

ENSYS YOCUM, INCORPORATED

Multiphase Flow Technology, Software, Services

VMSS3

Applications & Benefits

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I. Introduction

VMSS3 comprises a unique suite of “added value” tools for well flow rate prediction, performance monitoring and improvement.

The sections below provide an overview of VMSS3, its applications and benefits. A separate VMSS3 User Manual describes the specifics of VMSS3 operation.

Section II describes VMSS3's capabilities when used in different production configurations.

Section III provides an overview of the VMSS3 system and computational method.

Sections IV and V review VMSS3's online and offline applications and benefits.

Section VI provides support information.

II. VMSS3 CONFIGURATIONS & CAPABILITIES

VMSS3 adds value to production management by leveraging existing field data to improve well flow monitoring and performance

VMSS3 combines online and offline data management with powerful multiphase computation in the form of a system that can be added on to traditional or latest generation production configurations to yield significant benefits for improved multiphase flow rate prediction, well performance monitoring and optimization. Figure 1 illustrates how VMSS3 can be integrated into a conventional production system that has well real time sensors, test separator and potentially sampling but no multiphase type metering. Figure 2 shows how VMSS3 integrates into a production system that incorporates water cut, phase fraction or full multiphase metering.

In either configuration, VMSS3 utilizes well signals data for pressure and temperature, and for gas injection where applicable, supported by reservoir PVT and well configuration data. In the conventional configuration, the results of separator tests or wellhead samples are a required component of the total “system”. They are employed to provide starting values and an exogenous water cut for the well convergence calculations. When operating in conjunction with water cut, phase fraction or full multiphase metering, VMSS3 employs the water cut information generated directly and then uses additional values as starting points for its own rigorous well flow and performance calculations.

In the conventional configuration, management and engineers have available a comprehensive system for:

- rigorous online well multiphase flow computation with convergence to well pressures and temperatures
- calculation of key well performance parameters including:
 - oil, water and gas rates
 - tubing head, casing head and flowing bottom hole pressure profiles
 - gas and liquid ratios
- analysis of well rate and other trends
- allocation of total flow back to individual wells
- conversion of wellhead sample results into equivalent well test separator results
- rigorous offline well simulation, enabling detailed investigations into well performance leading to (a) calibration of the well data and calculations for

applications both online and offline and (b) optimization of well performance and production, including gas injection

- rigorous offline simulation of the test separator to cross-check reported separator flow rates and to compute liquid carry over, gas carry under, water in oil and oil in water.

Used in conjunction with hardware metering, VMSS3 provides all the functions of the conventional configuration but also enables real time updating of phase fraction data for VMSS3's rigorous well calculations plus redundancy and cross-checking between the flow rate computations of VMSS3 and those of any multi-phase meter. (As VMSS3 relies only on P and T sensors for its on-line inputs, it has high up time both in absolute terms and relative to hardware multiphase meters where up-time can be an issue.) In addition, VMSS3 generates fluid PVT properties and updates for use by the hardware multi-phase meter. Both configurations retain the offline functions which enable in-depth well performance analysis and optimization.

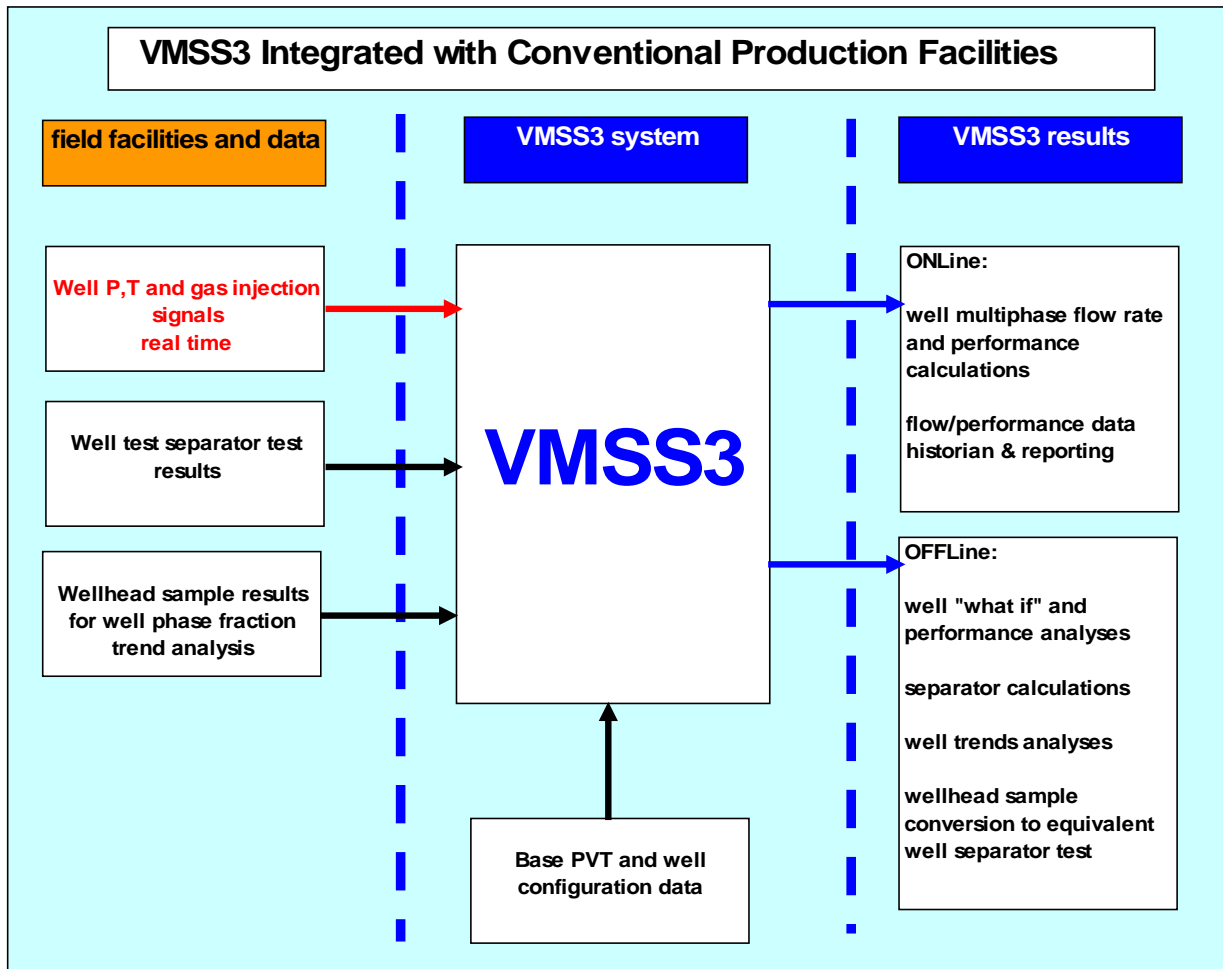


Figure 1 VMSS3 Integrated with Conventional Production Facilities

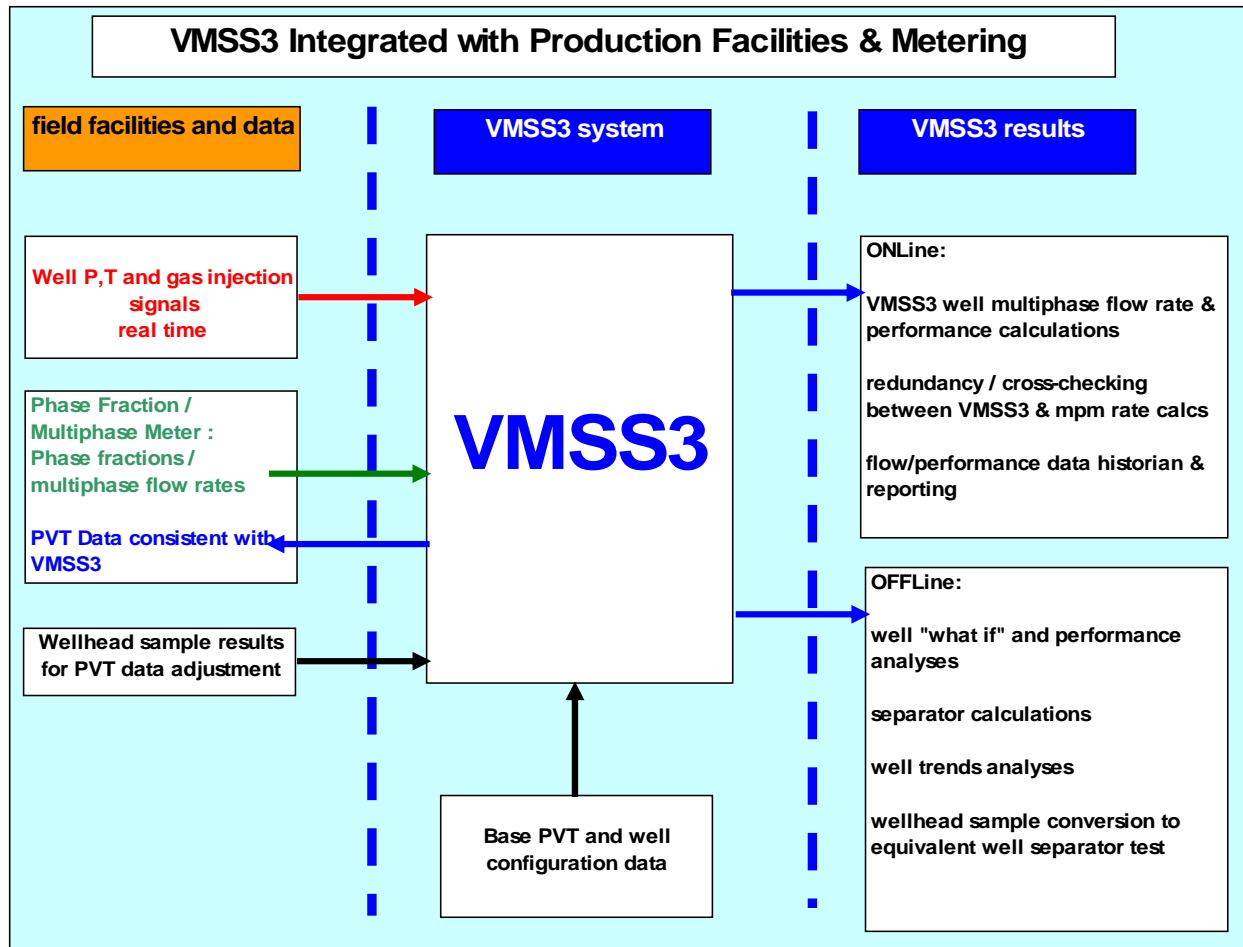


Figure 2 VMSS3 Integrated with Production Facilities & Metering

III. VMSS3 SYSTEM

VMSS3 provides petroleum production managers and engineers with a suite of simulation software to predict multiphase production flows online, to conduct offline "what if" well performance analyses, to analyze well test separator performance and to interpret and apply test separator tests or wellhead samples. VMSS3 achieves its Online functions using well pressure and temperature signals, plus gas injection information where applicable, supported by reservoir PVT and well configuration data plus the results of separator tests or wellhead samples. VMSS3 thus enables both flow rate computation and well analysis and performance improvement without the need to resort to exotic hardware. VMSS3 can however work with water cut / phase fraction meters where real-time phase fraction information is required and/or the ultimate in redundancy.

III.1 Structure

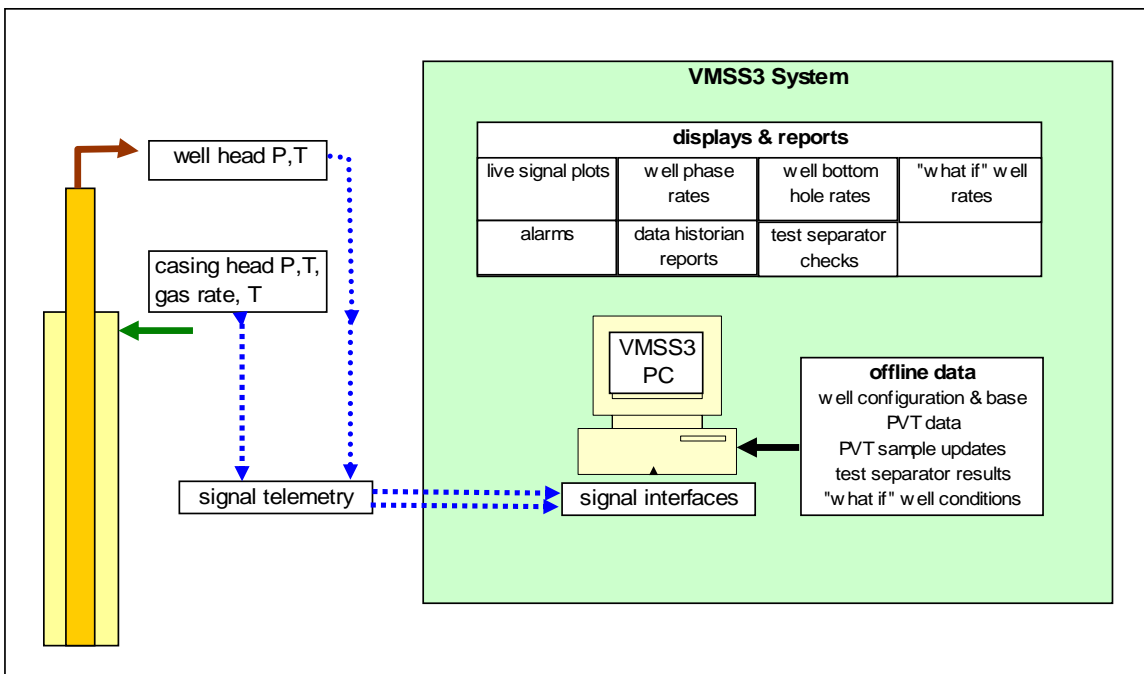


Figure 3: VMSS3 System Overview

The gas rate is calculated from signals for the manifold pressure, temperature and orifice delta P. Alternatively a flow computer signal (e.g. from a Daniels Flow Computer) can be accepted.

The VMSS3 Online system comprises two components. The Online “front end” system receives and interprets sensor signals from the wells. These comprise wellhead pressure and temperature, casinghead pressure and temperature plus either gas injection rate if a flow meter signal is available, otherwise gas injection orifice delta P and the associated upstream manifold pressure. Front end software applied with VMSS3 includes the Serck SCX© system and, potentially, National Instruments LabView©. The Front End system receives and interprets the well signals and then prepares them for input to VMSS3 Excel. Front End functions include:

- interpreting (“parsing”) the well signals data stream to extract the relevant signals for the wells being monitored
- logging signal data values, populating the historical signal database, generating backups of the signals, e.g, by day or shift
- charting signal values
- checking for and flagging out of range or ceased well signal values

The VMSS3 Online well calculational system is written primarily in Microsoft Excel. It undertakes a series of functions:

- It receives the signal updates (e.g. every 5 minutes) from the Front End.
- It then calculates oil, water and gas flow rates, plus ancillary information, for each well for each interval and logs these results. In doing so, it employs historical trend information taken from well separator tests or wellhead samples. Water cut trend values, PI and reservoir pressure inputs are obtained from the trend lines. Trend information for total liquid rate, formation gas rate and water cut are used as starting values to assist convergence of the well flow rate calculations. Static data for base reservoir fluid PVT properties and for the well configuration details are also taken in to VMSS3 Online for the well calculations from a VMSS3 Offline central database.
- The results from each well calculation cycle (e.g. every 5 minutes) are then saved internally, together with key input values
- At the end of each day, the computations for each well are averaged, the daily averages are logged into a historical day-by-day database and the full current plus historical information saved in a backup file. The daily average current and historical information is then available to the user from the backup file in both tabular and graphical formats. These enable the user to examine the well’s flow, pressure, temperature etc. performance. Standard charts are built in, enabling the engineer to track the primary well performance characteristics over time.

The use of Excel for VMSS3 affords several benefits, including:

- user flexibility to extract information for further manipulation and analysis

- ready integration with a range of SCADA software systems, e.g. via standard ODBC type database queries or, when programmed into LabView, via direct integration into the primary SCADA system
- potential for use in situations where there is only a rudimentary SCADA system. VMSS3 provides an effective capability when signals data are transferred via, say, a daily file rather than via interrogation of an on-line SCADA database.

III.2 Computational Method

The VMSS3 calculation relies on the input data, which falls into three categories:

- Real time sensor data including the tubing head pressure and temperature, the casing head (gas injection) pressure and temperatures and the gas injection rate or orifice pressure drop
- PVT physical properties data specific to each well. A full PVT assay is most desirable¹. Well head and/or test separator samples can be applied to modify an approximate assay and to adjust for changes in the fluid properties, due primarily to increasing water cut and gas breakthrough during the life of the well.
- Relatively invariant inputs such as the well and separator configurations.

With the input data established, VMSS3 performs mathematical and engineering pressure flow calculations based on the following elements:

- Multiphase fluid flow pressure/flow equations and correlations.
- Prediction of the flow regimes occurring in each increment.
- The applicable heat transfer equations for the well.
- The physical property equations and coefficients derived from regression analyses of the PVT data on the reservoir fluid, covering the entire operating range of anticipated pressures and temperatures.
- A stepwise incremental numerical calculation algorithm developed to achieve good accuracy, speed of computation and closure to a converged result. An integrated calculation is performed from well bottom hole to the well head.

These procedures are field proven and tested. They have been validated against field production data for approximately 450 well systems over a period of 35 years and a wide

¹ Comprehensive PVT data are essential to accurate functioning of the multiphase computations. Through its years of field experience, EYI has developed a database of PVT properties on some 65 reservoir fluids. These can be applied to cross-check supplied PVT assay data and/or to fill gaps.

range of oil and gas fields encompassing several million barrels per day of production. In addition, research and development findings at the pilot plant and laboratory level have been incorporated into the equations.

As the well calculation proceeds in increments from the bottom hole to the wellhead, the wellhead temperature and pressure are calculated, based on an initial assumption of well flow rates. VMSS3 then applies an extensively tested and efficient convergence technique to recalculate the multiphase flow rates to match the recalculated wellhead pressure and temperature with the sensor readings.

VMSS3 accepts GOR, water cut and phase densities in order to improve the accuracy of the well PVT representation based on samples taken at the wellhead, downstream piping or separator if available. Assays and sampling – or data from separator tests, phase fraction or multiphase meters - are thus key components of the VMSS3 system. Given a water cut input, that is used directly, plus a GOR as a starting value, VMSS3 calculates phase rates with high and stable levels of accuracy at all points across the system and over a full range of operating conditions.

IV. VMSS3 VALUE-ADDED ONLINE APPLICATIONS

As described above, the VMSS3 online software system calculates multiphase volumetric and mass flow rates by rigorously simulating oil well performance which conform to the well configuration, reservoir and bottom hole conditions, tubing and casing head pressures, gas injection rate and fluid properties. While the applications described below are for annular gas injection, VMSS3 can be applied to un-injected oil wells and to gas condensate wells. VMSS3 has been successfully applied to difficult flow systems, including extra-heavy foaming crude oils and retrograde condensates.

VMSS3 uses the same well configuration and PVT base assay data bases for both on and offline applications, thereby maintaining consistency of calculations. What is one system thus functions as a combination on-line well computational/monitoring system and short and long term well/field planning tool.

VMSS3 can be applied to monitoring an essentially unlimited number of wells within a field. The number of wells that can be accommodated within one PC is a function primarily of the calculation interval (e.g. 5 minutes versus 8 hours), and secondarily of the PC speed and configuration.

Current applications have demonstrated a high degree of on-line accuracy, which augments the value of VMSS3 for:

well monitoring and well performance improvement

In VMSS3, trends in multiphase flow rates and other well performance indicators are presented graphically and are updated². This allows the user to quickly identify the need for any potential remedial measures. Examples of these are described in the Section below in some detail.

use in tandem with venturi phase fraction/multiphase flow meters,
reducing costs and/or enhancing redundancy, reliability

When VMSS3 is used to predict multiphase flow rates without a multiphase or phase fraction meter installed, well head samples and separator tests are required to track changes in the PVT properties resulting from reservoir gas breakthrough, water cut increase and fluid assay changes (Figure 1 above). VMSS3 integrated with a phase fraction meter, constitutes a complete and lower cost alternative to full multiphase metering (Figure 2 above). Integrated with a full multiphase meter, VMSS3 provides the ultimate in flow rate redundancy cross-checking and back up. VMSS3 will provide a redundancy check for the meter and the

² The VMSS3 "front end" provides continuous updating of signal values. VMSS3 Excel well charts are generally updated daily.

multiphase meter will provide the phase fraction data. VMSS3 can act as a backup for metering hardware in the event of failure.

In addition, VMSS3 maintains consistent flow rate calculational accuracies over a wide range of conditions. It does not experience the “sweet spots” or rapid changes in uncertainty that are a characteristic of many hardware multiphase meters. Application of VMSS3 in conjunction with a multiphase meter therefore improves the reliability, cross-checking and uncertainty of the flow measurement system as a whole.

The PVT property correlations in VMSS3 can be used for any PVT correction software which the phase fraction or multiphase meter may employ (most commonly phase densities and slopes). The well simulation accuracy being achieved provides confirmation of the PVT property correlations being employed. EYI's proven PVT Meter system for PVT properties generation for multiphase meters can be readily applied to provide accurate and consistent PVT properties across all calculations.

calibration to improve rate prediction accuracies

In addition, the VMSS3 calculations can be calibrated over time to further increase rate prediction accuracy by adjusting such parameters as tubing diameter, roughness factors and others.

well allocation

VMSS3's ability to perform rigorous multiphase well flow calculation online and then to accumulate the results improves accuracy of well allocation.

V. VMSS3 VALUE-ADDED OFFLINE APPLICATIONS

V.1 Overview

The VMSS3 system functions in both offline and online modes. As described above, the online mode calculates the well multiphase flow rates in response to real time signals, including the well head and casing head pressures and temperatures, the gas injection rate and temperature and the manifold pressure.

The offline mode is tied into the same Excel well database containing the well configuration data, heat transfer coefficients and well roughness factors. The offline mode can be therefore be used to case study the effects of changes, in reference to the online results being accumulated, i.e. to investigate the effects of varying well configuration or well operating parameters. The costs associated with the change in design or flow conditions may be compared with the producing rate gain to determine a cost/benefit analysis.

V.2 "What If" Well Performance Analysis

Specific examples of "what if" optimization studies that have been carried out for gas injected wells include the following:

Determining the optimum gas lift valve string and orifice size for a set of specified reservoir conditions, i.e. PSO, PI and PFO

Relative to the required tubing head pressure, the multiphase flow rate performance of the well configuration can be calculated and expressed as a function of the tubing head pressure and temperature. This may be expressed as the total mass rate (pounds per second) or as volumetric flow rates.

Gas injection flow rate into the casing annulus depends upon the injection manifold pressure, minus the pressure drop across the Willis Choke and the gas injection pressure and rate are

related. The compressor horsepower requirements for gas injection depend upon the required injection pressures and the gas injection flow rates.

The gas is usually injected into the bottom CV Orifice. The resulting 3 phase flow rates include the additional gas rate from the injection process. The increased quantity of gas in the well section from the injection point to the tubing head serves to reduce the multiphase pressure head, although increasing the frictional pressure drop component. Up to a certain rate of gas injection, the oil production rate Q_{OIL} will increase (Q_{WTR} also is lifted). In order to design the optimum location of the gas lift valves and the bottom orifice in the tubing string, case studies are required where the orifice sizes are changed.

As more gas is injected into the multiphase tubing, there may be additional increments of oil production rate. The gas injection process has the associated cost of compressing the gas rate to the required manifold pressure. This cost can be set against the value of the additional oil production rate, taking into account any additional formation and associated gas that is produced along with the oil. There is an economic balance between the cost of injection and the oil rate gain. The optimum string and orifice sizes result from calculating several alternatives.

Optimizing the Gas Injection Rates for a flowing multiphase well

Figure 4 illustrates a study of increasing the gas injection rate per barrel of oil showing the increase in oil production diminishing as the gas injection/barrel ratio increases. In some cases, the gas injection ratio was increased beyond the optimum, and then the oil producing rate begins to decline. The objective of the gas lift optimization study is to determine the maximum economic gas injection rate that produces the maximum oil rate. Beyond a certain gas injection rate and casinghead pressure, there will be no increase in the oil producing rate and eventually there will be a decrease.

The offline mode of VMSS3 can be used to perform the necessary multiphase flow and gas injection flow rate calculations to determine the point where there is no increase in producing rate with increasing gas injection rates. These individual well calculations can be integrated into and used to form of the basis of zone or field wide gas lift optimization schemes.

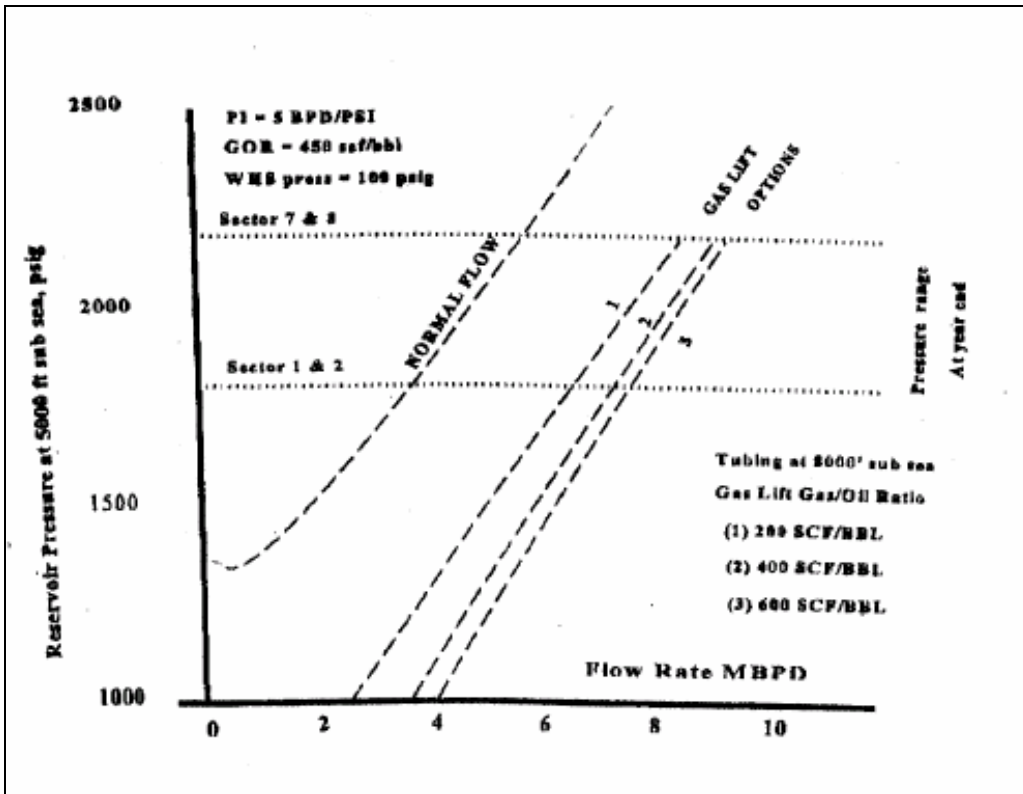


Figure 4: Gas Injection Rate Study

Analysis of the Reservoir Pay

In two example offshore wells, the bottom hole pressure PFO shows relatively rapid fluctuations versus time and the flow rates reflect this variation over time. The most efficient producing rates are homogeneous flow regimes operating with relatively low friction factors with an efficient use of the reservoir pressure drop.

The VMSS3 online mode operating system computes the 3-phase flow rates every 5 minutes and the PFO based on the input sensor signals. Thus the fluctuation of PFO versus time can be followed in detail along with the fluctuations in the oil, water and gas rates.

In horizontal wells, the fluctuating PFO versus time is often caused by slug flow in the large diameter open hole completions. The well production can be increased and produced more smoothly by the installation of a smaller liner after packing off the open hole. This substantially increases the velocity in the horizontal lateral which reduces the pressure, producing a smoothly flowing 3-phase mixture entering the inclined well. However, there is a cost associated with the installation of a new liner or of a smaller downhole liner.

Then the question is, *“Would the projected increase in oil and gas producing rates justify the cost of installing the liner in the horizontal lateral?”*

There is another reason why the PFO values fluctuate, which is largely due, in most cases, to fluctuating gas producing rates from some of the perforated intervals. In this case, a solution may involve plugging back certain perforations after a downhole logging survey has been made to identify these gas producing perforations. Again, there is the question of the production increase plus the more stable well flow versus the cost of the downhole work.

The well simulations that are achieved with VMSS3 enable these kinds of analyses to be undertaken.

Management of High Water Cut Zones with Time

Many reservoirs have increasing water cuts versus time. This is frequently due to coning from an underlying water aquifer or zone. The well producing rate can be reduced to minimize the water production. After a period of production, the water zones may break through such that the well produces at high water cuts. Following a downhole logging study, the water producing sections of the pay are identified and the well may be plugged back to the top of the water bearing perforations.

VMSS3 can compute the benefit of reducing the water cut. The oil and gas rates will increase because the water is no longer occupying the reservoir pay and inclined tubing. In addition, another advantage of eliminating the water cut would be a reduction in the cost of having to handle the water disposal into the sea or onshore, as controlled by environmental considerations.

By comparing the producing rates of oil and gas, the gain in production can be compared with the costs incurred for the downhole logging and subsequent workover to plug back the water bearing zones.

V.3 Well Performance Hydraulic Gradient Analysis

Hydraulic gradient well performance charts are generated automatically by VMSS3 in on-line mode. A hydraulic gradient chart is depicted in Figure 5 as an example.

The hydraulic gradient chart shows the well performance of the gas injected well including the reservoir pay, the multiphase well, and the casing annulus gas injection performance, on the same chart. The example is for a specific test, in this case, the Well LC2 test of 2/01/04. However, the VMSS3 online system is able to compute these hydraulic gradient charts for all wells. These charts are valuable for engineers and management to observe the current status of the well from the hydraulic and thermodynamic aspects and they may be also useful to engineers to aid in estimating what effect changes in the well input variables would have on the well performance.

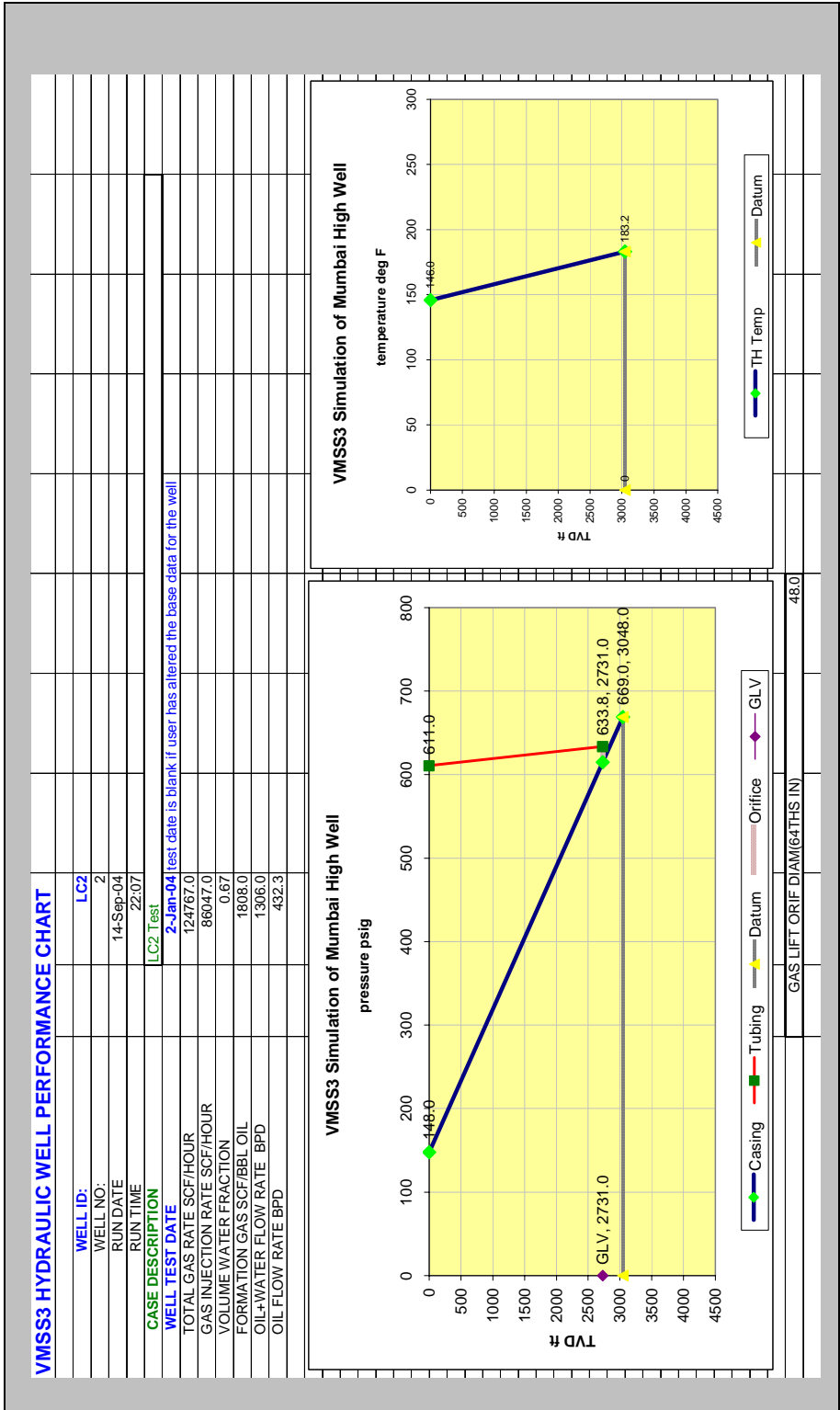


Figure 5: VMSS3 Hydraulic Well Performance Chart

VI Support

For issues relating to VMSS3, contact Bryan Yocum, Daniel Dunbar or Martin Tallett at EnSys Yocum or support@enssysocum.com.

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