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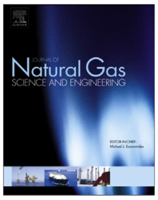

Experimental and numerical study of single-phase pressure drop in downhole shut-in valve

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A B S T R A C T

In this work an experimental and numerical analysis of single-phase pressure drop in a downhole shut-in valve is performed. The main goal was to develop a 1D numerical model suitable for both compressible and incompressible flow. For the experimental study a mock-up of the shut-in valve was built and instrumented with pressure sensors and flowmeters. The pressure drop along the different sections of the valve were recorded for various flow rates using water, oil and air as working fluids. For the numerical analysis a two-step approach was used. First a commercial CFD package was used for 3D simulations of the flow, and different turbulence models were compared. Then a 1D model was developed based on a spectral element method, with minor loss factors derived from the CFD simulations. Both the 3D CFD simulations and the 1D model simulations provided a good comparison with the experimental data. The small difference in the simulation results can be attributed to the difference in the frictional coefficient which showed a discrepancy of about 20% compared with the measurements. Minor loss factors derived from CFD simulations of incompressible flow are found to be valid also for 1D simulation of compressible flow of air. The 1D model is developed for future simulation of compressible multiphase flow.

1. Introduction

Downhole shut-in valves are used when testing oil and gas wells. The purpose of a shut-in test is to find the flow capacity and the size of the reservoir. The shut-in test consists of a pressure drawdown test period with an open valve, and a pressure buildup test period (pressure at wellbore perforation) with a closed valve (Zolotukhin and Ursin, 2000). During the first test with the valve open, the well starts to produce, and the well bottom pressure is reduced in time, see Fig. 1. The second test period starts by closing the shut-in valve, recording the following pressure buildup with memory gauges hanging below the shut-in valve.

There are two options for the test. These are known as the wellhead and downhole shut-in tests. In the wellhead shut-in test, the valve is located at the wellhead. This configuration avoids the costs and complications of installing a downhole valve, but the drawback is the problems of interpreting the data from the pressure buildup test. The measurement of pressure drawdown can be considered accurate, but pressure buildup is affected by the wellbore storage effect (Guerrero and Lessi, 2007). This effect is related to the two-phase volume of the wellbore above the pressure sensor and its unknown compressibility. An alternative to this is placing the shut-in valve downhole and thus avoid wellbore storage.

This work focuses on the fluid flow in the STC downhole shut-in valve. CFD has been used for similar purposes by a number of authors, as given in Table 1.

Amirante et al. (2006) used CFD for the simulation of fluid forces on a hydraulic directional control valve spool and validated the numerical results with experiments. Amirante et al. (2007) simulated the flow in a hydraulic proportional valve and found that the results matched the experimental data from the valve manufacturer. Chattopadhyay et al. (2012) investigated compressible flow in a spool type pressure regulating valve using CFD. Different turbulence models were evaluated, concluding that the realizable k-e model was the best option for turbulence modeling. Compressible flow in a butterfly valve was modeled with CFD by Leutwyler and Dalton (2008), and the torque on valve disc was validated with experimental values. Valdes et al. (2008) modeled equations for predicting flow and fluid forces in a hydraulic valve on basis of CFD simulations.

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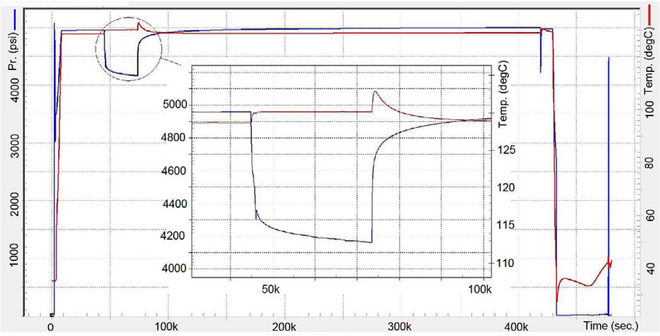

Fig. 1. Pressure and temperature curves from downhole shut-in operation.

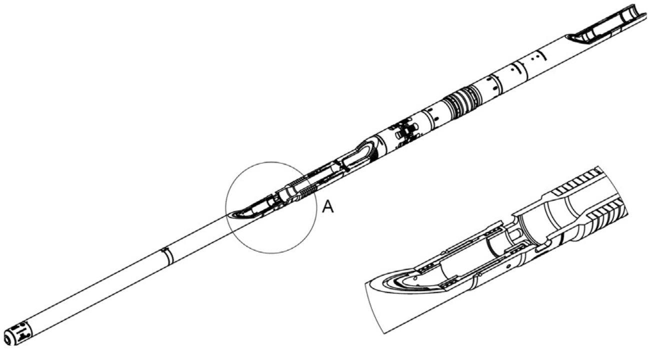

Fig. 2. Qinterra Technologies shut-in valve type STC on an RPD type retrievable packer.

Table 1
CFD simulation of flow in valves.

Author	Software	Type	Main observations
Amirante et al. (2006)	Fluent	3D section	Flow forces, validated
Amirante et al. (2007)	Fluent	3D section	Flow forces, validated
Chattopadhyay et al. (2012)	Fluent	2D/3D	Flow vs. pressure drop
Leutwyler and Dalton (2008)	CFX 10	3D section	Flow forces, validated
Valdes et al. (2008)	Fluent	2D/3D	Flow rates and flow forces

The flow through the shut-in valve can be regarded as flow through a series of different sections, with various shapes and interconnections. The different partial losses will be frictional (viscous) and so-called minor losses, which are dominated by inertia effects. The objective of this work is to investigate the single-phase pressure drop across the downhole shut-in valve, and develop a one-dimensional (1D) simulation model. This model will later serve as a basis for future work on two-phase flow. The approach here is to use 3-dimensional (3D) computational fluid dynamics (CFD) simulations with the Fluent package as a tool for predicting the internal axial pressure profile curve in the shut-in valve. Minor pressure loss factors for the 1D model will be derived from this curve.

It is assumed that a valid 1D model must be able to simulate both compressible and incompressible flow. The simulations will be validated by experiments on a full-scale valve mock-up. The laboratory tests will be performed using water, oil and air as the working fluid. Two-phase correlations are normally valid only for approximately incompressible flow, and it is therefore necessary to divide the total pressure drop into partial frictional and minor losses along the valve.

The shut-in valve is mounted onto a packer, that constitutes the seal and anchor between the valve and the well casing. Fig. 2 illustrates a typical shut-in sleeve valve, assembled with a retrievable packer. A common downhole assembly used by Aker Well Service with packer, shut-in valve, shock absorber and memory gauges hanging below the shut-in valve is shown in Fig. 3. A typical shut-in valve will have a complicated internal flow path, and it cannot be separated into standard minor losses such as sudden contraction, nozzles and bends. Reliable values for single-phase pressure loss can only be found by performing full-scale tests in a laboratory.

The lower part of the valve assembly contains a valve movement mechanism and a timer. When the packer is "set" in hole, a rubber element on the packer is compressed, giving an increase in the diameter of the rubber element, and this forms a seal between the valve-packer assembly and the production tubing (well casing). Setting the packer also forces the slips to move radially outwards,

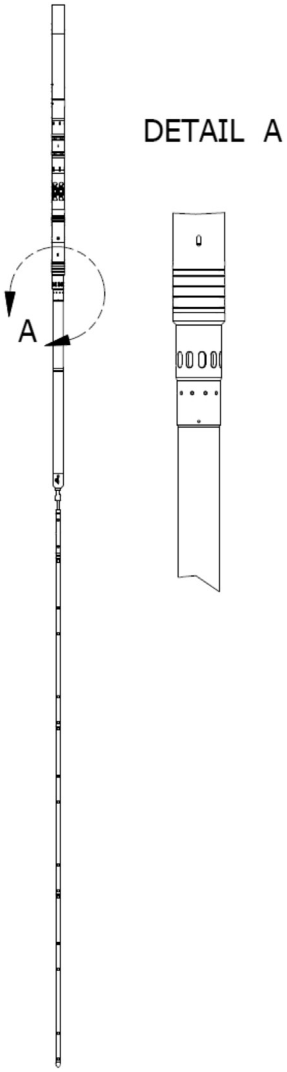

Fig. 3. Downhole assembly for shut-in valve (Qinterra Technologies AS).

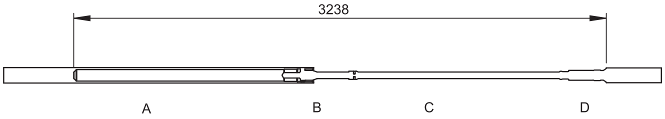

Fig. 4. Main parts of the flow path through the STC shut-in valve.