

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) 35.6694

 STEPS= 23   TIME= 0.3244D+02 NP= 0.1478D+04
 DELT= 0.1000D+02 CUM CYCLE= 53   TOTDES= 0.3275-301
 NT= 0.8203D+06 NPC= 0.1232D+00
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2770.177046
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2958.454329
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3068.261524
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3095.745540
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3101.436923
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3102.575458
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2770.173612
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2956.771401
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3065.832442
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3093.150757
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3098.809584
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.941618
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2770.166779
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) 32.6878

 STEPS= 24   TIME= 0.4244D+02   NP= 0.1805D+04
 DELT= 0.1000D+02 CUM CYCLE= 56   TOTDES= 0.3275-301
 NT= 0.8199D+06   NPC= 0.1505D+00
 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2754.565868
 BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2933.547973
 BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3056.190321
 BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3092.327403
 BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3101.054595
 BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3102.981666
 BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2754.562651
 BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2931.604323
 BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3053.258459
 BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3089.142857
 BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3097.813103
 BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.727793
 BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2754.556258
 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) 30.3701

 STEPS= 25   TIME= 0.5244D+02   NP= 0.2108D+04
 DELT= 0.1000D+02 CUM CYCLE= 59   TOTDES= 0.3275-301
 NT= 0.8196D+06   NPC= 0.1758D+00
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2741.779373
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2912.109622
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3043.969825
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3088.214277
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3100.320840
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3103.243741
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2741.776341
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2909.930392
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3040.558674
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3084.450850
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3096.468735
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3099.370812
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2741.770320
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) 28.4718

STEPS= 26   TIME= 0.6244D+02   NP= 0.2393D+04
DELT= 0.1000D+02 CUM CYCLE= 62   TOTDES= 0.3275-301
NT= 0.8193D+06   NPC= 0.1995D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2730.985792
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2893.525082
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 3031.893291
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3083.540792
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3099.232383
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3103.334232
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2730.982917
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2891.130252
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 3028.024479
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3079.209919
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3094.773936

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```
BLOCK NO. : 2 6  GAS PRESSURE, PSIA .....   3098.843689
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....   2730.977217
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) 26.8694

```
STEPS= 27     TIME= 0.7244D+02  NP= 0.2662D+04
DELT= 0.1000D+02 CUM CYCLE= 65     TOTDES= 0.3275-301
NT= 0.8190D+06  NPC= 0.2219D+00
```
****

```
BLOCK NO. : 1 1  GAS PRESSURE, PSIA .....   2721.703506
BLOCK NO. : 1 2  GAS PRESSURE, PSIA .....   2877.289539
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....   3020.144012
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....   3078.432729
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....   3097.798460
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....   3103.230484
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....   2721.700770
BLOCK NO. : 2 2  GAS PRESSURE, PSIA .....   2874.695266
BLOCK NO. : 2 3  GAS PRESSURE, PSIA .....   3015.837309
BLOCK NO. : 2 4  GAS PRESSURE, PSIA .....   3073.546103
BLOCK NO. : 2 5  GAS PRESSURE, PSIA .....   3092.738584
BLOCK NO. : 2 6  GAS PRESSURE, PSIA .....   3098.124262
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....   2721.695347
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
```

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```
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) 25.4913


```
 STEPS=  28      TIME=  0.8244D+02   NP=  0.2917D+04
 DELT=  0.1000D+02  CUM CYCLE=  68      TOTDES=  0.3275-301
 NT=  0.8188D+06   NPC=  0.2432D+00
```
****

```
BLOCK NO. : 1 1  GAS PRESSURE, PSIA .....    2713.617893
BLOCK NO. : 1 2  GAS PRESSURE, PSIA .....    2862.997422
BLOCK NO. : 1 3  GAS PRESSURE, PSIA .....    3008.830183
BLOCK NO. : 1 4  GAS PRESSURE, PSIA .....    3073.001464
BLOCK NO. : 1 5  GAS PRESSURE, PSIA .....    3096.036917
BLOCK NO. : 1 6  GAS PRESSURE, PSIA .....    3102.915099
BLOCK NO. : 2 1  GAS PRESSURE, PSIA .....    2713.615277
BLOCK NO. : 2 2  GAS PRESSURE, PSIA .....    2860.216989
BLOCK NO. : 2 3  GAS PRESSURE, PSIA .....    3004.103599
BLOCK NO. : 2 4  GAS PRESSURE, PSIA .....    3067.570823
BLOCK NO. : 2 5  GAS PRESSURE, PSIA .....    3090.381082
BLOCK NO. : 2 6  GAS PRESSURE, PSIA .....    3097.195638
BLOCK NO. : 3 1  GAS PRESSURE, PSIA .....    2713.610099
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) 24.2909

STEPS= 29   TIME= 0.9244D+02   NP= 0.3159D+04

DELT= 0.1000D+02 CUM CYCLE= 71   TOTDES= 0.3275-301

NT= 0.8185D+06   NPC= 0.2634D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2706.504803
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2850.324608
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2998.009497
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3067.342128
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3093.970992
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3102.375947
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2706.502294
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2847.369106
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2992.879420
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3061.379090
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3087.725130
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3096.046188
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2706.497332
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) 23.2349

STEPS= 30   TIME= 0.1024D+03   NP= 0.3392D+04

DELT= 0.1000D+02 CUM CYCLE= 74   TOTDES= 0.3275-301

NT= 0.8182D+06   NPC= 0.2828D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2700.195551
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2839.011452
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2987.706182
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3061.533839
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3091.626820

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BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3101.605845
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2700.193137
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2835.890276
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2982.187537
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3055.049798
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3084.797248
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3094.669217
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2700.188368
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) 22.2982

STEPS= 31   TIME= 0.1124D+03   NP= 0.3615D+04
DELT= 0.1000D+02 CUM CYCLE= 77   TOTDES= 0.3275-301
NT= 0.8180D+06   NPC= 0.3014D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2694.558900
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2828.848776
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2977.922687
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3055.641013
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3089.031602
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3100.602058
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2694.556571
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2825.569990
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2972.029087
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3048.647065
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3081.624944
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3093.062452
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2694.551975
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) 21.4614

 STEPS= 32   TIME= 0.1224D+03   NP= 0.3829D+04
 DELT= 0.1000D+02 CUM CYCLE= 80   TOTDES= 0.3275-301
 NT= 0.8178D+06   NPC= 0.3193D+00
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2689.490587
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2819.666846
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2968.647636
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3049.715132
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3086.212324
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3099.365693
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2689.488335
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2816.237455
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2962.391534
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3042.222028
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3078.235444
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3091.227433
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2689.483895
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) ..........      20.7089


  STEPS=  33      TIME=  0.1324D+03   NP=  0.4037D+04
  DELT= 0.1000D+02 CUM CYCLE=  83      TOTDES=  0.3275-301
  NT= 0.8175D+06   NPC=  0.3366D+00
 *************************************************************************


   BLOCK NO. : 1  1  GAS PRESSURE, PSIA .....    2684.906572
   BLOCK NO. : 1  2  GAS PRESSURE, PSIA .....    2811.326882
   BLOCK NO. : 1  3  GAS PRESSURE, PSIA .....    2959.861221
   BLOCK NO. : 1  4  GAS PRESSURE, PSIA .....    3043.796618
   BLOCK NO. : 1  5  GAS PRESSURE, PSIA .....    3083.194906
   BLOCK NO. : 1  6  GAS PRESSURE, PSIA .....    3097.901063
   BLOCK NO. : 2  1  GAS PRESSURE, PSIA .....    2684.904389
   BLOCK NO. : 2  2  GAS PRESSURE, PSIA .....    2807.753039
   BLOCK NO. : 2  3  GAS PRESSURE, PSIA .....    2953.254037
   BLOCK NO. : 2  4  GAS PRESSURE, PSIA .....    3035.814746
   BLOCK NO. : 2  5  GAS PRESSURE, PSIA .....    3074.654854
   BLOCK NO. : 2  6  GAS PRESSURE, PSIA .....    3089.168874
   BLOCK NO. : 3  1  GAS PRESSURE, PSIA .....    2684.900091
   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) ..........      20.0284


  STEPS=  34      TIME=  0.1424D+03   NP=  0.4237D+04
  DELT= 0.1000D+02 CUM CYCLE=  86      TOTDES=  0.3275-301
  NT= 0.8173D+06   NPC=  0.3533D+00
 *************************************************************************
```

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BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2680.738353
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2803.714534
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2951.538817
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3037.916644
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3080.003689
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3096.215073
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2680.736234
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2800.001695
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2944.591067
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3029.456019
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3070.907652
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3086.894041
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2680.732065
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) 19.4096

STEPS= 35   TIME= 0.1524D+03 NP= 0.4431D+04
DELT= 0.1000D+02 CUM CYCLE= 89   TOTDES= 0.3275-301
NT= 0.8171D+06 NPC= 0.3695D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2676.929570
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2796.734865
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2943.653406
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3032.098757
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3076.661155
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3094.316641
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2676.927509
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2792.887911
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2936.374799
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3023.169024

BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3067.016415
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3084.412180
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2676.923458
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) 18.8441

 STEPS= 36   TIME= 0.1624D+03   NP= 0.4619D+04
 DELT= 0.1000D+02 CUM CYCLE= 92   TOTDES= 0.3275-301
 NT= 0.8169D+06   NPC= 0.3852D+00
 ****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2675.447825
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2796.717363
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2936.908629
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3026.444234
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3073.197449
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3092.217073
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2675.445772
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2792.870058
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2929.322700
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3017.056308
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3063.011536
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3081.734905
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2675.441737
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 26.134128

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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 26.695518

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) 18.6241

 STEPS= 37   TIME= 0.1724D+03   NP= 0.4806D+04

 DELT= 0.1000D+02 CUM CYCLE= 94   TOTDES= 0.5283D+02

 NT= 0.8168D+06 NPC= 0.4007D+00

 ****

 BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2674.868519

 BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2796.697788

 BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2931.069475

 BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3021.008136

 BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3069.643699

 BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3089.930468

 BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2674.866469

 BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2792.850048

 BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2923.195644

 BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3011.173485

 BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3058.924421

 BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3078.876621

 BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2674.862440

 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 55.363598

 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 56.617048

 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) 18.5381

STEPS= 38   TIME= 0.1824D+03   NP= 0.4991D+04
DELT= 0.1000D+02 CUM CYCLE= 96   TOTDES= 0.1120D+03
NT= 0.8166D+06   NPC= 0.4162D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2674.637741
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2796.676543
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2925.958545
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3015.816217
BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3066.028685
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3087.472908
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2674.635692
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2792.828287
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2917.813074
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3005.546407
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3054.784106
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3075.853701
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2674.631666
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 87.088036
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 89.156686
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) 18.5038

STEPS= 39   TIME= 0.1924D+03   NP= 0.5176D+04
DELT= 0.1000D+02 CUM CYCLE= 98   TOTDES= 0.1762D+03
NT= 0.8165D+06   NPC= 0.4316D+00
****

BLOCK NO. : 1 1 GAS PRESSURE, PSIA 2674.541320
BLOCK NO. : 1 2 GAS PRESSURE, PSIA 2796.653878
BLOCK NO. : 1 3 GAS PRESSURE, PSIA 2921.439503
BLOCK NO. : 1 4 GAS PRESSURE, PSIA 3010.875805

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BLOCK NO. : 1 5 GAS PRESSURE, PSIA 3062.377423
BLOCK NO. : 1 6 GAS PRESSURE, PSIA 3084.861661
BLOCK NO. : 2 1 GAS PRESSURE, PSIA 2674.539272
BLOCK NO. : 2 2 GAS PRESSURE, PSIA 2792.805031
BLOCK NO. : 2 3 GAS PRESSURE, PSIA 2913.036205
BLOCK NO. : 2 4 GAS PRESSURE, PSIA 3000.182236
BLOCK NO. : 2 5 GAS PRESSURE, PSIA 3050.615813
BLOCK NO. : 2 6 GAS PRESSURE, PSIA 3072.683686
BLOCK NO. : 3 1 GAS PRESSURE, PSIA 2674.535247
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 120.931970
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 123.932569
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) 18.4895

 STEPS= 40   TIME= 0.2024D+03 NP= 0.5361D+04
 DELT= 0.1000D+02 CUM CYCLE= 100   TOTDES= 0.2449D+03
 NT= 0.8164D+06 NPC= 0.4470D+00
 ****

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PART D – VARIABLES AND INTEGERS

Table 5 List of variables used in FSGP simulator.

Variables	Description
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 (ft3)
VOLPHI	Vore volume of block (ft3)
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 (ft3)
VELOCITY	Velocity of gas (m/s)
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)

Table 6 List of integers used in FSGP simulator.

Integer	Description
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