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Experimental and numerical study of two-phase pressure drop in downhole shut-in valve with Unified Comprehensive Model formulation

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ABSTRACT

The Unified Comprehensive Model (UCM) formulation for two-phase flow identifies first the flow pattern, and applies subsequently the appropriate pressure drop calculation. In this work the UCM has been extended for dealing with the complex two phase flow in a shut-in valve. In particular, local two phase pressure drops were included where the loss coefficients were obtained from full 3D CFD simulations. The final mathematical model was solved by a least squares spectral element method. Two-phase flow simulations with the extended UCM were validated with experiments performed on a full scale mock-up of the valve. The suggested models provide a good estimation of the pressure drop. The predicted flow patterns from the UCM are also confirmed by the experiments.

1. Introduction

Valves and equipment in wells are exposed to two-phase flow of oil and gas, and it is a challenge to calculate the multiphase pressure drop with high precision. Downhole shut-in valves are used for testing reservoirs, and will during operation be placed close to the casing perforations. This is where the oil and gas flows from the reservoir into the well. Due to flow resistance in the rock formation, the bottom of hole pressure will be lower than the reservoir initial pressure when oil or gas are flowing. If the flow is suddenly stopped, the bottom of hole pressure will build up again with a pace determined by the permeability of the formation. This mechanism is utilized when interpreting shut-in pressure curves. In order to improve the quality of shut-in well tests, the pressure drop over the shut-in valve should be known as precise as possible.

For common singularities like globe valves, gate valves and plug valves some recommendations for two-phase flow calculation exist (Chisholm, 1983). In this work two-phase flow in a downhole shut-in valve was modeled and simulated. The geometry of the flow channel across the shut-in valve is complex, and it has details that cannot by compared to standard pipe components. In order to find the single phase flow loss coefficients in this valve, full 3D CFD simulations were performed by Edvardsen et al. (2015). Experiments with water and oil flow in a shut-in valve mock-up gave total and partial pressure losses close to values from CFD simulations. The Unified Comprehensive Model formulation by Gomez et al. will here be extended with two-phase pressure loss in singularities based on single phase loss coefficients. An example of a well shut-in pressure curve is given in Fig. 1. This pressure curve is recorded by gages hanging below a shut-in valve, and shows the recorded pressure before, during and after the shut-in test.

The detail in the center of the curve shows first a pressure draw-down period, initiated by opening a surface valve to let the well flow. At approximately 74 k sec., the shut-in valve has been closed, causing a pressure build-up below the valve. The shape of this build-up curve is the essential part for the test analysis. However, during the pressure draw-down period, the shut-in valve is open, and a detailed understanding of the pressure drop at two-phase flow can be useful. The measured pressure drop can be used to calculate a corresponding flow rate, and hence the flow through the shut-in valve can be recorded real-time and close to the bottom of the well. This will improve the quality of the test interpretation.

Abbreviations: CFD, computational fluid dynamics.

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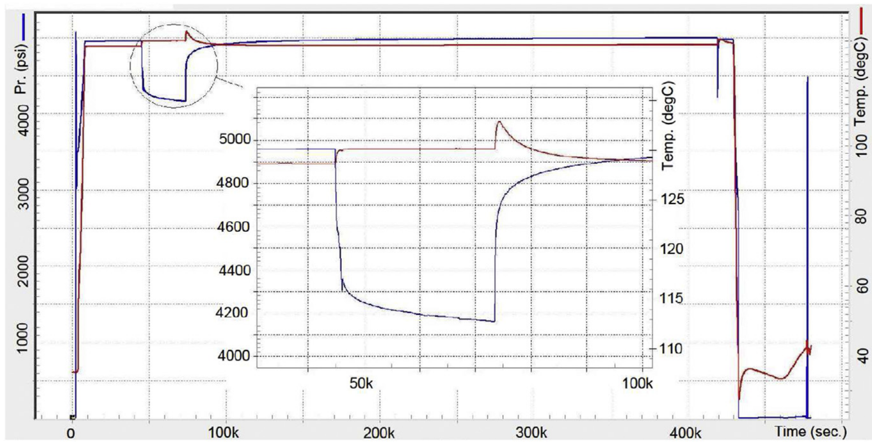

Fig. 1. Pressure and temperature curves from downhole shut-in operation.

The shut-in valve in question has been investigated experimentally and numerically for single phase flow by Edvardsen et al. (2015), and a 1-dimensional simulation model was developed. In Fig. 2, the valve is shown together with a packer.

This model is based on the Navier-Stokes equation for steady state flow, using the least squares method with spectral elements. The minor (or singular) losses for this model were calculated from 3-dimensional CFD simulations. This 1D simulation model provided good comparison with experimental data for both incompressible and compressible flow. Two-phase flow in this shut-in valve has also been simulated by Edvardsen et al. (2014a), using various two-phase correlations by Chisholm (1983), Mller-Steinhagen and Heck (1986) and Friedel (1979). The deviations in pressure drop prediction for these simulations were about 12%.

In this work, the Unified Mechanistic Model for steady-state two-phase flow by Gomez et al. (2000) will be implemented in an attempt to improve the precision at two-phase pressure drop calculations. In mechanistic modeling, flow patterns as stratified, slug or annular are predicted from analysis of two-phase physical phenomena. Individual models are then applied for the identified flow pattern for prediction of the liquid holdup and the pressure gradient. Models for two-phase flow pattern prediction have been developed by Taitel and Dukler (1976) and Barnea et al. (1985) amongst others, and separate models have been proposed for horizontal and vertical flow. There are also a number of studies on specific flow pattern transitions like Shoham and Taitel (1984), Cheremisinoff and Davis (1979) and Issa (1988). In this context, a comprehensive model contains both a flow pattern prediction part and a flow model part for liquid holdup and pressure gradient calculation. Unified models are models that can be applied to horizontal, inclined and vertical flow. A comprehensive mechanistic model for horizontal flow was proposed by Xiao et al. (1990), and similar comprehensive models for vertical flow was proposed by Ozen et al. (1987), Hasan and Kabir (1988) and Ansari et al. (1994). The unified, comprehensive model formulation by Gomez et al. (2000) is therefor an attractive model, capable of flow pattern prediction at all inclination angels. With flow models provided for all flow patterns, it is well suited for combination with the 1D Least Squares Spectral Element model.

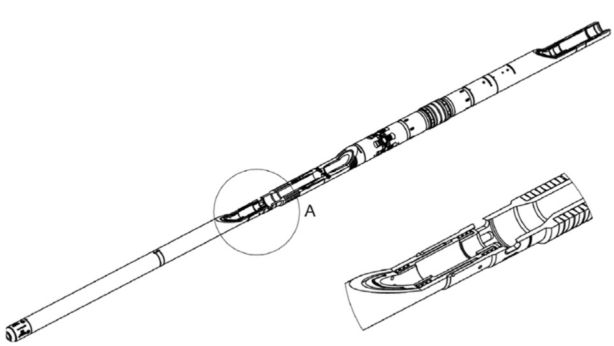

Fig. 2. Qinterra Technologies shut-in valve type STC on an RPD type retrievable packer.

The goal of the work presented was to develop a versatile tool for the prediction of the flow behavior in complex geometries, like a downhole shut-in valve. First the experimental setup will be presented. The theoretical part then presents the 1-D model, together with an explanation of the Least Squares Spectral Element method. The Unified Comprehensive Model formulation by Gomez et al. is presented in detail, and details from implementation in the 1-D model are given. The numerical solution is also described together with the solution algorithm. Finally the results from two-phase flow experiments and simulations are presented and discussed.

2. Experimental setup and testing procedure

The experimental tests were performed in the Multiphase Flow Laboratory at the Dept. of Energy and Process Engineering, NTNU. The flow loop consists of a supply system for oil, water and air, and has a separator for continuous recirculation of oil and water. Flow control valves and pumps with speed adjustment ensure that the flow rate can be set as wanted. A logging system records all flow rates and pressures continuously. Water and oil are circulated by centrifugal pumps, and air is supplied by a compressor. Flow rate of water was measured with an electromagnetic flowmeter with a range of 0–10 kg/s, and flow rate of oil (Exxsol D80) was measured with a Coriolis flowmeter with a range of 0–10 kg/s. Air flow was set by control valves and measured with a Coriolis flowmeter with range of 0–0.022 kg/s for small airflows. For large airflows, a vortex flowmeter with range 0.004–0.11 m^3/s at system pressure of 400 kPa was used, corresponding to a mass flow of 0.024–0.612 kg/s. The flowmeter specifications are given in Table 1.

The coriolis type oil flowmeter can also detect liquid density.

The test section consists of a full-scale mock-up of a shut-in valve, made in POM (polyoxymethylene, or acetal) and polycarbonate tubes. Roughness for the plastic tubes in the laboratory