EnSys Yocum
MULTIPHASE FLOW TECHNOLOGY

PRODSIM– Technical Description

Production Facilities Simulation Model for Black Oil & Gas/Condensate Field and Pipeline Development and Design

Sections to this technical paper include an Overview and Application example.

I. Overview

The Production Facilities Pressure Temperature/Flow Rate (PTQ) Simulation Computer Model (PRODSIM) describes the flow performance for the production system beginning at the reservoir, flowing through the well reservoir pay, then up the well, and through the surface or underwater facilities, devices and pipelines to the production manifold.

A companion computer simulation model, GOSPSIM, receives as input the multiphase flow rate, pressure, and temperature at the production manifold. GOSPSIM simulates the separator and process flow performance of the Gas/Oil/Water Separation plant and the associated downstream processing facilities.

PRODSIM and GOSPSIM are applied to both Gas/Condensate Fields and Black Oil Producing Fields. They entail the application of a complex set of algorithms and computational methods that originated in the late 1950’s. Since the late 1950’s, PRODSIM and GOSPSIM have been progressively improved based on field experience and literature survey and analysis and extended to cover 60 Fields.

We have developed extensive data banks and empirical data based correlations from our applying PRODSIM and GOSPSIM in 60 Oil and Gas/Condensate Fields. Accurate simulations of several hundred wells and surface/underwater producing systems were carried out over a five year period. The simulations are grounded in a comprehensive set of physically sound and theoretically correct algorithms that have been combined with he field test data, physical properties data, and computer based methodologies.

II. Detailed Description

The PRODSIM simulation model features are described in detail below.

Engineering and Field Basis

- The multiphase/single phase fluid flow mechanical equations and correlations have been rigorously developed and are contained in our simulation models. Extensive Engineering Field Research has provided empirical data which has led to more accurate multiphase flow algorithms. Contributions from several relevant technical papers have been incorporated in certain sub routines.

- Temperature relations are calculated from the heat transfer equations empirically modified by production test data gathered on the wells and surface/underwater producing system profiles and in line devices and elements. Flashing flow temperature drops are accounted for as are the Joules Thomson temperature drops across chokes, and control valves.

- The thermodynamic PVT properties of the flowing reservoir fluids change as the pressure in the producing system decreases, and gas flashes out of the liquid phase. The physical properties have been accurately correlated from the laboratory test data on the downhole reservoir fluid samples taken. The physical properties measured are the condensate and saline water densities, the gas phase density, the gas/condensate ratio, the mixture density, and the viscosities of each phase measured as a function of pressure and temperature (P&T) both below the bubble point. These span the range down to Standard Conditions and above the bubble point for the pressure liquid phase.

- This laboratory data has been regressed relative to multi-coefficient equations to determine coefficients that result in the set of equations describing the reservoir fluid mathematically within accuracy of 0.5-2%. The normal set of descriptive equations has twelve equations and 55 coefficients to accurately describe a reservoir fluid.

- This algorithm and set of correlation coefficients is referred to as the PVT program or the PVT subroutine. This program may be used on a standalone basis where it may be integrated into a multiphase meter data acquisition and control program to improve flow rate measurement accuracy and to translate flow rate results to other producing system conditions. (i.e. bottom hole reservoir, wellhead, separator, or Standard Conditions). In PRODSIM and GOSPSIM, the PVT subroutine is called in for the calculation of each flow increment along the system.

- Correlations for the other physical properties such as specific heat, surface tension, thermal conductivity, hydrate formation, and wax deposition are entered as subroutines and are invoked at each flow increment .

After many years of development and experimental research, the computer based numerical analysis methods have been created to solve the large number of equations and correlation coefficients that enter into the calculation of each flow increment reflecting any elements (pumps, compressors, valves, chokes, fittings, etc.) that are contained within the flow increment.

PRODSIM and GOSPSIM has been installed online for essentially instantaneous PTQ computations along the producing systems. These computations procedures are very efficient and accurate. The calculations proceed incrementally starting at the reservoir and calculating stepwise in appropriately sized increments through the reservoir pay and up the well and through the surface/underwater producing system including any devices, elements, or facilities in the system.

Depending on the problem at hand only part of the calculating system may be used for the computations (e.g. the reservoir pay plus well section only (WELLSIM); the surface producing facilities system only (PRODSIM, the Surface Facilities option); or the Gas/Condensate/Water Separation Plant and associated downstream facilities (GOSPSIM).

Reservoir

The reservoir input is the static reservoir pressure and temperature at the well depth at the top of the reservoir pay. If a Reservoir Simulation Model is used to calculate the reservoir pressures and flow rates versus time at the well, PRODSIM has an option where up to 100 parallel cases can be calculated to provide reservoir pay and well performance calculations versus time.

Reservoir Pay

The pressure drop versus flow rate across the reservoir pay is measured by the productivity index in many wells. Thus the PI of the Gas/Condensate well may be calculated from the reservoir parameters, permeability, porosity, pay thickness, and viscosities. The PI may be input directly to the Model.

In wells where the pressure drop across the pay varies with the flow rate, inflow performance equations are options to calculate the performance. These relationships normally have two or three coefficients and must be determined by two or three flow rate tests carried out by the wireline or production logging testing crews under Engineering

Supervision. The correlated coefficients are input to the program subroutine that generates the IFP function.

An optional subroutine can calculate the resulting reservoir pay pressure flow performance from a reservoir pay that is divided into 10 sections which can have varying PI's, water cuts, and Gas/Oil ratios in each zone. The resulting blended mixture then flows into the Gas/Condensate Well.

Gas/Condensate Well

Subroutines have been developed for the major classes of well configurations, vertical, inclined, horizontal, and extended reach configurations. Downhole chokes are integrated into the well calculation stream at a specific flow increment. The pressure/temperature flow rate performance of the wells are calculated with the inputs of flowing bottom hole pressure and temperature and Gas/Condensate flow rates input to the Well Model. The Model calculates up the well and can use as many as 50 increments to improve accuracy. The wellhead pressures and temperatures and the multiphase flow rates are the outputs of the Model Calculations. Options are available for changing the Gas/Oil ratios and the water cuts to generate well potential curves that reflect changes in reservoir conditions over time.

Extensive Engineering Research was carried out in 12 Fields. Production Testing was performed in 195 wells. Out of the 195 wells, 30 were Gas/Condensate wells. The Model Calculations were tested by matching the well potential curves (Wellhead Pressure, Temperature, and Oil, Water/Gas Flow Rates) with the production test results. Adjustments were made in the Simulation Model to provide the most accurate estimates.

The pressure loss functions in the wells were due to elevation pressure drops and frictional pressure drops. Acceleration pressure drops only appeared in high velocity wells. The key to accuracy in well performance proved to be the accuracy of the PVT properties. The ability in our PVT subroutine to calculate the physical properties with accuracy of 0.5-2% was critical in being able to calculate the flow performance accurately. Most wells were calculated with an accuracy in the +/-(1-2%) range. The accuracy would be less if the physical properties and well configuration data were not exact.

It is this accuracy that enables our WELLSIM model to be used for calculating flowing bottom hole pressures from wellhead pressures/temperatures/flow rates. The expensive procedure of installing pressure and temperature gauges in the bottom hole of the wells to measure the flowing bottom hole pressure was avoided thus saving substantial investment.
These downhole gauges had a very short life in difficult high pressure wells.

The wireline crews that collected bottom hole samples would check the bottom hole pressures usually on a quarterly basis. This information would be reconciled with the WELSIM Model calculations of the bottom hole conditions.

Surface/Underwater Multiphase Producing System

The PRODSIM pressure/temperature multiphase flow rate simulations have been carried out on several hundred surface and underwater producing systems. The configurations varied from hilly terrain to fairly level plains and including many underwater multiphase lines with risers to platforms and downcomers from off shore platforms.

The devices and elements in the lines are located within a flow increment and are computed in that increment. The devices and elements that can be entered into the model simulations are: wellheads, valves, control valves, chokes, sand and stone traps, and entrance effects and bends in the line, wellhead separators, and liquid removal drums along the line.

Depending on pressure and temperature at any point in the line or devices, correlations for hydrate formation and for wax deposition are called in to predict their occurrence. Sand settling rate correlations for multiphase flow are calculated along the line to predict sand deposition. Temperature effects due to high pressure drops across control valves or chokes are calculated at the location.

Engineering Research was carried out on 172 Surface Producing Systems operating in 12 Fields including 3 Gas/Condensate Fields. The pressure drops were due to frictional pressure losses, uphill elevation pressure losses, downhill pressure recovery factors which were functions of the flow regime, and acceleration pressure drops which were mostly negligible.

The production tests provided a large body of flow data so that uphill pressure loss correlations and downhill pressure recovery correlations could be developed by YCI and the Client Production/Reservoir Engineers. The frictional pressure loss correlations which depended on the flow regime in the pipeline increment were also correlated when slug flow was operating in the line, frictional pressure losses tended to be higher than for stratified flow and homogenous flow regimes. Thus it was necessary to develop a flow regime predictor for each increment in the line to make pressure drop estimates.

The 172 production tests were matched by the PRODSIM Model Simulation Calculations to +/-(4.5-7.9%) accuracy for homogenous and stratified flow conditions and +/-(10-12%) for slugging lines. A subroutine has been updated to the latest status of slug flow research and the slug trains composed of the liquid slug length followed by the gas bubble length are now predicted. These affect pressure drops, especially at lower flow rates, and are critical for the design of slug catchers at the end of the line.

A separate set of correlations have been entered as a subroutine for liquid holdup estimates in each increment along the line. The total volume of liquid holdup is calculated in the Simulation Model. Liquid holdup can play an important role in Gas Condensate pipeline calculations. Increasing liquid holdup reduces gas line capacity and sets the frequency of running pigs to eliminate the liquid holdup and meet guaranteed gas capacity requirements.

The GOSPSIM Simulation Model is contained in a separate description.

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