# Evaluation of a Virtual Multiphase Flow Meter

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## Abstract

*Accurate multiphase flow metering is essential to the operation of a production well. The conventional means of multiphase flow metering, well testing and multiphase flow meters are very costly. An alternative method of metering known as virtual multiphase flow metering, which uses software systems to estimate production flow rates, has recently emerged. This paper discusses the development of a virtual multiphase flow meter for a single well system. Software models of the flowline system and the choke for the well will be calibrated to historical well test data. These calibrated models will be used to infer oil, water and gas flow rates from measured pressures during production thus acting as a virtual multiphase flow meter.*

## 1.0 Introduction

Multiphase flow metering, in the oil and gas industry, refers to the measurement of the flow rates of the three component phases, oil, water and gas, of the fluid that is produced from a production well. Multiphase flow metering is required for fiscal metering, production allocation, production monitoring, production optimization and reservoir management activities (Al-Taweel 1999).

Conventionally, multiphase flow metering has been achieved by well testing. The multiphase flow from a single well enters a test separator in which the three phase fluid is split into individual streams of oil, water and gas. The flow rates of oil, water and gas can then be measured using single phase metering techniques. However, in most production systems, fluid from many wells are comingled upstream of the separator. Consequently, to monitor flow from a single well, all other wells flowing to the separator must shut-in for the duration of the well test.

Well testing has several problems relating primarily to large production deferments and also to flow assurance due to the shutting in of wells (Caetano 1997). Furthermore, to avoid deferring production, well testing is conducted infrequently. Consequently the measured flow rates of each well test are assumed to reflect the production for the time period succeeding that well test until another well test is conducted. This assumption is often incorrect (Poulisse et al. 2006).

A recent approach has been to develop and use multiphase flow metering instrumentation which can continuously measure production flow rates without needing to shut down wells and defer production. However installing and maintaining these hardware multiphase flow meters in a subsea environment is very expensive (Berg & Davalath 2002). Subsea multiphase flow meters also have limited reliability, accuracy and operating ranges. The proprietary nature of multiphase flow metering technology has resulted in only limited publicly available information regarding the performance of commercially available multiphase flow meters (Falcone et al. 2002).

Attempts have been made to develop virtual multiphase flow metering systems (VMFMS) to provide comparable functionality to subsea multiphase flow meters. A VMFMS uses software systems rather than hardware systems to determine flow rates, to avoid the high costs associated with of subsea hardware. A VMFMS is being developed as the basis for this study. This system aims to use pressure measurements obtained during normal production operations to infer the flow rates of oil, water and gas from a software model of a petroleum production system which has been calibrated to historical production data from conventional well tests.

## 2.0 Virtual Multiphase Flow Metering

A VMFMS is being developed to investigate the feasibility and effectiveness of employing a VMFMS as an alternative to frequent well testing or to subsea multiphase flow meters. The VMFMS is being developed for a simple one well production system (to be referred to as Well-4), which is tied back to a test separator on a Floating Production Storage and Offloading vessel (FPSO). The test separator is dedicated to Well-4 production and is not shared by other production wells. Consequently the actual flow rates of oil, water and gas can always be measured and can be compared to the flow rates predicted by the VMFMS.

## 3.0 Production System Model

Central to the VMFMS is a model of the Well-4 production system. This model must be able to relate pressure measurements along the flow trajectory to the mass flow rates of oil ($Q_{oil}$), water ($Q_{water}$) and gas ($Q_{gas}$). Figure 1 below is a schematic diagram of the Well-4 production system.

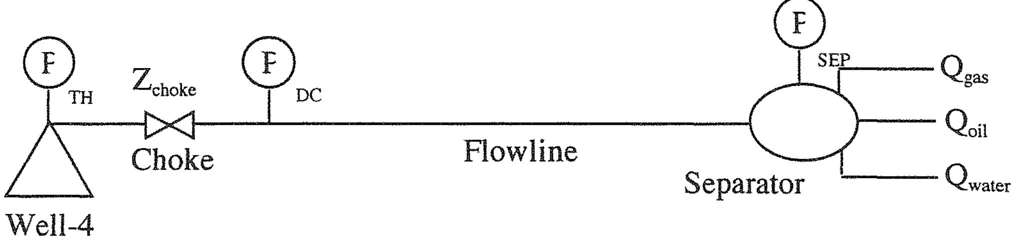

**Figure 1: Schematic of the Well-4 Production System.**

As shown in Figure 1, a three phase fluid, consisting of oil, water and gas flows from Well-4. The fluid leaves the well at the tubing head (TH) and then flows through a choke, through the flow line and to the separator. In the separator the fluid is separated into individual streams of oil, water and gas which exit the separator. These single phase streams then flow through single phase flow metering devices which measure the flow rates of oil, water and gas from Well-4.

Well-4 is represented as a simple (current) source of oil, water and gas. The pressure of the fluid is measured at the tubing head ($P_{TH}$), downstream of the choke ($P_{DC}$) and at the separator ($P_{SEP}$) by pressure gauges. Unfortunately the values of $P_{DC}$ are no-longer monitored, so historical values of $P_{DH}$ can only be used to help calibrate the model. The physical basis of the model is as follows: fluid flow rate (Q) is related to a measured pressure drop via $QZ = P_1 - P_2$ where Z is a general impedence to flow that, in general, can itself depend on Q or P. We split the production system model into a choke model and a flowline model, which leads to

$$QZ_{line} = P_{DC} - P_{SEP}$$
$$QZ_{choke} = P_{TH} - P_{DC}$$
$$Q(Z_{line} + Z_{choke}) = P_{TH} - P_{SEP}$$

The impedance of flow through the flowline is a function of the fluid mass flow rate Q, fluid composition, flowline dimensions, flowline elevation (_), flowline roughness (e) and fluid viscosity. The mass flow rate depends on the average pressure (P) and temperature (T) of the stream. The fluid's viscosity (_) is also function of *P* and *T*. Of these parameters the flowline dimensions, roughness and elevation are constant over time. The fluid composition changes due to the water cut (WC) changing with water breakthrough and the gas oil ratio (GOR) changing with reservoir depletion.

$$Z_{line} = Z_{line}(Q(P,T), WC, GOR, diameter, length, \_, e, \_(P, T))$$

The impedance of flow through the choke is a function of the fluid flow rate, fluid composition, and choke dimensions. For the choke, none of these parameters are constant over time. The choke diameter is adjusted as part of production operations to restrict the flow rate. The choke diameter is determined from the recorded choke open percentage which is the percentage of the cross sectional area of the choke opening out of the maximum possible cross sectional area of the choke opening.

$$Z_{choke} = Z_{choke}(Q(P,T), WC, GOR, choke\ open\ \%)$$

## 3.1 Historical Well Test Data

The historical well test data provides the calibration points to which the VMFMS's production system model can be matched. Data is available for the 105 well tests that have been conducted between 4-Apr-96 and 11-Dec-05; measurements included the duration of the well test, oil flow rate ($Q_{oil}$), water flow rate ($Q_{water}$), gas flow rate ($Q_{gas}$), separator pressure ($P_{SEP}$), tubing head pressure ($P_{TH}$) and the choke open percentage. The first 15 well tests conducted between 4-Apr-96 and 10-Mar-97 occurred prior to water break through and thus the WC for these 15 tests is 0. The pressure downstream of the choke ($P_{DC}$) was only measured for 21 of the well tests. Gas lift was introduced to Well-4 from 12-May-04 onwards. However, data for the gas rate lift was only provided for 12 of the 29 subsequent well tests.

The well test data does not contain reservoir pressure or flowing bottomhole pressure data. Consequently the well is not being modelled using inflow performance relations and tubing performance relations. Instead Well-4 is treated simply as a source of Well-4 fluid and gas lift gas.

Analysis of the well test data is being undertaken to determine the reliability and uncertainty in the measured data. The model will, at best, only be able to predict flow rates with an uncertainty equal to that of the data to which it was calibrated. Whether the duration of the well tests was adequate to produce steady state flow and thus reliable data is to be investigated so we can eliminate unreliable data.

Analysis of the well-test data reveals that the $Q_{gas,}$ and thus the GOR, data are inaccurate. The calculated GOR fluctuates significantly between well tests; however the reservoir pressure is above the bubble point of the Well-4 fluid, which means that the GOR should be stable. Consequently the GOR data from the well-tests were not used in the calibration process. Instead a constant GOR of 138 scf/STB, as measured in laboratory testing of the Well-4 fluid, was used.

Of the 21 well tests with a measured $P_{DC}$, 5 well tests have a recorded $P_{DC}$ which is greater than the $P_{TH}$. This would indicate a backward flow of fluid from the choke and into the well. This is clearly incorrect given that there is a drop in pressure from the choke to the separator. Consequently the $P_{DC}$ of these 5 well tests have been discarded.

## 3.2 Flowline Modelling

Based on the flowline dimensions, estimated flowline roughness, WC, GOR and the flow rates through the flow line it should be possible to estimate the pressure drop through the flowline based on various multiphase fluid flow models. A number of different models will be compared including:

- Poiseuille's Law for incompressible, single-phase fluids

- The Beggs and Brill correlation for multiphase fluid flow in inclined pipes (Beggs and Brill 1973)
- The Petroleum Experts General Allocation Program (GAP) software which contains a number of multiphase fluid flow correlations.

A flowline model will be chosen and calibrated using the 16 well tests with potentially valid $P_{DC}$ data (more data may be rejected on the basis of flow-time versus well-test duration as discussed). The aim of calibrating the flowline model is to adjust the model such that, for the $Q_{oil}$, $Q_{water}$ and $Q_{gas}$ measured in the well test, the pressure drop in the flowline calculated by the model accurately matches the pressure drop measured in the well tests. $P_{DC}$ can then be determined from the pressure drop in the flowline and $P_{SEP}$. If the flowline model is properly calibrated then it should be able to accurately predict the pressure drop for the remaining 99 well tests which lack measured $P_{DC}$ data. The calculated $P_{DC}$ can then be used to calibrate the choke model for those 99 well tests.

### 3.3 Choke Modelling

The choke model being investigated is the Perkins model (Perkins 1993). The Perkins model simulates the flow of fluid in the choke based on the following assumptions:

1. Fluid temperature varies with position, but at any point all phases are at the same temperature;
2. Fluid velocity varies with position, but at any point all phases are at the same velocity;
3. The gas compressibility is constant;
4. Liquids have negligible compressibility compared to gas;
5. Elevation changes are negligible;
6. The flow process is adiabatic and frictionless

The Perkins model incorporates a discharge coefficient which compensates for inaccuracies in mass flow rate predicitions due to the above assumptions. The discharge coefficient is defined as the ratio of the measured mass flow rate to the mass flow rate calculated by the Perkins model.

$$K = \frac{\dot{m}_{measured}}{\dot{m}_{Perkins}}$$

Based on the a maximum choke opening of 5", a choke open percentage, WC, GOR, $P_{DC}$ and $P_{TH}$ the Perkins model can be used to calculate a mass flow rate through the choke. The discharge coefficient can then be calculated. The velocity of the fluid through the choke will be also estimated and compared to the speed of sound in the fluid to check whether the flow through the choke is critical or sub-critical. It is hoped that a consistent discharge coefficient can be determined for the choke so that the choke model can be used to accurately calculate flow rates from $P_{DC}$ and $P_{THP}$.

## 4.0 Virtual Multiphase Flow Metering Procedure

With representative models of fluid behaviour in the flowline and the choke it should be possible to obtain flow rate estimates, which are as accurate as the flow-rates determined in well testing, based on the measurements of $P_{SEP}$ and $P_{TH}$. Figure 2 below is a flow chart of the algorithm that will be used to calculate $Q_{oil,}$ $Q_{water}$ and $Q_{gas}$ estimates.

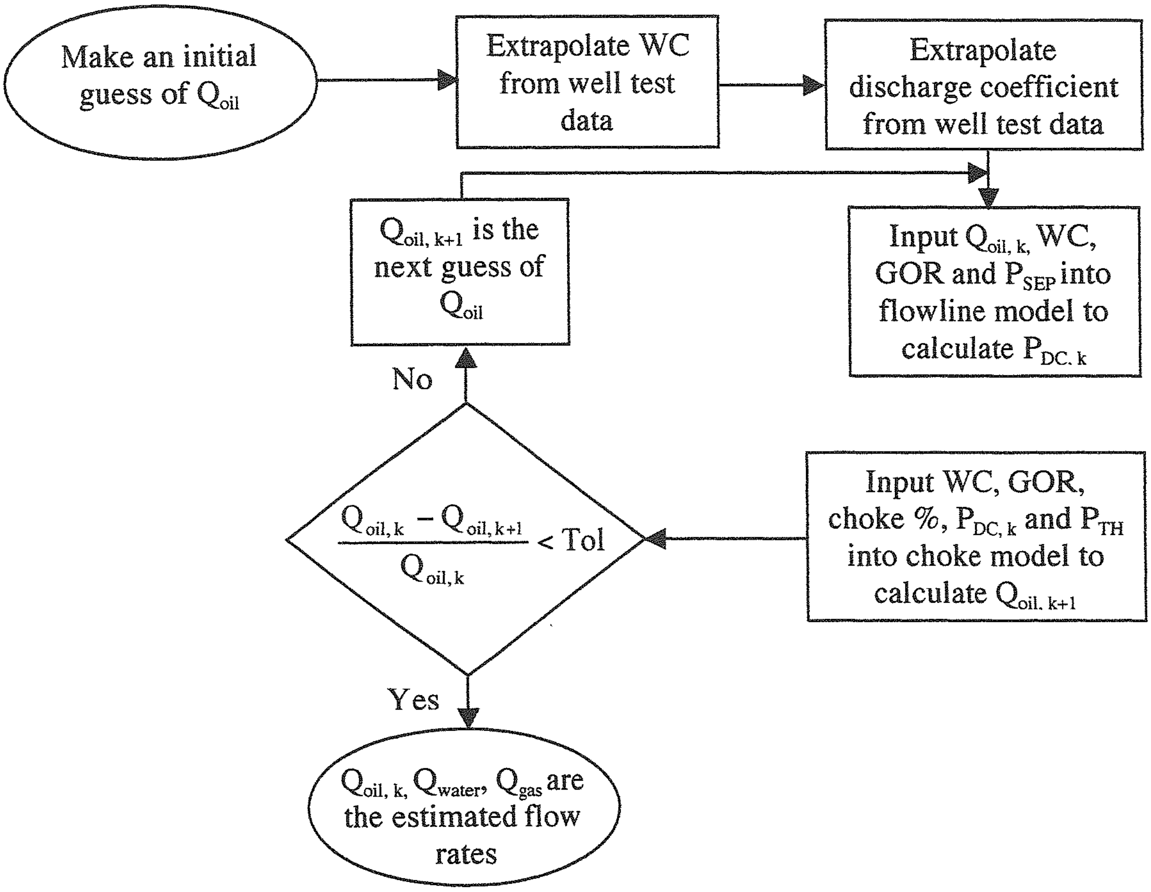

**Figure 2: Flowchart of intended VMFMS algorithm**

This algorithm assumes that:

- The reservoir pressure remains above the bubble point and the GOR stays constant at 138 scf/bbl.
- The WC can be extrapolated from the historical well test data, i.e. the WC will follow some reasonably well defined trend.
- That the discharge coefficient can be extrapolated from the discharge coefficients calculated from historical well test data by the choke model. i.e. the discharge coefficient will follow some reasonably well defined trend.

The algorithm involves an iterative procedure where the $Q_{oil}$ calculated by the choke becomes the next guess for $Q_{oil}$ in the flowline. An initial guess of $Q_{oil}$ in the flowline is obtained from the measured $Q_{oil}$ from the latest well test or the estimated value of $Q_{oil}$ calculated by the VMFMS for the preceding day. An estimate of the WC and the choke's discharge coefficient is made by extrapolation from well tests. For each iteration step k the $P_{SEP}$, $Q_{oil,k}$, WC and GOR are input into the flowline model to calculate $Z_{line}$(Q(P,T), WC, GOR, diameter, length, _, e, _(P, T)). Since a value of Q in the flowline is known the pressure drop in the flowline and thus $P_{DC,k}$ can be determined.

The calculated $P_{DC,k}$, discharge coefficient, WC and measured $P_{TH}$, choke open %, and GOR are input into the choke model to determine $Z_{choke}$(Q(P,T), WC, GOR, choke open %). Since a value of the pressure drop over the choke ($P_{TH} - P_{DC,k}$) is known, a value of $Q_{oil}$ can be calculated for the choke. This $Q_{oil}$ value becomes the next guess for $Q_{oil}$, i.e. $Q_{oil,k+1}$. If the $Q_{oil,k+1}$ is within a certain percentage tolerance of $Q_{oil,k}$ then $Q_{oil,k}$ is consistent with both the choke model and the flowline model. Iteration stops and $Q_{oil,k}$ is the estimated $Q_{oil}$ calculated by the VMFMS.

## 5.0 Conclusion

The accuracy of the VMFMS is completely dependant on the accuracy of the flowline and choke models. Since these models must be calibrated to historical production data, the VMFMS can at best be only as accurate as the data provided. It is not expected that the VMFMS will completely eliminate the need for well testing. Well tests will still be needed should extrapolation of the WC and discharge coefficient become unrepresentative of the actual WC and discharge coefficient. However it is expected that the VMFMS will be able to reduce the frequency of well testing.

## 6.0 References

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