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Full Length Research Article

ANALYSIS OF TEMPERATURE AND PRESSURE SURGE DISTRIBUTION FOR SINGLE PHASE GAS FLOW DURING WELLBORE SHUT-IN AND START-UP

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ABSTRACT
Analysis of temperature and pressure surge distribution for single phase gas flow during wellbore start-up and shut-in is a complex phenomenon for gas producing industries. Its occurrence forced the flowing gas to stop abruptly creating a pressure surge and high temperature within the wellbore system. This situation has to be studied for proper characterization, and protection of the producing wells from damage and premature closure. Many authors studies this phenomena in order to have a permanent solution but yet the problem still remain due to differences in environment. In this work, a one-dimensional transient governing equation based on depth and time dependent for start-up and shut-in has been developed. It is solved by finite difference scheme of Steger Warming Flux Vector Splitting Method (FSM). The method is fully transient and unconditionally stable. Surge pressure were analysed and wellbore temperature is predicted using the unsteady state heat transfer model. The results shows that if shut-in time is short, the sound wave propagation speed is faster than that of its longer time period. The result of this work provides a technical reliance to gas producing industries and can serve as guidance in field operations to avoid gas leakages or wellbore damage.

Keyword: Pressure surge, wellbore start-up and shut-in valves, Matlab software and FSM

INTRODUCTION

Pressure surge distribution for single phase gas flow during wellbore start-up and shut-in occurs when a flowing gas in motion stop forcefully or suddenly change direction. The problem commonly occurs when there is start-up or shut-in at wellhead and a pressure wave propagates in the flowline. The transient pressure can cause major problems from noise and vibration to flow line rupture. If the wellbore is closed swiftly at the wellhead, the mass of gas before the closure is still moving forward with a certain velocity, building up at high pressure surge.

The sound wave propagation of pressure for a short shut-in time is faster than that in the circumstance of shutting the gas well in a longer time. The situation normally cause well rupture because of waves traveling back and forth see figure 12. Wellhead pressure is generally considered to rise rapidly and then drops when shutting-in, then rises at starting-up and is always inconsistent with that of bottom-hole pressure making it difficult to conduct a well test analysis using surface data analysis. For this reason, transient flow model has to be develop to accurately reflect the value of surge pressure, and other parameters in the gas wellbore. With growing demand of natural gas Worldwide, many attempt were used in order to find lasting solution to gas production problems but yet no single method has finally been accepted.

Jaibal (2009) presented a model for water hammer transient pressure and solve using numerical and analytical method considering uniform velocity and the results shows that a pipe of diameter (1m) needs six (6) pumping stations in order to control the transient cause as a result of operation.

Guoqing et al, (2013), reported that pressure-transient analysis, facility maintenance, and workover, require a well shut-in, but this process led to sudden rises in pressure which is critical because they have a direct impact on equipment and the flowing fluid. Jung and Karney (2016) compared different water hammer models including rigid water column analysis and quasi-steady analysis. Their work also reported that Joukowski approach was based on the physical properties of the models, predictions of actual data, stability and accuracy. Later, they proposed some guidelines for the suitability of using any particular model according to the need of the flowing fluid. Jianhong et al., (2019), developed a mathematical model for wellbore annulus transient for multiphase flow characteristics which was solved by Method of Characteristics (MOC). They focused on the effect of gas cutting, shut-in time and friction on the water hammer pressure, and gas kick time and the results shows that gas cutting and gas kick time have few influences on maximum water hammer pressure. They also reported that the peak value of water hammer pressure declined with the increase of the shut-in time, and the effect of friction loss on water hammer pressure became significant with the increase of well depth.

He and Liang (2019) presented a transient model for pig speed and combined it with the gas flow equations which was solved by method of characteristics (MOC). The results shows that brake unit would lead to a sharp increase of the pressure on the tail of the pig. Susovan et al., (2021) suggested some newer developments in the numerical approach to water hammer analysis and summarizes the inherent limitations of traditional methods. The work also provides a systematic representation of past developments and directions for future research related to water hammer modelling in pipe line systems.

Mbaya and Hannafi (2021), presented a one-dimensional compressible model comprising conservation of mass and momentum to investigate the behaviour of the heat exchange between fluid temperature, surrounding earth and the flow environment of the wellbore. The model was solved by flux vector splitting method of Steger Warming to investigate the effect of wellbore diameter on the fluid and the temperature of the wellbore flow environment. The work shows that the temperature of the flowing fluid drop with Casing, Cement and earth temperature respectively.

Mbaya (2021), developed a one-dimensional system of governing equations and simplified it to generic function which was formulated

to accommodate a suitable closing laws by means of a polygonal segmented structure and solve by Laplace Transformation. The results obtained shows that back pressure wave shape and amplitude depend on the closing function of valves and in unique relationship together with understanding different closing laws.
Ruhe, et al., (2022), reported that bottom hole pressure is a key parameter to calculate single-well energy storage and dynamic reserved especially during the production testing period.
Jie et al., (2022), carried out simulation of complex wellbore environment under the coupling of multiphase and multifactor with the aim of making better understanding for industrial fluid production. They concentrate on the shortcoming of Ramey model and Hassan & Kabir model through transient analysis. They reported that wellbore temperature coupling method of high water bearing gas well for two phase gas-liquid flow has higher accuracy than Ramey model and Hassan & Kabir model. Amir and Reggie (2022), studied swab and surge pressure that occur during drilling in the oil well and reported that axial movement of the pipe in the wellbore causes pressure fluctuation in wellbore fluid and their intensity depends on the speed of the lowering down or withdrawing of the pipe.
Miji et al., (2022), investigate experimentally the effect of closing time on transient flow characteristics in a piping system and reported that the occurrence of cavitation in a pipe links very much with the closure time of the valve and the characteristics of water hammer pressure time.
All the models discussed in the literature does not focus on the temperature and pressure surge due to start-up and shut-in in the wellbore. In this work, a one-dimensional mathematical model for wellbore start-up and shut-in has been presented to study the temperature and pressure surge due to shut in under short time and longer time period and to analyse the propagation speed of pressure wave. It is numerically solved using finite difference of Steger Warming flux vector splitting method. The solution method was chosen because it does not have problem of numerical instability Toro, (2008). The result of this work will provide a technical reliance for gas producing industries when shut-in or start-up occurs.

Mathematical Model for Start-up and Shut-in

When the wellhead shut-in the flowing gas abruptly flow back down to the bottom hole causing pressure surge at that time and on the other hand, the start-up pressure will move up at high pressure causing the flowing fluid to exchange temperature with the flow environment. The Present model was developed on the assumption that:

1. Wellbore cross-sectional area is constant
2. The fluid in the wellbore is natural gas no contamination
3. The effect of kinetic energy change is neglected
4. Temperature is calculated from equation of state for natural gas
5. The sound of the pressure surge at short shut-in time and longer shut-in time is considered

Considering a wellbore with constant cross-sectional area, the one-dimensional equation for wellbore start-up and shut-in are the conservation of mass of continuity and momentum. The temperature of the flowing fluid in the tubing is determined by the rate of heat transfer along the tubing and the rate of heat exchange between the tubing and the flow environment.

$$\frac{1}{A}\frac{\partial\rho}{\partial t} = -\frac{\partial(A\rho u)}{A\partial x} \tag{1}$$

$$\frac{\partial(A\rho u)}{A\partial t} = -\frac{\partial\left(\rho u^2 + p\right)A}{A\partial x} - \frac{\rho f u|u|}{D} \tag{2}$$

In equation (1) and (2), A is cross section area considered to be constant. The gas law equation which is also known as gas equation of state can be used to manipulated for variable in the flow equations depending on the calculation of interest

$$PV = ZNRT \tag{3}$$

In (3) P is the gas pressure, V , volume of the flowing gas, Z , gas compressibility factor, R , natural gas constant and T , flowing gas temperature. The movement or speed of sound during shut-in or start-up is the rate of propagation of small disturbances of pressure pulse cause by shut-in at that period and is given by

$$\gamma = \sqrt{\frac{\partial P}{\partial\rho}} \qquad \rho\gamma^2 = P \tag{4a,b}$$

where γ is sound speed, p pressure and ρ gas density (Knudsen, 2008, Toro, 2008), integrating (4a) and simplifying gives (4b) . p can also be written as:

$$\rho\gamma^2 = P = \rho ZRT \tag{5}$$

Substituting equation (5) in Equation (2) the new flow equation during shut-in period in the wellbore when considering speed of sound can then be written as:

$$\frac{\partial(A\rho u)}{A\partial t} = -\frac{\partial}{A\partial x}\left(\rho u^2 + \rho\gamma^2\right)A - \frac{f\rho u|u|}{2d} \tag{6}$$

Flux Vector Form

Flux Vector Splitting Method is a generalization of non-linear systems in conservation form. It is a technique that has a natural consequence that regard a fluid as ensemble of particles measured along any coordinate such that some of this particle will move forward (start-up) and others backwards (shut-in) and can automatically split the fluxes of equation (1) and (6) into forward and backward fluxes. To solve Equations (1), and (6) a numerical procedure must to be followed which starts by writing the equation in a flux vector form as:

$$\frac{\partial Q}{\partial t} + \frac{\partial E(Q)}{\partial x} - H(Q) = 0 \tag{7}$$

Equation (7) is a first order hyperbolic equation and has a property that the flux vector E is a homogeneous function of degree one and defining $m = \rho u$ we got $Q,\ E(Q),\ H(Q)$ which are functions of density and mass flow rate given as

$$Q=\begin{bmatrix}\rho\\ m\end{bmatrix}, E(Q)=\begin{bmatrix}m\\ \dfrac{m^2}{\rho}+\rho\gamma^2\end{bmatrix}, H(Q)=\begin{bmatrix}0\\ \dfrac{fm^2}{2d\rho}\end{bmatrix} \quad (8a,b,c)$$

Solution Procedure

Equation (8) need a procedure that to solve it as mention earlier, the Steger-Warming flux vector Splitting method (FSM) has been considered in this work. The finite difference of the method begins by using the implicit scheme with the time derivative and is approximated by a first order backward difference approximation to provide

$$\frac{Q^{n+1}-Q^n}{\Delta t}+\left(\frac{\partial E}{\partial x}\right)^{n+1}-H^{n+1}=0 \quad (9)$$

in equation (9) E is implicit, the second and third term are expressed in $n+1$ time level. Since the flow is disturbed by shut-in or start-up, it warrant change in flow properties for time which can be defined as

$$\Delta Q=Q^{n+1}-Q^n \quad (10)$$

The non-linear term given by the flux vector E in Equation (10) must to be linearized. The process considers the Taylor series expansion which convert the second and the third term of Equation (10) to algebraic form. First, we expand $Q(x,t+\Delta t)$ and $Q(x,t)$ where the result of $Q(x,t+\Delta t)$ will be subtracted from the result of $Q(x,t)$ as:

$$Q(x,t+\Delta t)=Q(x,t)+\left.\frac{\partial Q}{\partial t}\right|_{x,t}(\Delta t)+\left.\frac{\partial^2 Q}{\partial t^2}\right|_{x,t}\frac{(\Delta t)^2}{2!}+O(\Delta t)^3 \quad (11a)$$

$$Q(x,t)=Q(x,t+\Delta t)-\left.\frac{\partial Q}{\partial t}\right|_{x,t+\Delta t}(\Delta t)+\left.\frac{\partial^2 Q}{\partial t^2}\right|_{x,t+\Delta t}\frac{(\Delta t)^2}{2!}+O(\Delta t)^3 \quad (11b)$$

Subtracting (11a) from (11b) we get

$$Q_j^{n+1}=Q_j^n+\frac{1}{2}\left[\left(\frac{\partial Q}{\partial t}\right)_j^n+\left(\frac{\partial Q}{\partial t}\right)_j^{n+1}\right]\Delta t+\left[\left(\frac{\partial^2 Q}{\partial t^2}\right)_j^n-\left(\frac{\partial^2 Q}{\partial t^2}\right)_j^{n+1}\right]\frac{(\Delta t)^2}{2!}+O(\Delta t)^3 \quad (11c)$$

Further expansion on $\left(\dfrac{\partial^2 Q}{\partial t^2}\right)_j^{n+1}$ and substituting in (9) and then simplify give equation (12)

$$Q^{n+1}=Q^n+\frac{1}{2}\left[\left(\frac{\partial Q}{\partial t}\right)^n+\left(\frac{\partial Q}{\partial t}\right)^{n+1}\right]\Delta t+O(\Delta t)^3 \quad (12)$$

Substituting (12) into (7) produces equation (13)

$$Q^{n+1}-Q^n=-\frac{1}{2}\left[\left(\frac{\partial E}{\partial x}-H\right)^n+\left(\frac{\partial E}{\partial x}-H\right)^{n+1}\right]\Delta t+O(\Delta t)^3$$

(13)

Equation (13) is an implicit finite difference element (FDE) with nonlinear term $\left(\dfrac{\partial E}{\partial x}-H\right)^{n+1}$ and to be linearized. Repeating the Taylor series expansion of order $(\Delta t)^2$ we have

$$E^{n+1}=E^n+\Delta t\left(\frac{\partial E}{\partial t}\right)^n,\ E^{n+1}=E^n+\Delta t\left(\frac{\partial E}{\partial Q}\frac{\partial Q}{\partial t}\right)^n+O(\Delta t)^2, \quad (14a)$$

$$E^{n+1}=E^n+\left(\frac{\partial E}{\partial Q}\right)^n\left(\frac{\partial Q}{\partial t}\right)^n+O(\Delta t)^2, E^{n+1}=E^n+A^n\left(Q^{n+1}-Q^n\right) \quad (14b)$$

Similarly, $H^{n+1}=H^n+B^n\left(Q^{n+1}-Q^n\right)$ (15)

$$\left(\frac{\partial E}{\partial x}-H\right)^{n+1}=\left(\frac{\partial E}{\partial x}-H\right)^n+\left(\frac{\partial A}{\partial x}-B\right)^n\left(Q^{n+1}-Q^n\right) \quad (16)$$

where A and B are the Jacobian matrices of $E(Q)$ and $H(Q)$ respectively. Substituting (14), (15) and (16) into (13) and simplifying we get equation (17)

$$Q^{n+1}-Q^n+\frac{1}{2}\Delta t\left(\frac{\partial A}{\partial x}-B\right)^n\left(Q^{n+1}-Q^n\right)=-\Delta t\left(\frac{\partial E}{\partial x}-H\right)^n \quad (17)$$

Matrices A and E are spitted using their eigenvector (Hofman and Chain, 2000; Toro, 2008)

$$A=A^+ + A^-,\ E=E^+ + E^- \quad (18a,b)$$

define A^+ as the transpose of a matrix whose rows are the right and left eigenvectors of matrix A such that E^+ is the product of A^+ with Q and E^- is the product A^- and Q. Now substituting (18) into (17), we obtain equation (19a)

$$Q^{n+1}-Q^n+\frac{1}{2}\Delta t\left(\frac{\partial}{\partial x}\left(A^+ + A^-\right)-B\right)^n\left(Q^{n+1}-Q^n\right)=-\Delta t\left(\frac{\partial}{\partial x}\left(E^+ + E^-\right)-H\right)^n \quad (19a)$$

Taking the backward and forward difference space step on positive and negative part of the spitted matrices due shut-in or start-up and which causes the flow propagation, Equation (19a) as:

$$\frac{\Delta Q}{\Delta t}+\frac{\partial}{\partial x}(A\Delta Q)-B\Delta Q=-\frac{\partial E^n}{\partial x}+H^n \quad (19b)$$

Factoring Equation (19b) will give:

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$$\left[I+\Delta t\left(\frac{\partial A}{\partial x}\right)-B\Delta t\right]\Delta Q=-\Delta t\left(\frac{\partial E^{n}}{\partial x}-H^{n}\right) \qquad (19c)$$

where I is an identity matrix and further simplification gives equation (19d)

$$\left[I+\frac{\Delta t}{\Delta x}\left(A^{+}+A^{-}\right)-B\Delta t\right]\Delta Q=-\left[\frac{\Delta t}{\Delta x}\left(E^{+}+E^{-}\right)-H\Delta t\right] \qquad (19d)$$

Taking a backward difference approximation for positive terms and a forward differencing for negative term on Equation (19d) we have:

$$\left[I+\frac{\Delta t}{\Delta x}\left(A_{j}^{+}-A_{j-1}^{+}+A_{j+1}^{-}-A_{j}^{-}\right)-\Delta tB\right]\Delta Q=\frac{\Delta t}{\Delta x}\left(E_{j}^{+}-E_{j=1}^{+}+E_{j+1}^{-}-E_{j}^{-}\right)-\Delta tH_{j} \qquad (19e)$$

Rearranging Equation (19e) we have:

$$\left[I+\frac{\Delta t}{\Delta x}\left(A_{j}^{n(+)}-A_{j}^{n(-)}\right)-\Delta tB_{j}^{n}\right]\Delta Q_{j}-\left(\frac{\Delta t}{\Delta x}A_{j-1}^{n(+)}\right)\Delta Q_{j-1}+\left(\frac{\Delta t}{\Delta x}A_{j+1}^{n(-)}\right)$$

$$=-\frac{\Delta t}{\Delta x}\left[E_{j}^{n(+)}-E_{j-1}^{n(+)}+E_{j+1}^{n(-)}-E_{j}^{n(-)}\right]+\Delta tH_{j}^{n} \qquad (20)$$

Equation (20) is the Steger Warming Scheme for wellbore flow which under disturbance by any means and has been proved to be unconditionally stable (Toro, 2008). The subscript *j* indicate the spatial grid point while the superscript indicates the time level and in equation (20) *I* is an identity matrix. *A* and *B* are Jacobian matrix defined in equation (17) and are given as:

$$A^{+}=\begin{bmatrix}\frac{a^{2}-u^{2}}{2a} & \frac{u+a}{2a}\\ \frac{(u+a)^{2}(a-u)}{2a} & \frac{(u+a)^{2}}{2a}\end{bmatrix} A^{-}=\begin{bmatrix}\frac{u^{2}-a^{2}}{2a} & \frac{a-u}{2a}\\ \frac{(u+a)(a-u)^{2}}{2a} & -\frac{(a-u)^{2}}{2a}\end{bmatrix} \qquad (21a,b)$$

$$E^{+}=\begin{bmatrix}\frac{\rho(u+a)}{2}\\ \frac{\rho(u+a)^{2}}{2}\end{bmatrix} E^{-}=\begin{bmatrix}\frac{\rho(u-a)}{2}\\ \frac{\rho(u-a)^{2}}{2}\end{bmatrix} \qquad (22a,b)$$

Treatment of Boundary and Initial Conditions

The process to which one can understand pressure surge due to shut-in or start-up if field data is not available is to develop an equation for shut-in and start-up during wellbore operation which often depends on the accurate measurement or estimation of the bottom hole pressure. In this work, we consider solving the developed equations to serve as boundary condition to the Steger Warming Splitting Method

$$\frac{\partial P}{\partial x}=\frac{\rho}{144} \qquad (23)$$

It was reported that the fluid in the wellbore is gas, therefore, the gas state equation can be considered

$$PV-ZNRT \qquad (24)$$

In (23), ρ is the density of gas at the shut-in or start-up and can be calculated as follows

$$\rho=\frac{PM}{ZRT} \qquad (25)$$

Substituting equation (25) in (23) and simplifying we obtain (26)

$$\frac{\partial P}{\partial x}=0.1165\frac{P}{ZT} \qquad (26)$$

Integrating equation (26) taking Z and T to be constant and the value of gas constant R to be 10.73 psi $\frac{ft^{3}}{16}$ mole in degree Ronke we have,

$$P_{i+1}=\pm P_{i}e^{0.1165\frac{x}{ZT}} \qquad (27)$$

The sign in equation (27) indicate the direction which the flow occurs follows, the negative shows that it is during start-up while positive indicate that the gas goes back to the reservoir at the time of shut-in. This equation is calculated and serve as boundary condition to shut-in pressure or start-up pressure in the wellbore during gas production in gas producing industries. For the density at shut-in and start-up, the (Zhou and Adewumi, 1995) was considered

$$\rho_{0}^{n+1}=\rho_{0}^{n}+\frac{\Delta t}{\Delta x}\left(m_{0}^{n}-m_{1}^{n}\right) \qquad (28a)$$

$$\rho_{nj}^{n+1}=\rho_{nj}^{n}+\frac{\Delta t}{\Delta x}\left(m_{nj}^{n}-m_{n1}^{n}\right) \qquad (28b)$$

Equation (28a) was the density at the wellbore bottom while (28b) is the density at wellhead or at point of shut-in or start-up. At the time of shut-in or start-up of the wellbore, the temperature of the flowing fluid has an impact on the flow environment. When a well that has been producing gas is shut-in for some period of time the temperature causes the gas to expand or contract in response to changes in the well. These changes affect the heat transfer in and around the wellbore which will decrease with time during shut-in period, especially at the initial stages of production. The interest is to analysis fluid temperature during shut-in. According to Fourier the rate of heat flow through a body is directly proportional to the temperature gradient in the medium. At this point the rate of heat transfer between the flowing fluid and inside tubing wall is given as (29)

$$Q=2\pi r_{ti}k_{t}\left(T_{f}-T_{ti}\right)\Delta x \qquad (29)$$

Where $T_{f}-T_{ti}$ is the temperature difference between the inside tubing and the flowing fluid at the time of shut-in, r_{ti} is the radius of the inner tubing, k_{t} is the thermal conductivity of the tubing, and Δx is the incremental distance. Conduction of tubing wall can be calculated as Mbaya and Hanafi (2021)

$$Tubing\quad Q=\frac{2\pi r_{to}k_{tub}\left(T_{ti}-T_{to}\right)\Delta x}{\ln\frac{r_{to}}{r_{ti}}} \qquad (30)$$

Equation (29) and (30) is combine to obtain the temperature equation for shut-in as in (31)

$$T_f = T_{to} + \frac{Q}{2\pi\Delta x}\left[\frac{\ln\frac{r_{to}}{r_{ti}}}{k_{tub}} + \frac{\ln\frac{r_{co}}{r_{ci}}}{k_{cas}} + \frac{\ln\frac{r_h}{r_{co}}}{k_{cem}}\right] \quad (31)$$

The initial condition is based on the movement of the fluid in the wellbore from shut-in down to bottom hole, time steps is considered simultaneously with the length of the wellbore. The disturbance that occur at the time of shut-in and start-up and at the initial point of shut-in, $\rho(0,t) = \rho_0(t), \frac{\partial u(0,t)}{\Delta x} = u_0(t), T(0,t) = T_0(t),$ $P(0,t) = P_0(t)$ where $\rho_0,$ is gas density at the point of shut-in or start-up, Δx, depth (m), T_0, is the temperature of the fluid at the point of shut-in or start-up and P_0 is the pressure at the disturbed point.

Friction Factor

At the point of shut-in the behaviour of the flowing gas due to friction at the wall of the wellbore is investigated. The behaviour of friction on the flowing gas is related to the work of Ramey (1962) during hot fluid injection in wellbore. He gave the friction as

$$\frac{1}{\sqrt{f}} = 1.14 - 2\ln\left(\frac{e}{d} + 21.25/R_e^{0.9}\right) \quad (32)$$

$$f(t_D) = \begin{cases} 1.28\sqrt{t_D}\left(1-0.3\sqrt{t_D}\right) & t_D \le 1.5 \\ \left(0.4063+\sqrt{\ln t_D}\right)\left(1+\frac{0.6}{t_D}\right) & t_D > 1.5 \end{cases} \quad (33)$$

In equation (33), the value of t_D is estimated based on gravity of the shut-in. It is therefore given as $t_D = \frac{\lambda t}{r_{wb}^2}$ (34)

where λ is define with respect to an acentric factor Ω; a factor which is applied when dealing with a single component (gas), and is calculated as

$$\lambda = \left[1+\Omega\left(1-\sqrt{T_{pc}}\right)\right] \quad (36)$$

$$\Omega = 0.48 + 1.574\Psi - 0.176\Psi^2 \quad (27)$$

RESULTS AND DISCUSSION

Shut-in and start-up pressure was plotted from the new method and the result was compared with existing work of Zhou et al., (2013) figure 1. A well of 7000 m was used with the following parameters; well roughness 0.001, ground temperature 160 °C, ground thermal conductivity 2.06, ground temperature gradient 0.00218 °C/m, friction coefficient was varied, initial density 1000 *kg/m³* and bottom pressure is 70 *Mpa*. Temperature was varied from *108 k, 120 k, 130* k and *140 k* and geothermal temperature gradient is *T = 0.023x+b*. From figure 2, the shut-in and start-up pressure was simulated. It was observed that transient pressure distribution was so dispersed during shut-in due to the effect of the shut-in and for the start-up it was almost in steady state but was slightly disturbed due to well geometry. The wellbore temperature was also varied for both shut-in and start-up. It was observed that the two process has no much effect on the flowing gas. The simulation was done by keeping one constant and the other simulated, the changes in both was observed to be simultaneously, figure 3. At different values of temperature, density profile was plotted. It was observed that during shut-in density decreases with time which was observed to be the same as the shut-in velocity, figure 4 and 5. The wall geometry of tubing during shut-in causes the friction factor to increase as time increases and it was further observed that when the time for shut-in is shorter than the return time of the reflected surge pressure it leads to enormous pressure increase but extension of the shut-in time reduces the extreme pressure, this can be seen in figure 6. Figure 7, shows the effect of sound wave propagation on the flowing fluid. At the shut-in period the sound was heard at higher profile but goes down with time, similarly the earth thermal conductivity was tested and was observed to decreases during shut-in time figure 8. In figure 9 geothermal gradient was tested at different point of the wellbore during shut-in and was observed to increase due the mixture of the fluid temperature and the flow environment. Figure 10 shows the sound propagation of the flowing fluid stabilised after longer period of time. Figure 11 and 12 shows wellhead valves and the effect of the shut-in or start-up on the pipe wall. It has been observed that the intensity of pressure surge developed from pressure surge during shut-in at the downstream cause damage to pipe which has less resistors to temperature and surge pressure.

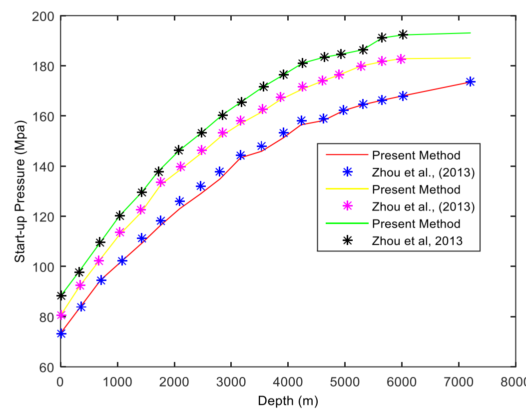

Figure 1: Present method Compared

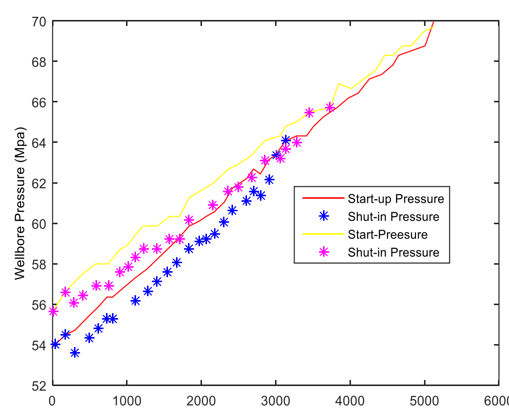

Figure 2: Start-up and Shut-in Pressure

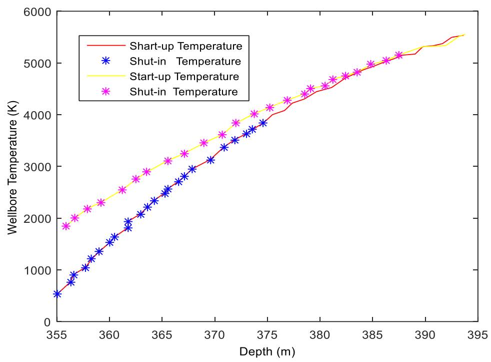

Figure 3: Temperature distribution

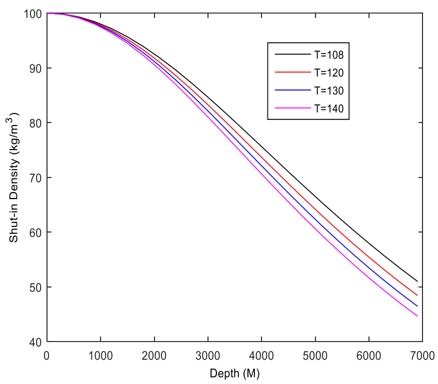

Figure 4: Density distribution

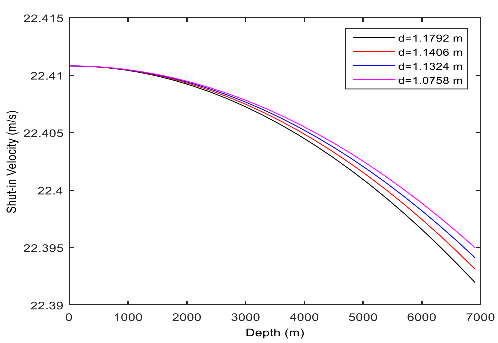

Figure 5: Velocity

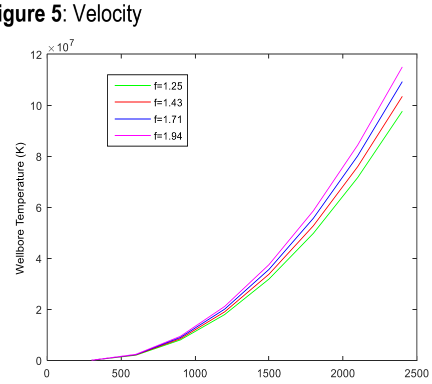

Figure 6: Friction Factor

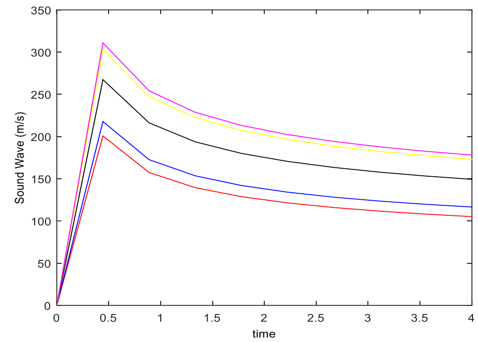

Figure 7: Sound Wave distribution at shorter time

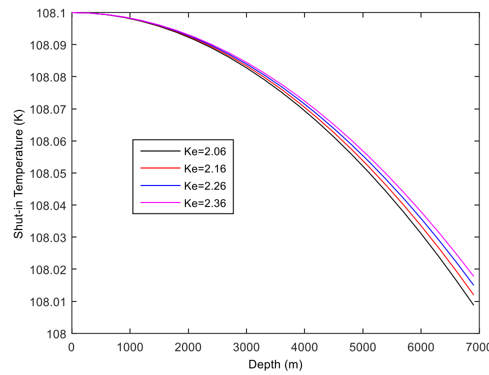

Figure 8: Earth thermal Conductivities

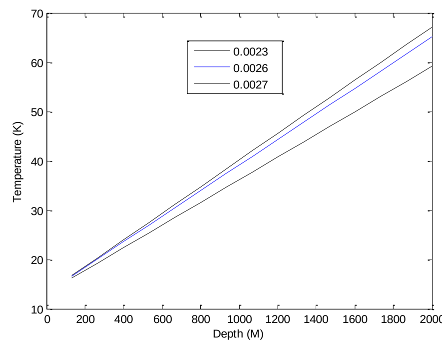

Figure 9: Temperature at different geothermal gradient

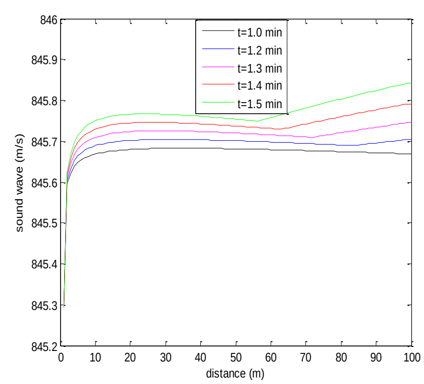

Figure 10: Sound wave distribution at shut-in at longer time

Figure 11: Wellhead Valve

Figure 12: Effect of gas Shut-in and Shut-up. Start-up and shut-in valves (courtesy, Types of Valves in Gas Industry, 2017)

Conclusions

A method for the analysis of temperature and pressure surge distribution during Shut-in and Start-up was developed and compared with existing work and was in good agreement. Pressure and temperature during shut-in and start-up was plotted and observed to be increasing during shut-in and getting to steady state in start-up. The effect of shut-in or start-up at shorter time and longer time was observed. At longer time after shut-in the pressure and the sound wave propagation stabilizes to steady state. The work will be of importance to gas producing industries especially in the area of pipe (tube) selection in order to avoid pipe rupture or damage which will lead to disaster or loss of human life.

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