GMAN

The Optimizing Gas Management System

A development of **MARACO**, Inc.

GMAN is a unique set of computer programs that analyze performance, and optimize development and operation, of gas production facilities. The GMAN software provides rapid and realistic projections of physical performance of wells, reservoirs and integrated surface networks of gas production facilities. In addition GMAN combines such projections with cash flow analysis using an efficient optimizing logic. Thus, GMAN is the most fully capable tool available for planning, budgeting and managing gas supply activities. Its convenient facility for inputting data and the broad range of graphical and tabular output make GMAN an ideal tool for managing all sizes of reservoirs, both old and new.

DESCRIPTION

On the ***small*** scale GMAN analyses individual wells. These analyses include:

1. history matches,
2. effects of liquid production on vertical flow,
3. impact of size of production tubing and surface flowlines on deliverability,
4. stimulation and perforation strategies and
5. generation of IPR and tubing performance curves.

On the ***intermediate*** scale GMAN evaluates drilling, production and compression strategies for individual or groups of reservoirs in a physical, economic or optimal mode. A specially tailored gas nodal analysis simulator considers flow between and from layered reservoir blocks up the production tubing and through the surface flowline network to a central delivery point. Production response to any size central and/or booster compressor is determined. Evaluations may include impact of :

1. aquifer strength and connectivity and
2. possible distribution of required spare capacity.

On the ***grand*** scale GMAN determines the optimal way for a group of reservoirs to supply a time-varying, seasonal demand vector against a possibly time-varying outlet backpressure. The simulator measures interactions between reservoirs in the flow network allowing GMAN to strike the optimal balance between wells and compressors (including timing and location of both). Here, the full scope of GMAN's capabilities may be brought to bear:

1. 50 reservoirs with 15 interconnected producing cells (*The latest version of*

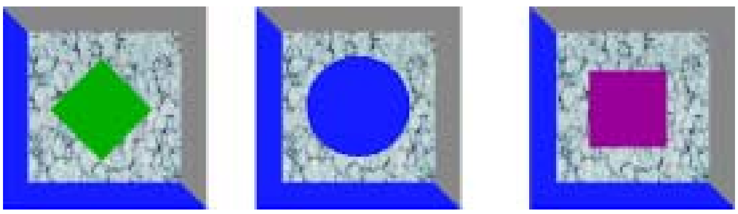
GMAN now being beta-tested allows 50^{+} *producing cells in a reservoir*) containing 5 producing layers;

2. 250 capacitated flow segments with specified flow limits and/or chokes at intermediate nodes (platforms or manifolds) accounted for.

This realistic physical model is integrated with GMAN's economic evaluation program, which translates price, cost and flow rate projections into net revenues, taxes, royalties and economic yardsticks for each possible investment in a well or a compressor. The physical and economic calculations are performed in tandem under control of GMAN's optimizing routine to determine optimal development and production strategies to meet offtake requirements over a specified planning period. GMAN's scope and versatility is exemplified by the range of questions that can be studied:

- short or long run deliverability,
- increase in production capacity from wells or compressors,
- marginal economic evaluations of capacity expansions,
- sensitivity to prices, cost, taxes, demand swings,
- spare capacity requirements,
- length and diameter of any flowline segment
- reservoir parameters including liquid recovery from each reservoir;
- desirability of possible contract gas delivery rates;
- farm outs, farm ins, purchases and sales of reserves;
- exploration prospects,
- gas tolling and purchase tenders.

Benefits to engineers and managers are many, and most importantly include understanding of how critical economic and physical outcomes and tradeoffs may affect future business activities. Economic numbers compared to measured desirability and risk, are truly indicative, each being the optimum for the scenario it represents. Sound long-range plans, that guide each year's budget and operation, can with GMAN be updated at any time to determine optimal response to new information or unexpected business developments. Optimal feedback management becomes an achievable goal. Thus, managers are able to steer the organization along the path of maximum profit and investment return.



GMAN's TWO OPERATIONAL MODES

1. As a gas reservoir/trunkline simulator—Given the configuration of producing formations in the reservoirs, the details of the production tubing, surface

flowlines, compression and separation facilities GMAN calculates the physical performance of the entire system with an accuracy sufficient for engineering design and performance assessment. The gas offtake specification for simulations may be to deliver a targeted rate or to produce at capacity. GMANSIM performs this function and, in addition, contains a program feature, GMANHST that facilitates history matching of recorded reservoir performance. The simulator mode contains an additional, multi-faceted reservoir analysis module, GMANVFR. This module incorporates the one-, two- and three phase, vertical and horizontal, flow correlation options available in GMANSIM in subprograms that compute flow and pressure performance and graph results for:

- flow through production tubing in individual wells (GMANVFO in earlier versions) in a program framework that allows detailed study of vertical flow predictions and calibration of the VFO equations to match field observations,
- flow through production tubing connected to a horizontal surface flowline,
- flow through production tubing connected to a horizontal surface flowline connected in turn to a vertical riser,
- flow through several production tubings connected to a common manifold connected in turn to a horizontal flowline and a vertical riser and
- an IPR curve for a well (GMANIPR in earlier versions). IPR (Input Productivity Relation) and tubing performance curves are plotted on a common graph, thus allowing convenient determination of reservoir and vertical flow behavior with different tubing sizes.

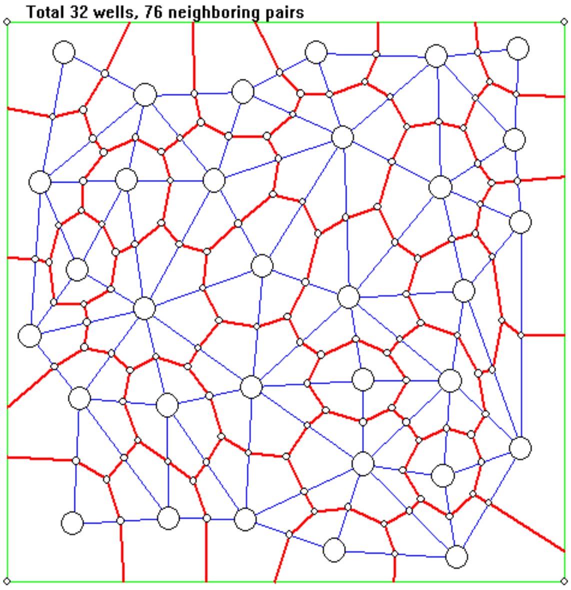
2. As an optimizer—Given a desired offtake rate plus exogenous limits on development and/or production, plus the simulation and economic input files, GMANOPT systematically sorts through the many possible decisions to find the set that satisfies offtake requirements and maximizes discounted cash flow. In this mode the simulator and economic evaluator are used as subprograms to determine the economic desirability of each possible investment decision.

THE GMAN MODULES

Currently, the GMAN Software Suite consists of six modules: GMANGRID, GMANDAT, GMANSIM, GMANHST, GMANVFR, GMANOPT.

GMANGRID — is a program module that generates a computing grid for a set of ‘well’ points (computing cells) whose locations are specified by clicking a spot on the screen. The well point may be dragged to another location if desired. A well point may be specified as containing zero wells in GMANDAT. In this case the point is a drainage cell whose hydrocarbons are produced from adjacent, interconnected cells containing producing wells. In the general case the reservoir’s outer boundary (green) is a polygon. A cell (red) is a polygon surrounding a well point (circle). Using a tailored algorithm GMANGRID draws the red boundaries of all cells onscreen before the user’s eyes. The grid applies to all formation layers.

Clicking on various objects onscreen brings out an input panel to specify physical data – boundary segment → aquifer presence, size and permeability; well circle → vertical/horizontal well, permeability, thickness, porosity. Fault lines and fracture designators may be inserted manually. With the cells fitted into an x-y grid and the required input parameters input, a click by the user causes GMANGRID to calculate interregional flow coefficients, cell volumes and parameters and aquifer parameters needed for simulation calculations. These are stored in a text file that is imported into GMANDAT.



Thus, GMANGRID relieves the user of the tedious manual task of generating a computing grid that limits efficient use of reservoir simulation.

A primary objective of GMANGRID, which is currently in the early beta-testing stage, is to cause GMAN to conform to a reservoir engineer's normal mode of analysis, which starts with a study of individual wells. To this end a goal with GMANGRID is to allow #grid cells ≥ #wells.

To support GMANGRID we plan to add two submodules, RESERVOIR WELL DATABASE (**RWD**) and UNIVERSAL WELL MODULE (**UWM**). The goal is to put into RWD all well data needed to support reservoir simulations and supporting well analyses. Flexibility is a keynote characteristic of RWD. Slots to store additional data items and input panels to accommodate them can be readily be created. Likewise for links to other data sources. RWD's prospective inventory of data for a well is as follows:

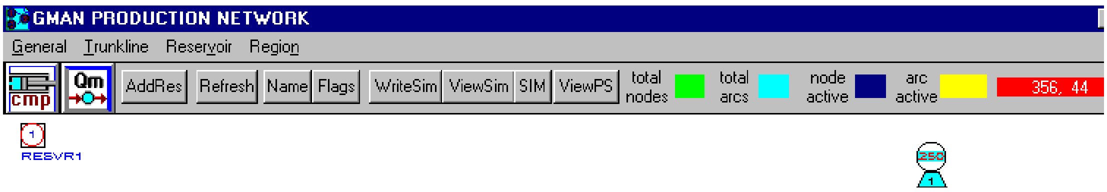
- spud date, surface/bottomhole coordinates
- list of well logs with link to source
- lithology/formation characteristics, e.g., fractures, shale content, vertical /horizontal permeability, porosity/thickness of layers
- fluid levels/compositions
- pressures/rates from well tests
- production rates or links to data sources
- completion details & parameters of well's flow model.

Planned output of UWM is a flow model for each well that is ported into the simulator (via GMANDAT). The core of UWM is a collection of computational objects that cover the full scope of effects needed to simulate the behaviour of any well. Included are routines for:

- deviated, vertical, horizontal and lateral wells

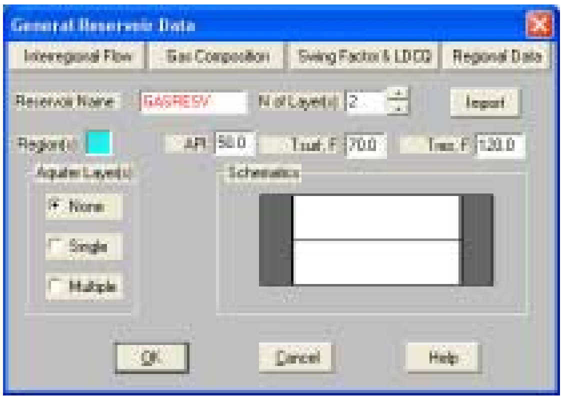
- completion types including impact of formation lithology and fracturing
- effect of fluid content and composition including various correlations for density, PVT and pressure drop.
- impact of horizontal/vertical permeability ratio, saturation dependent relative permeability and turbulence in formation
- aggregating production string details to obtain a compact model for tubing and annular flow
- chokes and surface completion effects
- linking UMW to GMAN.VFR to calibrate flow models with measured data from well tests

GMANDAT — is an easy-to-use, Windows-based facility for building a BDS file containing a database for making one or many runs with GMANSIM and the other GMAN programs. GMANDAT's Main Windows screen contains a toolbar and a menu bar for calling out input data templates, tables and boxes for entering all required data. But GMANDAT's centerpiece is a graphics window, the Project Network Screen (PNS), containing the network analysis diagram of the project in the BDS file. All data entries are conveniently made by invoking the data option lists and entry panels, directly from the PNS. The diagram below shows the PNS when it is first opened. A graphical layout of the entire model – reservoirs, regions, flowlines, trunklines and connecting nodes some with compressors – is easily generated in the PNS via a series of mouse clicks and typing entries. Major models can be laid out in minutes! As the diagram is constructed GMANDAT sets up the logic to control all data input so that all that remains for the user to do is to click icons that bring up data input panels and to type in the required data. GMANDAT contains specially designed features that reduce typing to a minimum.



GMANSIM — simulates performance of a gas production system. A basic tenet of GMANSIM is that a full nodal analysis from the aquifer through the formation, production tubing, surface flowlines and compressors must be performed to obtain an accurate estimate of instantaneous gas deliverability. Reservoir pressure drives deliverability, which feeds production, which causes reservoir pressure to fall. It follows that to predict the declining profile of production over time, a sequence of nodal analyses must be performed. The basic reservoir and pipe flow equations are solved in each nodal analysis to determine deliverability. The corresponding flows enter into material balance equations for the producing layers to define the traces of reservoir pressures through time.

"GMANSIM uses a novel method of discretizing the flow equations that yield's solutions rapidly. This speed makes it practical to imbed the gas simulator into the optimizer thereby supporting realistic evaluations of all investment alternatives. The addition of GMANGRID with the resultant smaller cell volumes necessitated a major reworking of GMANSIM’s cell routines to achieve smooth convergence to the correct solution.”

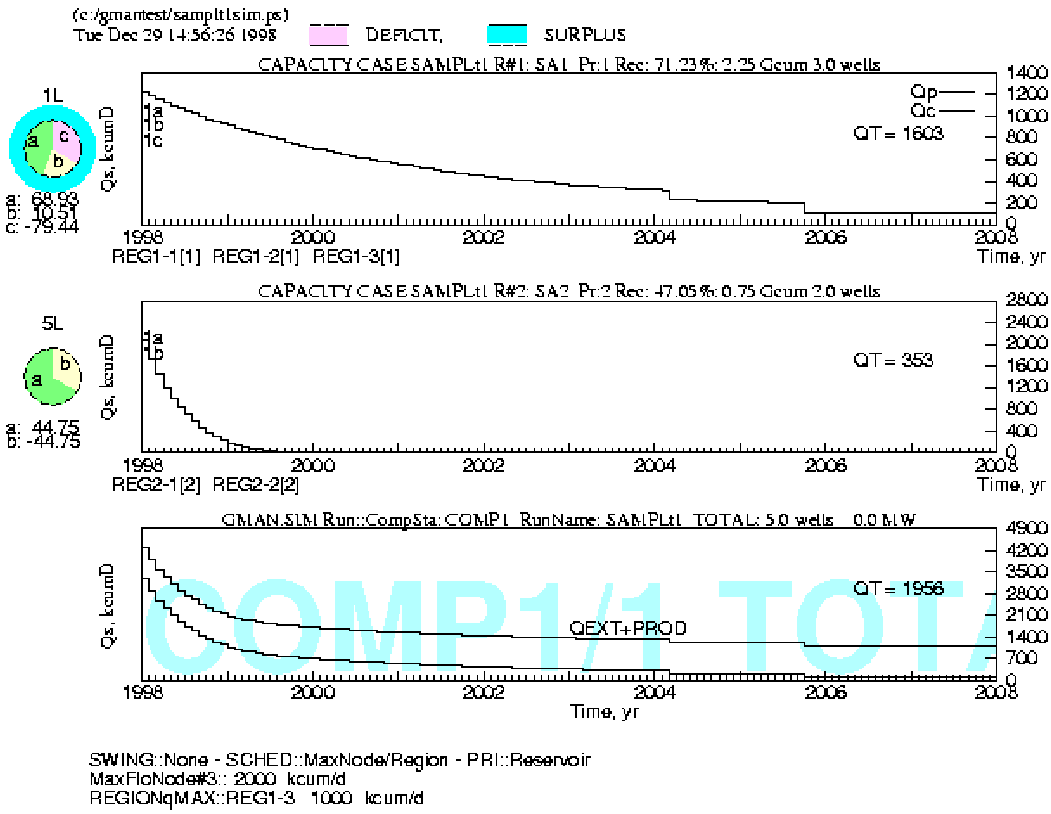


The example opposite illustrates a simple two-reservoir, three-region GMANSIM network simulation model.

Previously up to 15 blocks (computing cells) could be used in each reservoir, but with the addition of GMANGRID a larger number of computing cells is required. Although no absolute upper limit for number of cells that can be handled with GMANSIM has been established (The largest such grid tested to date contained approximately 50 cells.) an expected upper limit for efficient operation is 100. Using fewer cells greatly reduces computing time in optimization runs. A few years ago computing time was a serious consideration, but with modern day PC’s that limitation has become relatively unimportant. Experience shows that for most gas reservoirs the loss in accuracy resulting from using only a few grid cells, rather than the large numbers often used in simulations reported in the literature, is small. For example, for a moderately large, dry gas reservoir in Australia, an unpublished comparison of decline in deliverability with cumulative production predicted by a three-cell predecessor of GMANSIM and a multi-cell high-end simulator model showed differences to be insignificant. [The differences pale in comparison to errors resulting from improper aggregation of layers with different permeabilities.] This insensitivity to grid size arises because with the relatively small value of gas viscosity; pressure gradients in a producing gas layer with permeability greater than 0.5 md. are insignificant. [With very tight formations the essential problem is to establish an economic well spacing that yields timely and effective depletion of each drainage volume.]

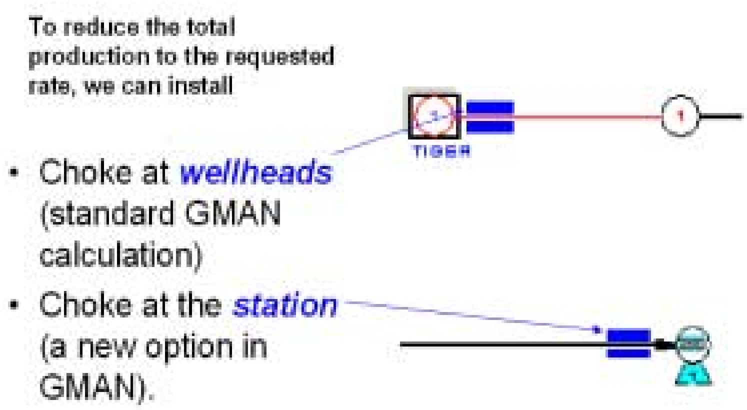
Pressures differ greatly between layers, but not within an individual layer. With nearly uniform pressure a large, multi-cell model is not required to determine that performance varies in direct correlation with the average permeability used. The experience cited in the previous paragraph notwithstanding, the issue here is not to debate the relative technical merits of a sparsely gridded simulation model. Instead, the situation is that reservoir models with few cells are used in GMAN in order to reduce computing time to desired levels. These models incorporate most of the fundamental equations that describe gas reservoir behavior and have been demonstrated to give satisfactory results in many instances. However, if results are available from more extensive simulation models [which may account for complex effects such as spatial distribution of water influx, drop out of condensates in the formation, or compartmentalization of the producing formation by fractures], the required action is to calibrate GMANSIM’s models to accurately match the more detailed models. The input database for reservoir studies [which for upwards of 50 reservoirs can become very large] is conveniently managed by GMANDAT in a binary data system [BDS] file. Input data files for GMANSIM runs with all or only some of the reservoirs in the BDS file are obtained with only a few clicks of the mouse.

This example shows the Reservoir Performance Graph generated by GMANSIM for a two -reservoir, five region model in which the 2nd reservoir contains 5 producing layers. [QEXT is external gas tolled through a part of the trunkline network to the station.]



BACKOUT - New Feature

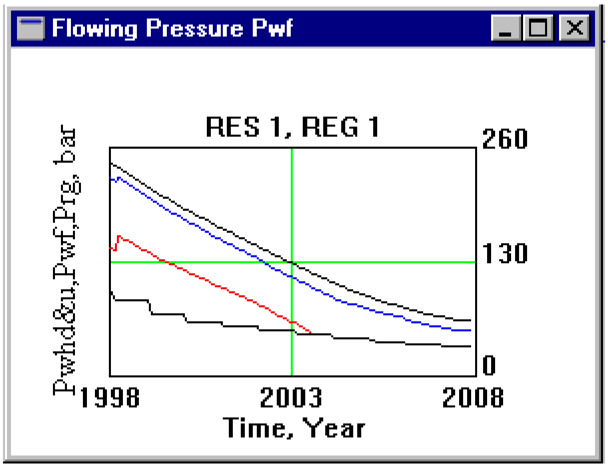
A new BACKOUT feature added to GMANSIM provides an option to determine which reservoirs are shut in when flow is throttled at the station to obtain a less-than-capacity production rate. (The alternate option is to throttle each reservoir individually at the wellhead.) With the station option low pressure reservoirs may be 'backed out' by flow from a higher pressure reservoir.



GMANDAT & GMANSIM work together synergistically to quickly provide solutions to a considerable variety of gas reservoir/trunkline problems. GMANDAT creates and maintains the BDS file containing the database and generates input SIM files that are read by GMANSIM, which computes and displays desired results. The most convenient way to operate is with each module's Main Window in view onscreen: Clicking the SIM button in GMANDAT transfers control for a run with GMANSIM; clicking the DAT button in GMSNSIM returns control to GMANDAT for changes in data or run type.

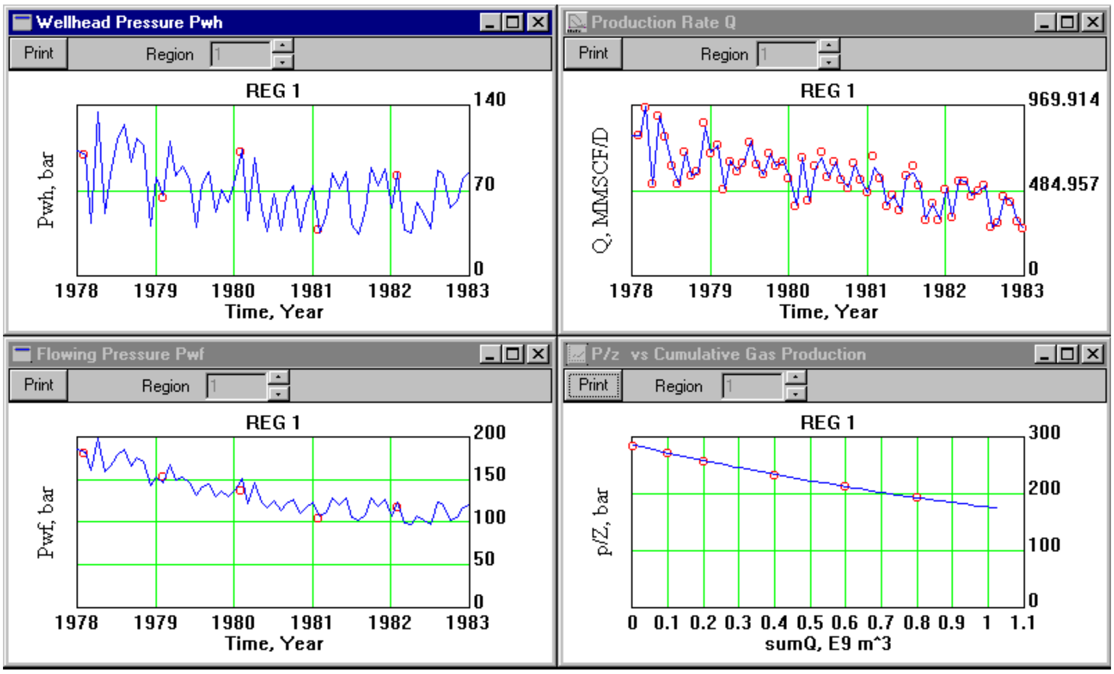
GMANHST — the history matching module that performs three functions:

1. Generates detailed graphical presentations of results from a GMANSIM run. GMANHST's input for this output interpretation is a text [XLS] file from GMANSIM [that is formatted for convenient input into any spreadsheet program]. By selecting any time step with a click of the cursor and then placing the cursor over any facility [formation, wellbore, wellhead, flowline, trunkline segment, compressor, etc.], pressure drop and flow rates in that facility can be viewed. A right click of the cursor brings up a pair of options that when clicked yield an onscreen Windows graph of flow rate and pressure vs time. Another right click in any graph's window and hardcopy is obtained. In this example starting from the top the four pressures plotted for Region 1 in Reservoir 1 are pres, pwf, pwh, and pwhc. The latter is pressure downstream of a wellhead choke.

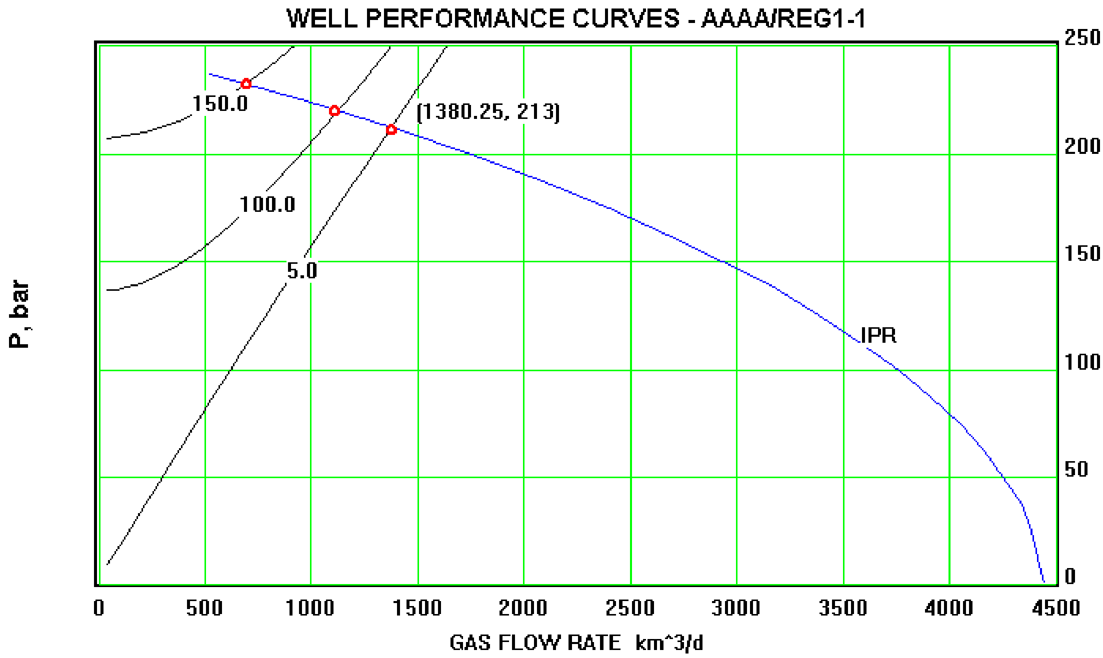


2. Facilitates preparation of observed data files for history matching [HM] runs. Historical production rates from each producing region are required for a HM run. A separate HST file created by GMANHST contains these rates for each reservoir in the model. A Windows-based input interface is included in GMANHST. The data are entered into specially formatted Windows dialog boxes allowing visual inspection before writing to the file on disk. Onscreen plots of these data vs time [such as the example graphs below but with only the red data points] allow rapid detection of gross typing errors and the contents of any HST file can be called back onscreen for checking and editing. HST files for all reservoirs are input into GMANSIM in a HM run.

3. Generates displays with historical data points overlaying graphs of results computed by SIM in a HM run. GMANHST reads a binary [BIN] file output by GMANSIM plus all of the HST file s. The example shows pwf, pwh and qg vs t and p/Z vs cumulative production for Region 1. Plots such as these are keys for HM. Reservoir properties are adjusted so that differences between calculated and observed become smaller until a satisfactory model is obtained.



GMANIPR — generates an IPR curve [bottomhole flowing pressure vs instantaneous formation deliverability determined by GMANSIM for a specified formation pressure]. GMANIPR also calculates and plots tubing intake (TI) curve(s) [bottomhole flowing pressure vs tubing flow rate] for up to 5 different wellhead pressure(s). For the latter calculation tubing and fluid parameters are obtained from GMANSIM. If included in the GMANSIM input file, observed data points (pwh, pwf, qt) are also plotted on the output graph. The TI curves demonstrate the behavior of the tubing string and the combined plots show the operating point for the different well head pressures. Both Windows-based and Postscript graphs are available and hardcopy of each are readily obtained from the computer's printer. This example is a Windows graph.



GMANVFO — For an input wellhead pressure, pwh, GMANVFO calculates equilibrium flow rates in the production tubing using a selected vertical flow option (VFO) [GMANSIM includes 4] for tubing intake pressures decreasing from just below pwh down to the flow point. Provision is made to input observed data points (pwh, pwf, qt) obtained from well tests. [If pwh differs from pwh, pwf must be adjusted for the difference.] In the output graphs the input points are superimposed on the calculated TI curve allowing "history matching" to select the VFO and tubing parameters that best fit the observations. Both Windows-based and PostScript graphs are available and hardcopy of either is readily obtainable.

GMANVFO has now been replaced with GMANVFR, which is an extended version of the module that also allows the user to model the subsurface to surface risers, etc. VFR has a powerful interactive graphics interface that makes constructing a model a relatively simple task.

GMANOPT — is a program that determines the optimal development and production schedule for one or more gas reservoirs producing through single or multiple compressor stations(s). The optimal solution specifies the schedule of drilling wells and adding HP over time to meet a specified offtake rate. GMANSIM is used as a subprogram within GMANOPT. An input file of economic data is prepared with GMANOPT's Windows-based input interface.

The GMAN Development

E.L. Dougherty, Ph.D.

GMAN is the combined result of over 20 years extensive research, development and application by **Dr E. L. Dougherty** (Professor Emeritus of Chemical & Petroleum Engineering, University of Southern California) through his company Maraco, Inc., where he is ably assisted by his partner **Dr. Jincai Chang** and their colleagues. Dr Dougherty has specialized throughout his career in the study and application of large scale engineering and economic computer systems for the oil and gas industry, and has written numerous papers on the subject (see Publications). The practicality and effectiveness of this approach to optimal planning is well demonstrated as previous versions of the program have been in heavy use for over 18 years by Santos Limited in Australia. This usage has now been extended to include operators in Europe, USA, and the Middle East.

Publications

1.Dougherty, E.L, Juber, F. and Chang, J.: “Prediction and Analysis of Gas Wells Producing from Reservoirs Containing Several Non-communicating Layers,” SPE 25908 presented at Rocky Mountain Regional and Low Permeability Reservoirs Symposium (Denver) April 28,1993.

2. Dougherty, E.L., et. al.: “A Method for Simulating Pressure/Production Performance of Volumetric Dry Gas Reservoirs,” JPT (Nov. 1985) 2059-70.

3. Dougherty, E.L., Lombardino, E., Zagalai, B., O’Donnell, B., Goode, P. & Hollis, R.,”A New Systems Approach to Optimizing Investments in Gas Production and Distribution”, Proc. 1983 Hydrocarbon Economics and Evaluation Symposium, Dallas (March 1985) p. 33-48.

4. Dougherty, E.L., Lombardino, E., & Hutchinson, P., “Impact of Investment Criteria, and Reservoir Characteristics, Taxes, Royalty and Price on Optimal Field Development Plans”, Proc. 1985 Hydrocarbon Economics and Evaluation Symposium, Dallas (March 1985) p. 21-32.

5. Dougherty, E.L., Lombardino, E., & Hutchinson, P. & Goode, P.A., “Use of Mathematical Decomposition to Optimize Investments in Gas Production and Distribution”. J. Pet. Tech. (Jan. 1986) p.70-84.

6. Dougherty, E.L., Dare, D., Lombardino, E., & Hutchinson, P., “Optimizing SANTOS’s Gas Production and Processing Operations in Central Australia Using the Decomposition Approach”, INTERFACES 17:1 (Jan/Feb 1987) p. 65-93.9

Hardware Requirements

GMAN is designed for, and operates very efficiently on a PC. Minimum requirements are a Pentium 600 computer with a minimum of 64 MB RAM, Windows 95, 98, NT and 2000 operating systems.

Consulting Services

MARACO, Inc. has successfully performed consulting projects for major operators and governments throughout the world. Major assignments include gas and oil field* optimizations in Holland, Australia and Kuwait. Services offered include full project management, field optimization and oil and gas simulation training, and contract software development.

*Oil field optimization is performed using the GOMAN program, which was originally developed for the Kuwait Oil Company. This program is now available as a commercial product and Maraco is seeking oil company participation to further develop this software.

New Developments

The next release of GMAN is due out in October 2004 and will include the new RESERVOIR WELL DATABASE (**RWD**) and UNIVERSAL WELL MODULE (**UWM**) as described in this document. Please contact Maraco or one of its agents for more information on this release.

To learn more about the GMAN program and our other products and services please contact:

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