A Comparison of the Density Perforations for the horizontal Wellbore

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Abstract: - In this paper study the flow behavior in horizontal wellbore with 60 and 150 perforations of perforation densities equivalent to 6 and 12 SPF respectively has been studied. The pressure drops in a perforated pipe that includes the influence of inflow through the pipe walls compares for two pipes that difference in perforation density. 3D numerical simulations for the pipe with two numbers of perforations were investigated by using ANSYS CFX modeling tool with Reynolds number ranging from 28,773 to 90,153 and influx flow rate ranging from 0 to 899 lit/hr to observe the flow through perforated pipe, measure pressure drops. The effect of density perforations on the flow through perforated pipe was conducted. CFD simulations yielded results that are reasonably close to experiments data.

Key-Words: - perforation density, pressure, numerical, CFX.

1 Introduction

In a horizontal well, depending upon the completion method, fluid may enter the wellbore at various locations and at various rates along the well length. The complex interaction between the wellbore hydraulics and reservoir flow performance depends strongly on the distribution of influx along the well surface and it determines the overall productivity of the well. Therefore, the optimization of well completion to improve the performance of horizontal wells is a complex but very practical and important problem.

The most commonly used assumptions in studying horizontal well production behavior are: infinite conductivity, and uniform influx. Infinite conductivity assumes no pressure drop along a horizontal well, and uniform influx assumes that the influx from the reservoir is constant along a horizontal well. It has been argued in the literature that the infinite conductivity wellbore assumption is adequate for describing flow behavior in horizontal wells. Although this may be a good assumption in situations where the pressure drop along the horizontal section of the wellbore is negligible compared to that in the reservoir, it is also reasonable to expect the friction and acceleration effects to cause noticeable pressure drops in long horizontal wellbores Yuan et al. [1].

The petroleum industry started investigating horizontal wellbore was proposed by Asheim et al. [2] which included acceleration pressure loss due to continuous fluid influx along the wellbore. They assumed that the injected fluid enters the main flow with no momentum in the axial direction. Kloster [3] performed experimental work and concluded that the friction factor versus Reynolds number relationship for perforated pipes with no injection from the perforation does not show the characteristics of regular pipe flow. The friction factor values were 25-70% higher than those of regular commercial pipes. He also observed that small injections through perforations reduced the friction factor.

Dinkken [4] presented a simple isothermal model that links single phase turbulent well flow to stabilized reservoir flow. It was proposed that the pressure drop inside the horizontal wellbore was totally contributed by wall friction.

The flow in perforated tubes differs from conventional pipe flow as there is radial fluid inflow through the perforations. The injection disturbs the velocity profile and boundary layer Kato et al. [5] such that the pressure gradient along the length of the perforated tube is affected. Boundary layer injection reduces the friction of the surface the wetted surface. This effect was observed clearly in the transpiration experiments of Kays [6] and Eckert et al. [7]. The reduction in friction for transpiration experiments was proportional for porous surfaces since the average diameters of the surface are sufficiently small.

Yuan et al. [1] the flow behavior in horizontal wells with a single perforation and with multiple perforations of perforation densities equivalent to 1, 2 and 4 shots per foot were investigated. Experiments were conducted with Reynolds numbers ranging from 5,000 to 60,000 and influx to main flow rate ratios ranging from 1/5 to 1/100 for the single injection case and from 1/100 to 1/2000 for the multiple injection case and for the no influx case. Horizontal well friction factor correlations were developed by applying experimental data to the general friction factor expressions. It was observed that the friction factor for a perforated pipe with fluid injection can be either smaller or greater than that for a smooth pipe, depending on influx to main flow rate ratios.

2 Model Description

Theoretical analysis was carried out to determine the total pressure drops, frictional, acceleration and additional pressure drops with different mass flow rate and density perforations. Fluid flow in a wellbore is considered as shown in Fig. 1 and assumed an incompressible, isothermal condition along a uniformly pipe. The test pipe is a partly perforated one and the rest is a plain pipe without perforation. Pipes and perforation geometry for theoretical study are listed in **Table 1**. The first one was 60 perforations but the other one 150 perforations with same diameter. The computational domain taken up in this study is same as that of the dimensions considered in the experimental rigs [8, 9]. The geometry has been analyzed using 3D Computational Fluid Dynamics (CFD). Fig. 2 is the structured computational grids. The calculations were carried out with commercial finite volume code ANSYS FLUENT 14 CFX to solve Navier-Stokes equations, using a first scheme and turbulent with k epsilon model.

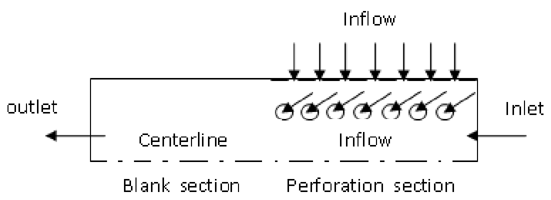

Fig. 1- Configuration of partly perforated test pipe (not to scale).

Table 1- Geometry of the test pipe.

Item	Pipe 1	Pipe 2
Inner Diameter	22 mm	22 mm
Perfo. Diameter	4.0 mm	4.0 mm
Total perfo. number	60	150
Perfo. phasing	60 °	60 °
Perfo. density	6 SPF	12 SPF

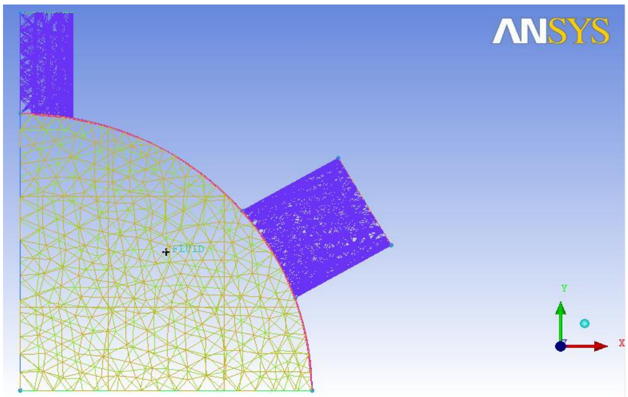

Fig. 2- The unstructured mesh for partly perforated pipe.

3 Simulation Parameters

The fluid considered for the simulations is water with constant density of 998.2 kg/m^3 and dynamic viscosity of 0.001 kg/m s. Three tests were carried out with Reynolds number of the inlet flow ranging from 28,773 to 90,153. In each of the tests, flow rate through the perforations was increased from zero to maximum value. The roughness of the test pipe wall was 0.03 mm; the type of the test pipe was PVC. Test details are summarized in **Table 2**. Uniform water mass flow is introduced at the inlet of a partially perforated pipe. Two boundary conditions are considered. At the inlet mass flow is taken into consideration both axially and radially where as at the exit outlet pressure is considered as the boundary condition. It is assumed that no-slip boundary conditions occur along the isothermal walls. Water enters at a uniform temperature (T) of 25˚C. For the symmetry lines both velocity and pressure is kept constant.

Table 2- Parameters of partly perforated pipe tests.

Test	Inlet Flow Rate (liter/hr)	Perforation inlet Flow Rate (liter/hr)	Inlet Flow (Re)
Test 1	5,157 to 5,618	0-841	82,756 to 90,153
Test 2	3,361 to 3,836	0-854	53,935 to 61,557
Test 3	1,793 to 2,318	0-899	28,773 to 37,198

4 Fluid Flow Model for Perforated Section

The pressure drop of the fluid in the perforated section comprising: a pressure drop caused by the frictional resistance generated by fluid flow in the wellbore Δp_{wall}. Reservoir fluids flow into the well and confluence with the mainstream fluid, which causes the mixed pressure drop $\Delta p_{mix.}$.

Meanwhile, radial fluid inflow makes well section become variable mass flow, so the acceleration occurs and produces accelerated pressure drop $\Delta p_{acc.}$, besides, there is a pressure drop due to perforation roughness $\Delta p_{perfo.}$ should be taken into consideration.

Divided the perforated section into the length of ΔL and the number of n perforation unit according to the number of holes, each the unit contains a hole. The pressure loss Δp of i unit is obtained from the sum of above several pressure loss.

$$\Delta p_i = \Delta p_{walli} + \Delta p_{acc.i} + \Delta p_{mix.i} + \Delta p_{perfo.i} \qquad (1)$$

The last two terms in Eq. (1) combine into one term as $\Delta p_{add.}$

Equation (1) can be written as:

$$\Delta p_i = \Delta p_{walil} + \Delta p_{acci.} + \Delta p_{addi.} \qquad (2)$$

The total pressure loss of the horizontal wells perforated sections Δp_T is stated as follows:

$$\Delta p_T = \sum_{i=1}^{n} \Delta p_i \qquad (3)$$

Where n is the number of perforated holes.

In perforated section, each unit of wall friction pressure drop algorithm is the same as the non-perforated section:

$$\Delta p_{walli} = \frac{1}{2} f_i \frac{\rho \Delta L}{D} v_i^2 \qquad (4)$$

The friction factor f_i can be calculated

$$f_i = \left\{ -1.8 \log \left[\frac{6.9}{\text{Re}} + \left(\frac{\varepsilon}{3.7D} \right)^{1.11} \right] \right\}^{-2} \qquad (5)$$

When the wall surface inflow and mainstream outflow ratio (the perforations radial flow and wellbore axial flow ratio) is less than the critical value, the radial fluid flow smooth the pipe flow, reduce the pressure drop. At this point, the mixing pressure drop caused by the perforations friction and radial inflow can be written as follows:

$$\Delta p_{mix.i} = \Delta p_{perfo.i} - 0.031 x \,\text{Re} \left(\frac{q}{Q} \right)_i \qquad (6)$$

Where q is radial flow of a single perforation, m^3/s; Q is axial flow of horizontal wellbore; m^3/s. Perforation friction pressure drop $\Delta p_{perfo.i}$ can be obtained by perforation friction coefficient $f_{perfo.i}$ shown below:

$$\Delta p_{perfo.i} = \frac{1}{2} f_{perfo.i} \frac{\rho \Delta L}{d} v_i^2 \qquad (7)$$

Accelerated pressure drop is only associated with the density of the fluid, and the flow rate, it can be expressed as:

$$\Delta p_{acc.i} = \frac{\rho}{2} \left(v_{i+1}^2 + v_i^2 \right) \qquad (8)$$

5 Results and Discussion

In this paper, theoretically were carried out on the pipes that were simulated with the experimental pipe[8, 9]. Three tests with different pipe flow rate were carried out for the perforated pipe. Fig. 3 shows the acceleration pressure drop due to momentum for three tests. The pressure drop due to momentum change (acceleration pressure drop) was calculated from Eq. 8. The acceleration pressure drop increases with increase of the total flow rate ratio. We notice at the test 1 when the axial flow is large and the radial flow is low, there is a small difference between the acceleration pressure drop for the two pipes (60 & 150 perforations) with ranges from 2.95% at zero flow rate ratio to 0.039% at maximum flow rate ratio. For test 2 there is a difference in values of acceleration pressure drop with increases of the total flow rate ratio with ranges from 0.0192% at zero flow rate to 0.164% at maximum flow rate ratio. But for test 3 there is a difference with ranges from 0.989% at zero flow rate ratio to 0.0876% at maximum flow rate ratio. Because the pressure drop due to momentum depends upon the axial velocities at the inlet and the outlet of the pipe.

. Fig. 4 presents the frictional pressure drop with total flow rate ratio for two pipes (60 & 150 perforations). The frictional pressure drop increases as the flow rate ratio increases for all tests and perforation density. For test 1 the frictional pressure drop is greater than tests 2 & test 3. Therefore, the frictional pressure drop increases as the axial flow increases. The friction pressure drop increases with decrease the perforation density i.e. the frictional pressure drop for pipe with 60 perforations greater than the frictional pressure drop for pipe with 150 perforations.

The total pressure drop in a perforated pipe section is contributed by the combined effect of fluid mixing and perforation roughness, ordinary frictional and accelerational pressure drops. The numerical results were examined in terms of the total pressure drop with total flow rate ratio, as shown in Fig. 5 for the tests conducted on pipe with different perforation density. The total pressure drop increases as the total flow rate ratio increases. The total pressure drop increases as increase of the perforation density.

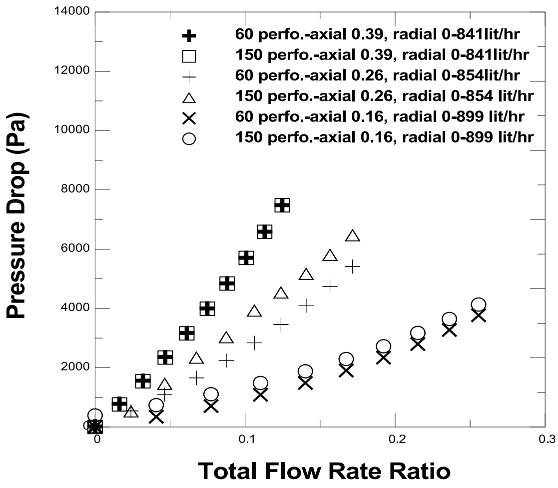

Fig. 3- Acceleration Pressure Drop for three tests

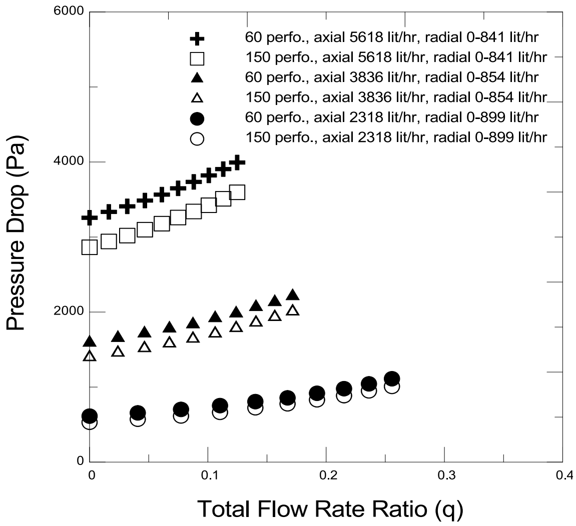

Fig. 4- Friction Pressure Drop for three tests

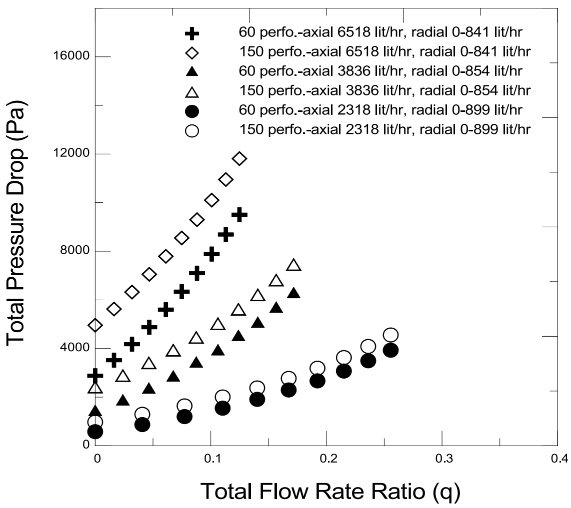

Fig. 5- Total Pressure Drop for three tests

The additional pressure drop, which is the combined effects of fluid mixing and perforation roughness with total flow rate ratio for 60 and 150 perforations pipes, as shown in Figs 6 and 7 respectively. The additional pressure drop decreases as the total flow rate ratio increases. This shows a lubrication (smoothing) effect to the pipe flow by inflow through perforations in the pipe wall. It is demonstrated that the additional pressure drop due to perforation roughness was reduced by the smoothing effect, and that the total pressure drop was reduced [10].

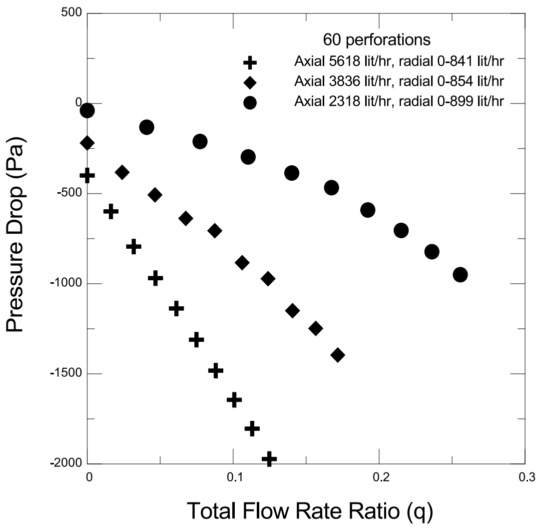

Fig. 6- Additional pressure drop for 60 perforations model

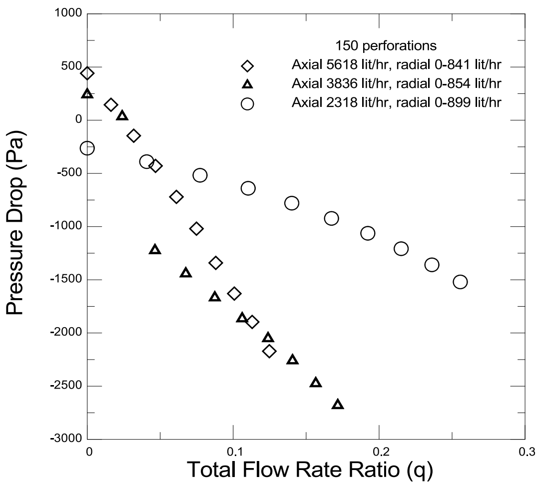

Fig. 7- Additional pressure drop for 150 perforations model

Effect of perforation density on the pressure drop coefficients of the total pressure drops is shown in Fig. 8. The pressure drop coefficients of pipe with 150 perforations were obviously larger than those of pipe with 60 perforations. This was because the perforation density of 150 perforations pipe was twice and half as larger that of 60 perforations pipe.

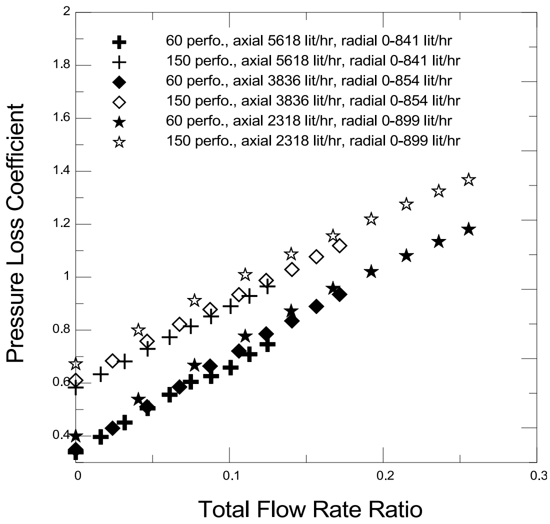

Fig. 8- Pressure drop coefficient for 60 & 150 perforations

4 Conclusion

Numerical simulations have been carried out on the flow in a partly perforated pipe with inflow through perforations. The geometry of the pipe used was similar to the pipe used in the experimental tests[8, 9, and 10] with two perforation densities 60 and 150 perforations. The accelerational pressure drop for 60 & 150 perforations is small difference in the values for the three tests as shown above because it depends upon the axial velocities at the inlet and outlet of the pipe. The frictional pressure drop values for 60 perforations pipe are greater than 150 perforations pipe. The friction pressure drop increases with decrease the perforation density. The total pressure drop increases as the total flow rate ratio increases. The total pressure drop increases as increase of the perforation density. All the additional pressure drop values for 60 perforations are negative but some values of 150 perforations pipe are positive. The pressure drop coefficient of 150 perforations pipe is larger than 60 perforations pipe.

References:

[1] Yuan, H., Sarica, C. and Brill, J.P. “Effect of Perforation Density on Single Phase Liquid Flow Behavior in Horizontal Wells”. Paper SPE 37109, *International Conference on Horizontal Well*

Technology, Calgary, Alberta, Canada, 18-20 November 1996.
[2] Asheim, H. *et al.*: "A Flow Resistance Correlation for Completed Wellbore," *J. Petrol. Sci. Eng.*, 1992, 8 (2), pp. 97-104.
[3] Kloster, J.: "Experimental Research on Flow Resistance in Perforated Pipe," *Master thesis, Norwegian Int. of Technology,* Trondheim, Norway (1990).
[4] Dikken, B.J.: "Pressure Drop in Horizontal Wells and its Effect on Production Performance," *JPT* (November 1990) 1426.
[5] Kato H., Fujii, Y., Yamaguchi, H. and Miyanaga, M. "Frictional Drag Reduction By Injection High-Viscosity Fluid into Turbulent Boundary Layer," *Fluid Engineering*, June 1993, Vol. 115, pp. 207-212.
[6] Kays, W.M. "Heat Transfer to the Transpired Turbulent Boundary Layer," *International Journal of Heat and Mass Transfer*, 15: 1023-1044, 1971.
[7] Eckert, E.R.G., Lomdardi, G., Sparrow, E.M. "Experiments on Heat Transfer to Transpired Pipe Flows," *International Journal of Heat and Mass Transfer*, 17: 429-437, 1973.
[8] Su, Z. and Gudmundsson, J.S. "Pressure Drop in Perforated Pipes," *PROFIT Projected Summary Reports*, Norwegian Petroleum Directorate, Stavanger (1995).
[9] Su, Z. and Gudmundsson, J.S.: "Pressure Drop in Perforated Pipes," report, *Department of Petroleum Engineering and Applied Geophysics*, U. Trondheim, Norway (1995).
[10] Su, Z. and Gudmundsson, J.S.: "Perforation Inflow Reduces Frictional Pressure Loss in Horizontal Wellbores," *J. Petrol. Sci. Eng.*, 1998, 19, pp. 223-232.