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USER'S GUIDE AND DOCUMENTATION MANUAL FOR "BOAST-VHS FOR THE PC"

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ABSTRACT

The recent advancement of computer technology makes reservoir simulations feasible in a personal computer (PC) environment. This manual provides a guide for running BOAST-VHS, a black oil reservoir simulator for vertical/horizontal/slant wells, using a PC. In addition to detailed explanations of input data file preparation for simulation runs, special features of BOAST-VHS are described and three sample problems are presented.

BOAST-VHS is a cost-effective and easy-to-use reservoir simulation tool for the study of oil production from primary depletion and waterflooding in a black oil reservoir. The well model in BOAST-VHS permits specification of any combination of horizontal, slanted, and vertical wells in the reservoir. BOAST-VHS was designed for an IBM PC/AT, PS-2, or compatible computer with 640 K bytes of memory. BOAST-VHS can be used to model a three-dimensional reservoir of up to 810 grid blocks with any combination of rows, columns, and layers, depending on the input data supplied. This dynamic redimensioning feature facilitates simulation work by avoiding the need to recompiling the simulator for different reservoir models. Therefore the program is only supplied as executable code without any source code.

The manual starts with a general background of reservoir simulation in Section I and continues with the mechanism, capabilities and limitations of BOAST-VHS in Section III. System requirements for the PC and step-by-step procedures for running this simulator are explained in Section IV. This is followed by explanations for preparing an input data file with reservoir data in Section V and recurrent data in Section VI. Example data inputs are enclosed after explanations of each input line to help the user prepare his or her data files. Major items of the output files are reviewed in Section VII. Section VIII guides the user in planning a typical simulation run. Finally, three sample problems for running BOAST-VHS are described in Section IX and input files and part of output files of these problems are listed in the appendix.

I. INTRODUCTION

1.1 Background

Reservoir studies are performed to predict the future performance of a reservoir based on its current state and past performance and to explore methods for increasing the ultimate recovery of hydrocarbons from a reservoir. Reservoir simulators are routinely used for these purposes. A

reservoir simulator is a sophisticated computer program which solves a system of partial differential equations describing multiphase fluid flow (oil, water, gas) in a porous reservoir rock.

Simulators can be classified according to the systems they are able to simulate;

1. Number of phases and components in the reservoir modelled by the simulator.
2. Type of reservoir process to be modelled.
3. The direction(s) of fluid flow to be modelled.
4. Formulation to be used to solve the flow equations.

According to the number of phases, a reservoir simulator can be a one-, two-, or three-phase model (gas, oil and/or water) and the number of components could vary from 1 to N. . According to the type of process, a reservoir simulator can be classified as a black oil, compositional, or enhanced oil recovery (EOR) simulator. According to the direction of fluid flow, a reservoir simulator can be one-, two-, or three-dimensional. According to the formulation, a reservoir simulator can be an IMPES (implicit in pressure - explicit in saturation) model, a fully implicit model, or an adaptively implicit model.

The bases for reservoir simulators are:

- reservoir engineering principles,
- a set of partial differential equations to describe the flow of fluids through porous media,
- finite difference techniques to obtain numerical solutions for the partial differential equations for fluid flow, and
- computer programming to perform a the calculations electronically

1.2 Mechanics of Simulation

The reservoir is first divided into segments, or blocks, using X, Y, and Z axes. Rock and fluid properties are then assigned to each block to describe the reservoir system. Computations are carried out for all phases in each block at discrete time steps. The results, or output, usually consist of production volumes and rates, pressure and saturation distributions, material balance errors, and other process specific information provided at selected time steps.

1.3 Black Oil Simulators

The most routinely used type of reservoir simulator is the "black oil simulator." Black oil simulators describe multiphase flow in porous media without considering the composition of the hydrocarbon fluid. They assume that the liquid hydrocarbon phase consists of only two components: oil and gas in solution. The gas phase consists of only free hydrocarbon gas. Mass

transfer of oil components from the liquid to the gas phase is not considered. Phase behavior is represented by formation volume factor and gas/oil ratio curves.

The reservoir fluid approximations are found to be acceptable for a large percentage of the world's oil reservoirs. Thus, black oil simulators have a wide range of applicability and are routinely used for solving field production problems. Example applications include: aquifer behavior, up-dip gas injection, flank water injection, vertical water influx, vertical equilibrium, single well operations, simulation of large multi-well structures, reservoir cross sectional analysis, gravity segregation effects, heterogeneity effects, simulation of large reservoirs of several non-communicating producing horizons, multiple completions with or without commingled production, stratified flow patterns, and analysis of migration across lease lines.

Although black oil simulators are well suited for studies of numerous problems, they do have some limitations in their scope of applications. They cannot be used to study cases where mass transfer between phases is important. For example, black oil simulators cannot be used to study problems associated with gas condensate and volatile oil reservoirs. In these reservoirs, the composition and physical properties of the phases change with pressure. Similarly black oil simulators cannot be used to simulate EOR processes, such as thermal (steam and in situ combustion), chemical (surfactant and polymer), hydrocarbon miscible, and CO_2 flooding.

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III. BOAST-VHS

3.1 Model Overview

Black Oil Applied Simulation Tool for Vertical/ Horizontal/Slant Wells (BOAST-VHS) is a three-dimensional, three-phase, finite-difference black oil simulator developed for use on a personal computer. The model is based on the widely known, public domain, black oil model BOAST,[1] which was published by the Department of Energy (DOE) in 1982. The horizontal and slanted well model[2] added to BOAST-VHS can be used to simulate the production and injection from any combination of vertical, horizontal, and slanted wells. BOAST II[3] was published by DOE in 1987 to add features useful in full field simulation. Most of the features added to BOAST in the BOAST II version are not in BOAST-VHS for the PC because of the operating system's (DOS) memory constraint.

The BOAST-VHS program simulates isothermal, darcy flow in three dimensions. The simulator assumes that the reservoir fluids can be described by three fluid phases (oil, water, and gas) of constant composition whose properties are functions of pressure only. BOAST-VHS can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and imbibition mechanisms.

BOAST-VHS employs the implicit pressure - explicit saturation (IMPES) formulation for solving its system of finite-difference equations. The IMPES method finds the pressure distribution for a given time step first, then the saturation distribution for the same time step. The IMPES formulation is straightforward, requires less arithmetic per time step, and hence is faster than other formulations. Further, the IMPES formulation requires less storage than a fully implicit formulation. This permits the simulation of larger problems on a small computer such as a microcomputer.

Because of the explicit treatment of saturation in the IMPES method, the solution obtained by use of this method may not be stable for some cases. This is especially true for cases where rapid changes in saturation result from high flux rates or the use of small grid blocks. In such cases, the stability can be restored by reducing the time step size drastically. This then can cause computing time requirements to become excessive. Since near-wellbore coning problems result in rapid saturation changes, models based on IMPES formulations are unsuitable for the study of such problems. Therefore, BOAST-VHS is not recommended for use in simulating single-well coning phenomena.

BOAST-VHS employs the line-successive, over-relaxation (LSOR) iterative solution technique to solve the system of pressure equations. This method requires less storage and usually is faster for larger problems than other methods. The central processing unit (CPU) time for the iterative methods depends on the type of problem to be solved and the selection of the iterative parameter. This is the main disadvantage of the iterative method.

3.2 Model Features

BOAST-VHS is recommended as a cost-effective reservoir simulation tool for the study of such problems as primary depletion, pressure maintenance (by water and/or gas injection) and basic secondary recovery operations (such as waterflooding) in a black oil reservoir using slanted or horizontal wells, in addition to conventional vertical wells. The model is a modification of the DOE BOAST simulator with some added user friendly features. Like BOAST, BOAST-VHS can

simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and capillary imbibition mechanisms.

The well model in BOAST-VHS permits specification of rate or pressure constraints on well performance. The model also allows the user to add or recomplete wells during the period represented by the simulation. Several other features are included in the model, such as flexible initialization capabilities, a bubble point pressure tracking scheme, an automatic time step control method, a zero transmissibility option (inactive grid blocks), and a material balance check on solution stability.

The program permits the input of all data using the field-free format. The term "field-free format" as applied to BOAST-VHS means that an item of data need not appear in a particular location on a data input line. One restriction is that the values must be entered in a specific sequence although they are not confined to specific locations. The main advantage of format free data entry is that it simplifies the preparation, review, and visual checking of the data, thus minimizing input errors. A "key word" convention is not used.

One useful feature of BOAST-VHS is dynamic redimensioning of the rows, columns, and layers in defining the grid block model. This feature allows the program operator to change the grid dimensions using the data input file instead of rewriting the computer code as required in the original BOAST program.

Another feature permits the user to stop the program, modify the data file, and then restart the simulation run. This feature can be useful to reduce the computing time for a study that determines the best operating conditions for a reservoir.

3.3 Dynamic Redimensioning

The purpose of the dynamic redimensioning is to allow the operator of the program to set the grid block number in three-dimensional simulation using the data input file. This allows the user to tailor the simulation to the level of data available and his specific requirements. The more grid blocks in a simulation the more accurate the representation of the reservoir and therefore the better the prediction of reservoir performance. However, the larger the number of grid blocks, the more time required for the computer to complete the simulation.

Dynamic redimensioning is the ability of the program to adjust the three-dimensional grid blocks of the reservoir arrays. The main program has an array with non-adjustable bounds that can call a subroutine with a reservoir array having adjustable dimensions. This allows variables such

as pressure, fluid saturation, porosity, and permeability to be passed to the subroutine as arguments for each grid block. The size and bounds of this reservoir array are determined by the set of arguments also passed to the subroutine and are controlled from the input file. As many as 810 grid blocks can be simulated in any combination of rows, columns, and layers, depending on the input data supplied. For example, the input data could require a 28 by 28 grid with 1 layer or a 20 by 20 grid with 2 layers, and so on. The product of the three dimensions can be any value up to the limit of 810. This limit is imposed by the 640 kilobyte limitation inherent in Microsoft™ DOS for Intel™ computer processing chips used in IBM-AT/IBM-compatible personal computers.

3.4 Restart Capabilities

An important additional program feature to BOAST is the restart capability after a normal reservoir simulation run. The program can be instructed to run a simulation for a given time period and then, after normal termination, be restarted from that point in time with a new set of operating conditions. This feature is activated by entering the flag for restart in the initial input data file. This flag will cause the program to generate a restart file that ends "RST". This new restart data file needs to be modified to enter the new operating conditions for the time period from the end on the first simulation until the new ending time. TMAX is reset to the duration of the combined simulations – the initial simulation plus the period after restart. The restart file needs to be renamed with an extension other than "RST" to avoid the new restart output file from overwriting the new input file. If a new TMAX is not entered into the restart file with a text editor, the simulation will not continue. Other data structures in the restart input file may need to be removed with the editor if the production/injection strategy needs to be changed from the previous simulation run. For example, waterflood injection rate completed during the first simulation may need to be removed before the restart begins if the injection plan varies with time. These changes usually occur in the recurrent data records.

3.5 Program Limitations

BOAST-VHS does have certain limitations which must be recognized to be able to use the program effectively. The major limitation of BOAST-VHS is that the program is not recommended for simulating coning phenomena. Further, because of the memory limitations of a microcomputer, this simulator cannot be used to perform very large simulations. The program also is not recommended for estimating the performance of a reservoir under active waterdrive or for modeling gas production wells. These limitations are inherent in IMPES solutions. BOAST has some mathematical instabilities that are self-correcting, so that cumulative productions and average production rates are reasonably accurate. Unfortunately, some of the instantaneous production

rates are not reasonable and can show sharp spikes in the graphed curves when ratios, such as GOR, are plotted against time. Smaller time steps can reduce this effect. As long as the application does not involve rapid pressure changes that are a problem with IMPES, BOAST-VHS should give reasonable results in the range of those obtained by other horizontal well simulators.[3] Comparative results are discussed in section X.

While BOAST-VHS does have some limitations, it is versatile enough to handle a large number of commonly encountered black oil simulation problems on microcomputers. With memories at 640 kilobytes or larger and a hard disk drive, BOAST-VHS can accommodate as many as 810 grid blocks and is very economical for conducting small to moderate size simulations. It can be used to simulate single wells in different geometry throughout a reservoir. The angle of penetration can be varied from 90° to 180°. The example problems included with this manual illustrate the scope and capabilities of this simulator.

3.6 Restart Limitations

Under the RESTART option (shown under Section 5.3 data input line 3 and 4), a run with a short time limit followed by a restart run with a long time limit will show production rates noticeably different from those of a continuous simulation run over the total time period. On the other hand, a restart run with a long time limit period followed by a restart with a short time limit would show much closer agreement to one continuous simulation over the total period.

This problem arises because the restart parameters are stored in an editable text file similar to the original input data file. Only a binary file of all simulation variables being used could overcome this "butterfly" effect. Another problem is the inherent mathematical instability of BOAST. If the first simulation ends on a spike in the gas production, the restarted simulation suffers an additional inaccuracy.

IV. SYSTEM REQUIREMENTS AND STARTING UP BOAST-VHS

4.1 What You Need

The minimum system requirements to run BOAST-VHS on a personal computer are as follows:

Computer - IBM PC/AT, PS-2, or compatible.

Operating system - PC-DOS or MS-DOS version 2.1 or later.

Memory - 640 K minimum.

Disk capacity - 1.2 megabyte 5 1/4 or 1.44 megabyte 3 1/2 floppy drive. A hard disk drive is a must for all but the smallest simulation. A second floppy drive is assumed in the manual, but it is not necessary if a large hard disk drive is used.

Disk capacity - 1.2 megabyte 5 1/4 or 1.44 megabyte 3 1/2 floppy drive. A hard disk drive is a must for all but the smallest simulation. A second floppy drive is assumed in the manual, but it is not necessary if a large hard disk drive is used.

Printer - Dot matrix or ink jet printer. A wide carriage is preferred.

Math coprocessor is strongly recommended, because it can speed up the program's operation (8087, 80287, or 80387 are math coprocessor. A i486™ has a built-in coprocessor but the new 486SX has the coprocessor turned off.). BOSTVHSM.EXE has an emulated math coprocessor built into the software to operate on machines without a coprocessor. (NOTE: BOSTVHSM.EXE should be renamed BOASTVHS.EXE when it is loaded on the hard disk - see section 4.4.)

4.2 How It Works

BOAST-VHS is a program that needs an input data file from your disk and that writes an output file to your disk.

Using BOAST-VHS is a two-step process. First you create an input file on your disk with the DOS line editor "EDLIN" or any other text editor that generates an ASCII output. You can use a word processing program to generate an ASCII input file, if it is able to generate an ASCII file When the program is run, it creates an output file in printable form. You can then scan the output on a screen and/or, use the DOS "PRINT" command to print the file.

4.3 Backing Up

It is a good idea to back up the program as soon as reasonable. For this, you will need a blank, formatted diskette to serve as the backup. Unless otherwise specified, the term disk (or diskette) refers to a floppy diskette that meets the specifications listed above.

Load your DOS diskette in drive A and place a blank diskette in drive B. Then type in a response to the DOS prompt A>:

FORMAT B: and press the Enter key

Follow the instructions on the screen as the system asks you to insert a diskette in drive B. When formatting is complete, the system will ask if you would like to format another diskette-respond by typing N. The A> prompt will now appear.

Remove your DOS diskette from drive A and replace it with your BOAST-VHS diskette. Now type in response to the DOS prompt A>:

COPY *.* B: and press the Enter key

This will back up the programs on your BOAST-VHS diskette to the blank diskette, which you should label and store in a safe place.

4.4 Loading the BOAST-VHS Program onto the Hard Disk

The BOAST-VHS program should be copied onto a hard disk under the subdirectory BOAST. To install BOAST-VHS onto a hard disk, use the following procedure. It is assumed that your system default drive is A and that your hard (fixed) drive is C. (If your computer does not have a math coprocessor, substitute BOSTVHSM.EXE for BOASTVHS.EXE or rename it to BOASTVHS.EXE.)

1. Make certain that DOS is ready and that A> is displayed.

2. Now, type in response to the DOS prompt.

   A>C: and press the Enter key.

   This will then establish your hard disk as the default drive and the DOS prompt C> will appear on the screen. (NOTE: If you are using Microsoft version of DOS, the DOS prompt will be C:_>)

3. To create a subdirectory BOAST, type in response to the DOS prompt.

   C>MD BOAST

   DOS will create the subdirectory BOAST in the current directory in drive C.

4. Next, to access the subdirectory BOAST, type in response to the DOS prompt:

   C>CD BOAST

   After a few seconds, the DOS prompt C> will appear on the monitor. If your 'AUTOEXE.BAT' file includes the command "PROMPT $ P$G", then the following will appear on the screen.

   C:/BOAST>

5. The software for BOAST-VHS is on one diskette. The diskette contains the simulator program, BOASTVHS.EXE and BOSTVHSM.EXE. To copy BOAST-VHS onto a hard disk under the subdirectory BOAST, insert BOAST-VHS diskette in drive A and type the following in response to the DOS prompt:

   C>COPY A:BOASTVHS.EXE (or A:BOSTVHSM.EXE) BOASTVHS.EXE

This procedure will copy the BOASTVHS.EXE program to the subdirectory BOAST in the hard disk.

4.5 Starting Up the Program

From the hard disk, go to the subdirectory BOAST and type in response to the DOS prompt:

C>BOAST-VHS and press the Enter key.

(It is assumed that you have copied BOAST-VHS.EXE program onto the hard disk in the subdirectory BOAST)

After a few seconds, the following will appear on the screen.

PLEASE ENTER YOUR DISK DRIVE AND INPUT FILE NAME, SUCH AS "C: BOASTVHS.DAT"

In response to the DOS prompt, type the name of the disk drive and the name of the input file as:

C> A: INPUT.DAT and press the enter key

In the above example, A is the drive in which you plan to insert your input file diskette containing the file INPUT.DAT. It is assumed that you have created the input file INPUT.DAT. If you are using a hard disk and if your input file INPUT.DAT resides in the hard disk, then type in response to the DOS prompt:

C>C: INPUT.DAT

It is assumed that both BOAST-VHS and the input files reside in the same directory on the hard disk. The next section explains in detail how to build an input file. After entering the input file name and pressing the Enter key, the following will appear on the screen:

PLEASE ENTER YOUR DISK DRIVE AND OUTPUT FILE NAME

(Another CR will default to "A:INPUT.OUT")

In response to the DOS prompt, type the name of the disk drive and output file name as

C> B: OUTPUT.DAT and press the Enter key

Caution: Be certain that you specify a file name and have adequate disk space for the file(s). In the above example, B is the drive in which you plan to insert a blank formatted diskette. The program will write all the output information on this diskette and label it as OUTPUT.DAT. If the restart

flag has been set, OUTPUT.RST will also be created. These files will be found in the subdirectory BOAST if you have followed the above suggestions.

Caution: You should select the print code judiciously so that only the needed information is printed. Otherwise a large volume of output will be created and you will risk running out of disk space before the simulation is completed. The time to print the details of the simulation can be significant.

4.6 Data Input Requirements

This section describes briefly the input requirements for BOAST-VHS. A complete description of the input data required to run BOAST-VHS is given here and in Sections IV and V. A brief discussion on how to create and edit an input data file using DOS line editor is also included in Section IV.

All input data for the simulator are contained in a single file. This data can be divided into two groups: (a) initialization data and (b) recurrent data. The initialization data include reservoir geometry, rock porosity and permeability, initial pressure and saturation data, relative permeability and capillary pressure tables, and fluid PVT data. Also included in this section are the necessary run control parameters and solution specifications.

The recurrent data include the location and initial specifications of wells in the model, time step control information for advancing the simulation through time, a schedule of individual well rates and/or pressure performance, changes in well completions and operations over time, and controls on the type and frequency of printout information provided by the simulator.

Throughout the description of input data in Sections IV and V, the term "header" is used to refer to specific input data records. These records are designed to serve as delineators and/or as data identifiers. The header record may be used to identify conveniently specific data items on the subsequent record or records.

All data values are identified by a name that corresponds to the actual variable name in the model. All data except the 'header' records are entered as free-field format. The term "free-field format" as applied to this program means that an item of data need not appear in a particular location on a data input line. The term 'line' refers to an individual line in an input data set as entered on the monitor. Input data must be entered in a sequence, and a value must be specified for each input datum. If more than one value must appear on a line, each value must be separated from neighboring data by at least one space.

As an example of "free-field format," suppose that you wish to read an integer value of 8 and a real value of 76.9 on one input line. This may be entered as follows:

```
    8  76.9
or  8      76.9
or  8      7.69E01
```

However, it can not be entered as 876.9. All header records are read with an 'A' format.

4.7 Comments Concerning Data Input Conventions

If a full grid of input values of rows (x-direction), columns (y-direction), and layers (z-direction) (II, JJ, and KK values respectively) must be read for a particular parameter, the following input order must be followed:

To read in a full grid of input values for a particular parameter (II = number of grid blocks in x-direction, JJ = number of grid blocks in y-direction, KK = number of grid blocks in z-direction), Layer 1 (K = 1) is read first. The data in each layer are read in by rows, starting with Row 1 (J = 1). Values of the parameter for Columns I = 1 to II are read for the first row, starting with column 1 (I = 1). After II values have been read for the first row, values are read for the second row (J = 2), etc. until JJ rows of data are read. This process is repeated for Layer 2 (K = 2), etc. until KK layers of data are read.

BOAST-VHS uses a right-handed coordinate reference. The Z-direction values will increase going down. For K = 1, II x JJ values must be read in the following order.

```
J = 1, I = 1,2 . . . .II
J = 2, I = 1,2 . . . .II
J  =.................II
J = JJ, I = 1,2  . . .II
```

Because II x JJ x KK values are required for each reservoir parameter, the complexity and size of the input file grows in direct proportion with the number of grid blocks.

4.8 Hints on How To Run BOAST-VHS

BOAST-VHS is a sophisticated simulation tool that permits the study of a variety of problems encountered in reservoir management and production operations. The program contains several

options, and to be able to use it most effectively to predict the performance of a reservoir, the user must be familiar with them.

Perhaps the best way to become acquainted with BOAST-VHS, and to have a feel for the operating parameters, is to run the program with different sets of input data. It is suggested that the user first scan through the data input sections (Sections IV and V) to become familiar with the general format of the input and then look at the examples in Section IX. These examples illustrate the capability of the model to simulate multi-well, multidimensional reservoir engineering and production problems. These examples can be used as a general guide.

Although no default values are provided for input parameters (a value must be entered for all parameters), the range of typical values for most parameters can be seen in the three test problem input files.

BOAST-VHS contains an automatic time-step control feature and material balance calculations for each fluid phase. Although time-steps can be controlled, it is recommended that automatic time-step control be used for most runs. This feature allows the program to maintain a step size that is large enough for the problem being simulated, yet small enough to avoid pressure and/or saturation oscillations and to give acceptable solutions. A minimum time-step size of 0.1 day is recommended for automatic time-step control. This minimum time-step will be used only if it is needed to satisfy the user-specified maximum pressure and saturation constraints. The maximum recommended saturation changes are 5 to 10 % for typical problems. Maximum pressure change is normally less critical and typically may be 50 to 100 psi. To help determine if saturation and pressure changes are acceptably small, the user should study both time-step and material balances.

BOAST-VHS performs material-balance calculations at the end of each time-step, as a check to determine the degree to which the finite-difference solutions obtained from the IMPES procedure actually satisfy the conservation equations. This basically involves comparing the change of each fluid phase over time with the quantities of fluid produced and injected over the same time period. The change in fluid content (STB or MCF) is estimated directly from calculated pressures and saturations. Quantities produced and/or injected are determined from the production and injection rates at all wells.

Time-step material balances are printed on each summary report and should always be checked carefully before accepting any run as a 'final' result. In general, time-step material balance errors should normally be less than 0.1 %.

An excessive material-balance error is an indication of a large saturation and/or pressure change that causes the results of BOAST to be an inaccurate simulation. The problem can usually be overcome by reducing the time-step size. This can be performed by specifying a smaller minimum step-size and reducing saturation and pressure tolerances.

V. DATA INITIALIZATION

5.1 Introduction

This section describes in detail the data required to initialize the simulation program. These include the reservoir model grid dimensions and geometry, porosity and permeability distributions, relative permeability and capillary pressure data, fluid PVT data, initial pressure and saturation distributions within the reservoir, run control and diagnostic parameters, time step control parameters, and parameters for LSOR solution procedures. (BOAST-VHS uses the LSOR solution procedures of BOAST.[1] Other solution techniques available in BOAST and BOAST II were not included so that the BOAST-VHS program has the maximum number of grid blocks for simulation and still runs on a PC.) These data are read only once at the beginning of the simulation. They must be read in the order in which they appear in the following input data sections.

5.2 How To Build an Input Data File

This section describes briefly how to build an input data file using a DOS line editor. Using a text editing program that is designed for programming and preparing data input files can save time and is recommended if moderate size input files are expected.

First, you will need a blank, formated diskette to write the input file you plan to create. Suppose you want to create an input file INPUT.DAT. Load your DOS diskette in drive A and place a blank formatted diskette in drive B. Make sure DOS is ready and C> is displayed on the screen.

Then type

```
C> EDLIN B:INPUT.DAT   and press the Enter key.
```

The following message and prompt will then appear on the screen.

```
New File
*
-
```

Note that the prompt for EDLIN is an asterisk (*)

During the insert mode of operation, successive line numbers will appear automatically each time you press the enter key.

When you have finished creating your input file, press Ctrl-Break (Control-Scroll Lock) key. This will get you out of the insert mode of operation, and the EDLIN prompt (*) will appear on the screen. Now type

E and press the Enter key.

The file you have just created will then be saved by writing it to diskette on drive B and labeled as 'INPUT.DAT'. If the hard disk is used for the input file, change your current directory to BOAST. When DOS is ready and C> (or C:_BOAST>) is displayed on the screen, type in response to the DOS prompt.

C>EDLIN INPUT.DAT and press the Enter key.

For more information on how to use the DOS line editor, consult your DOS manual.

The next several sections describe in detail the input data for the simulator. Each input entry is illustrated by an example.

5.3 Grid Dimensions and Geometry

Line 1: Title or name of the run
FORMAT: 40A2
READ: Header
Note: This line is used to enter the title of the simulation program. Enter any desired alphanumeric run title information up to 80 characters.
Example: BOAST-VHS TEST RUN: PRIMARY DEPLETION OF A HORIZONTAL WELL IN 40 ACRES

Line 2: This line is used to enter the number of grid blocks in each direction.
READ: II, JJ, KK
II = number of grid blocks in the X-direction (cannot exceed 200)
JJ = number of grid blocks in the Y-direction (cannot exceed 200)
KK = number of grid blocks in the Z-direction (cannot exceed 20)
Note: Total number of grid blocks (= II x JJ x KK) cannot exceed 810 for an IBM-PC/AT.
Example: 9 9 1
This specifies that there are nine grid blocks each in the X- and Y-, direction, respectively, and one in the Z direction.

Line 3: Use this line to identify the next set of data
READ: Header (40A2)

Line 3: Use this line to identify the next set of data

READ: Header (40A2)

Example: SO SHALE RESTART DT

Line 4: Enter switch codes or flags.

READ: NSO, NSHALE, NRESTART, NDT

NSO = 1, oil saturation distribution files will be created.
0, oil saturation distribution files will not be created.

NSHALE = 1, "SHALE ZEROING" option will be invoked.
0, "SHALE ZEROING" option will not be invoked.

NRESTART = 1, "RESTART" data file will be created at the end of simulation run.

NRESTART = 0, "RESTART" data file will not be created at the end of simulation run.

NDT is the interval of time steps for which summary results will be printed in the summary table.

Example: 0 0 1 5

Line 5: Use this line to identify the next set of data.

READ: Header (40A2)

Example: SAME X,Y, AND Z LENGTHS FOR ALL GRIDS.

Line 6: This line is used to enter codes for inputting grid block dimensions.

READ: KDX, KDY, KDZ

KDX = Code for specifying X-direction grid dimensions (see Table 5-1)

KDY = Code for specifying Y-direction grid dimensions (see Table 5-1)

KDZ = Code for specifying Z-direction grid dimensions (see Table 5-1)

Example: -1 -1 -1. Specifies a single length for each dimension of the grids.

Line 7: This line is used to enter the X-direction grid dimensions in ft.

READ: DX

Example: 147

This specifies that the X-direction grid block length is 147 ft.

Note: See table 5-1 for the number of values. When KDX = 0 or 1, the order of input must be as follows:

J = 1, I = 1,2, ... II

J = 2, I = 1,2, ... II

. . . . . .

J = JJ, I = 1,2,. . . . II

TABLE 5-1. - Options for grid-block geometry

Code	Value	Grid dimension specifications
KDX	-1	X-direction grid dimensions are the same for all grid blocks; input only one DX value
KDX	0	X-direction grid dimensions are read for each grid-block in the first row (J = 1) of layer one (K = 1) input II values of DX. These same x-direction dimensions are assigned to all other rows and all other layers in the model grid.
KDX	1	X-direction dimensions are read for every grid block in layer one (K = 1). input II x JJ values of DX. These same X-direction dimensions are assigned to all other layers in the model grid.
KDY	-1	Y-direction grid dimensions are the same for all grid blocks; input only one DY value.
KDY	0	Y-direction grid dimensions are read for each grid block in the first column (I = 1) of layer one (K = 1). Input JJ values of DY. These same Y-direction dimensions are assigned to all other columns and all other layers in the model grid.
KDY	1	Y-direction dimensions are read for every grid block in layer one (K = 1); input II x JJ values of DY. These same Y-direction dimensions are assigned to all other layers in the model grid.
KDZ	-1	Z-direction grid dimensions are the same for all grid blocks; input only one DZ value.
KDZ	0	A constant value of thickness is read for each layer in the grid; input KK values of DZ.
KDZ	1	Z-direction grid dimensions are read for every grid block; input II x JJ x KK values of DZ.

Line 8: This line is used to enter the Y-direction grid dimensions in ft.

READ: DY

Example: 147

This specifies that the Y-direction grid block length is 147 ft.

Note: See table 5-1 for the number of values. When KDY = 0 or 1, the order of input must be as follows:

I = 1, J = 1,2, ... JJ
I = 2, J = 1,2, ... JJ
. . . . . .
I = II, J = 1,2,. . . . JJ

Line 9: This line is used to enter the Z-direction grid dimensions in ft.

READ: DZ

Example: 20

This specifies that the Z-direction grid block length is 20 ft.

Note: See table 5-1 for the number of values. When KDZ = 1, the order of input must be as indicated in line 5 above with the layer order K = 1,2,....KK.

5.4 Modifications to Grid Dimensions:

Line 1: Use this line to identify the next set of data.

READ: Header (40A2)

Example: GRID BLOCK DIMENSION MODIFICATIONS

Line 2: This line is used to enter the number of grid blocks where grid dimensions are to be changed; plus print code.

READ: NUMDX, NUMDY, NUMDZ, IDCODE

NUMDX = Number of grid blocks where X-direction grid dimensions (DX) is to be changed.

NUMDY = Number of grid blocks where Y-direction grid dimensions (DY) is to be changed.

NUMDZ = Number of grid blocks where Z-direction grid dimensions (DZ) is to be changed.

IDCODE = Print code for grid dimension alterations.
If IDCODE = 0, do not print the modified grid dimensions.
If IDCODE = 1, print the modified grid dimensions.

Example: 0 0 0 0

This specifies that there is no change in grid dimensions; and that the dimensions are not to be printed (even if they were modified).

Line 3: Use NUMDX set of lines to enter the coordinates of the blocks in the X-direction whose dimensions are to be modified; omit this line if NUMDX = 0.

READ: I, J, K, DX

I = X-coordinate of block to be modified
J = Y-coordinate of block to be modified
K = Z-coordinate of block to be modified
DX = New X-direction grid dimension (DX) for block (I, J, K)

Note: NUMDX lines must be read.

Line 4: Use NUMDY set of lines to enter the coordinates of the blocks in the Y-direction whose dimensions are to be modified;
omit this line if NUMDY = O.

READ: I, J, K, DY
I = X-coordinate of block to be modified
J = Y-coordinate of block to be modified
K = Z-coordinate of block to be modified
DY = New Y-direction grid dimension (DY) for block (I, J, K)

Note: NUMDY lines must be read

Line 5: Use NUMDZ set of lines to enter the coordinates of the blocks in the Z-direction whose dimensions are to be modified;
omit this line if NUMDZ = O.

READ: I, J, K, DZ
I = X-coordinate of block to be modified
J = Y-coordinate of block to be modified
K = Z-coordinate of block to be modified
DZ = New Z-direction grid dimension (DZ) for block (I, J, K)

Note: NUMDZ lines must be read.

5.5 Elevations to Top of Grid-Blocks in Layer I

Remember that with the coordinate system used here, Z-direction values increase going down. Thus, elevations must be read as positive depths below the user selected reference datum. Negative values will be interpreted as heights above the datum.

Line 1: Use this line to identify the next set of data.

READ: Header (40A2)

Example: CAPROCK AT BASE DEPTHS

Line 2: This line is used to enter the code for inputting grid-block elevations.

READ: KEL
KEL = Input code

REMARKS: (1) If KEL = 0, a single constant value is read for the elevation at the top of all grid blocks in Layer 1. (i.e., horizontal plane).
(2) If KEL = 1, a separate elevation value must be read for each grid block in Layer 1. II x JJ values must be read.

Example: 0

This specifies that a single elevation value is to be read.

Line 3: This line is used to enter the depth values.

READ: ELEV

ELEV: Elevation to top of grid blocks in feet

Example: 8325.0

This specifies that the top of the formation is 8325 feet below the datum.

REMARKS: (1) When KEL = 0, read only one value

(2) When KEL = 1, read II x JJ values. These values must be read in the following order:

J = 1, I = 1,2, ... II
J = 2, I = 1,2, ... II
. . . . . .
J = JJ, I = 1,2,. . . . II

(3) Elevations to the top of the grid-blocks in layers below Layer 1 will be calculated by adding the layer thickness to the preceding layer elevation; i.e.,

TOP (I, J, K + 1) = TOP (I, J, K) + DZ (I, J, K)

5.6 Porosity and Permeability Distributions

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: POROSITY AND PERMEABILITY INPUTS

Line 2: This line is used to enter the code for controlling porosity and permeability data input.

READ: KPH, KKX, KKY, KKZ

KPH = Code for controlling porosity input data (See table 5-2)

KKX = Code for controlling X-direction permeability (See table 5-2)

KKY = Code for controlling Y-direction permeability (See table 5-2)

KKZ = Code for controlling Z-direction permeability (See table 5-2)

Example: -1 -1 -1 -1

This specifies that porosity and permeabilities are uniform over the grid. Only one porosity value and one value for each X, Y and Z direction permeability is to be read.

Line 3: This line is used to enter porosity values as a fraction.

READ: PHI

Example: 0.25 specifies 25% porosity

Note: (a) Porosity is read as a fraction (not as a percentage)

(b) See table 5-2 for the number of values. When KPH = + 1, the order of input must be as indicated below with layer order

K = 1,2, . . . KK

J = 1, I = 1,2, ... II

J = 2, I = 1,2, ... II

. . . . . .

J = JJ, I = 1,2,. . . . II

TABLE 5-2. - Options for grid-block properties

Code	Value	Porosity and permeability specifications
KPH	-1	Porosity is uniform over the grid; input only one PHI value.
KPH	0	Porosity varies by layer; input KK values of PHI
KPH	+1	Porosity varies over the entire grid; input II x JJ x KK values of PHI
KKX	-1	X-direction permeability is uniform over the grid; input only one KX value
KKX	0	X-direction permeability varies by layer; input KK values of KX
KKX	+1	X-direction permeability varies over the entire grid; input II x JJ x KK values of KX
KKY	-1	Y-direction permeability is uniform over the grid; input only one KY value
KKY	0	Y-direction permeability varies by layer; input KK values of KY
KKY	+1	Y-direction permeability varies over the entire grid; input II x JJ x KK values of KY
KKZ	-1	Z-direction permeability is uniform over the grid; input only one KZ value
KKZ	0	Z-direction permeability varies by layer; input KK values of KZ
KKZ	+1	Z-direction permeability varies over the entire grid; input II x JJ x KK values of KZ

Line 4: This line is used to enter X-direction permeability values in md.

READ: KX

KX = X-direction permeability values

Example: 200.0

This specifies that the X-direction permeability is 200 md.

Note: (a) Permeabilities read in millidarcies (md); KX is a real variable.

(b) See table 5-2 for the number of values. When KKX = + 1, the order of input must be as indicated for Line 3 above with layer order K = 1,2, ... KK

Line 5: This line is used to enter Y-direction permeability values in md.

READ: KY

KY = Y-direction permeability values (in millidarcies)

KY is a real variable

Example: 200.0

This specifies that the Y-direction permeability is 200 md.

Note: See table 5-2 for the number of values. When KKY = + 1, the order of input must be as indicated for line 3 above with layer order K = 1, 2, ... KK

Line 6: This line is used to enter Z-direction permeability values in md.

READ: KZ

KZ = Z-direction permeability values (in millidarcies);

KZ is a real variable

Example: 20.0

This specifies that the Z-direction permeability is 20 md.

Note: See table 5-2 for the number of values. When KKZ = + 1, the order of input must be as indicated for line 3 above with layer order K = 1, 2, ... KK

5.7 Modifications to Porosity and Permeability Distributions

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: POROSITY AND PERMEABILITY MODIFICATION LINES

Line 2: This line is used to enter the number of grid blocks where porosity and/or permeability values are to be changed, as well as the print code.

READ: NUMP, NUMKX, NUMKY, NUMKZ, IPCODE

NUMP = Number of grid-blocks where porosity (PHI) values are to be changed

NUMKX = Number of grid-blocks where X-direction permeability values (KX) are to be changed

NUMKY = Number of grid-blocks where Y-direction permeability values (KY) are to be changed

NUMKZ = Number of grid-blocks where Z-direction permeability values (KZ) are to be changed

IPCODE = Print code for porosity and permeability alterations

If IPCODE = 0, do not print modified porosity and permeability alterations

If IPCODE = 1, print modified porosity and permeability distribution

Example: 2 0 0 0 1

This specifies that the porosity values are to be modified in two grid blocks; no permeability changes and print the modified values.

Line 3: Use NUMP sets of lines to enter the coordinates of the blocks where porosity is to be modified; omit this line if NUMP =0.

READ: I, J, K, PHI

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

PHI = New value of porosity in fraction for block (I, J, K)

Example: 1 1 1 0.125

9 1 1 0.125

This specifies that the porosity of the grids (1,1,1) and (9,1,1) are to be changed to 0.125.

Note: (1) Porosity must be entered as a fraction

(2) NUMP lines must be read

Line 4: Use NUMKX sets of lines to enter the coordinates of the blocks in the X-direction where permeability (KX) is to be modified.

READ: I, J, K, KX

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

KX = New value of X-direction permeability (KX) for block (I, J, K) in millidarcies

Note: (1) NUMKX lines must be read

(2) KX is a real variable

Example: No line in our example problem.

Line 5: Use NUMKY sets of lines to enter the coordinates of the blocks in the Y-direction where permeability (KY) is to be modified.

READ: I, J, K, KY

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

KY = New value of Y-direction permeability (KY) for block (I, J, K) in millidarcies

Example: No line in our example problem.

Note: (1) NUMKY lines must be read

(2) KY is a real variable

Line 6: Use NUMKZ sets of lines to enter the coordinates of the blocks in the Z-direction where permeability (KZ) is to be modified.

READ: I, J, K, KZ

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

KZ = New value of Z-direction permeability (KZ) for block (I, J, K) in millidarcies

Example: No line in our example problem.

Note: (1) NUMKZ lines must be read

(2) KZ is a real variable

5.8 Transmissibility Modifications

Note: It is extremely important to keep in mind the directional convention used in specifying transmissibility modifications. For example, in grid block (I, J, K).

TX (I, J, K) is the X-direction transmissibility which refers to flow across the boundary between blocks I-1,J,K and I,J,K

TY (I, J, K) is the Y-direction transmissibility which refers to flow across the boundary between blocks I,J-1,K and I,J,K

TZ (I, J, K) is the Z-direction transmissibility which refers to flow across the boundary between blocks I,J,K-1 and I,J,K

5.8.1 Shale Zeroing Options

Line 1: Use this line to identify the next set of data.

READ: Header (40A2)

Example: SHALE BREAKS

Line 2: This line is used to enter the code for selecting shale zeroing (vertical transmissibility modification) options. Shale zeroing means the Z-direction transmissibility (TZ) is set equal to 0.0 and no flow can occur across the layer.

READ: NSHOPS

NSHOPS = Code for selecting shale options

Example: 0; this specifies no shale (option)

REMARKS:
(1) If NSHOPS = 0, no shale option is selected. Go to Line 7
(2) If NSHOPS = 1, zero out the entire layer(s) i.e., continuous shale layer.
(3) If NSHOPS = 2, simulate broken layers, i.e., discontinuous shale layer
(4) Skip lines 3 through 6 if NSHOPS = 0

Line 3: This line is used to enter a single value representing the total number of boundaries (between layers) affected. Omit this line if NSHOPS = 0.

READ: NTLAYR

NTLAYR = Total number of shale streaks to be introduced. For example, if you want to introduce two shale barriers, one between Layers 1 and 2 and the other between Layers 5 and 6, then set NTLAYR = 2. If you want to introduce broken or discontinuous shales streaks between two layers, then NTLAYR = 2 again.

Example: No line in our example problem.

Line 4: Omit this line if NSHOPS = 2.
Line 4 is used to enter the location of an interface where transmissibilities are to be zeroed. Read NTLAYR values; one value per line.

READ: KT

KT = Location of the interface

Example: No line in our example problem.

Note: (1) NTLAYR lines must be read

(2) To zero out the interface between layers 1 and 2 (i.e., no flow across the boundary between layers 1 and 2), then set KT = 2. Similarly to zero out the interface between layers 2 and 3, then set KT = 3, etc.

(3) Caution: If you set KT = 1, there will be flow out of the model.

Line 5: Omit this line if NSHOPS = 1

Line 5 is used to enter the layer location and the location of the block where you want the Z-direction transmissibility to be zero.

Read NTLAYR set of values;

READ: KT,NUTM

KT = location of the interface

NUTM = Number of blocks along the interface where you want no flow (see examples below).

Example: No line in our example problem.

Note: (1) NTLAYR lines must be read.

(2) To zero out the interface between layers 1 and 2 (i.e. no flow across the boundary between layers 1 and 2), set KT = 2. Similarly to zero out the interface between layers 2 and 3, set KT = 3, etc.

(3) Caution: If you set KT = 1, there will be flow out of the model.

(4) Read this line only if NSHOPS = 2

Line 6: Omit this line if NSHOPS = 1

Line 6 is used to enter the X-coordinate of the block where the interface transmissibility is set to zero. Read NUTM lines, one value per line.

READ: IGBL

IGBL = X-coordinate of the block whose transmissibility is to be modified.

Example: No line in our example problem.

Note: (1) Read NUTM sets of lines, one value per line.

REMARKS: The following examples are presented to help clarify shale zero option inputs.

Example 1: Continuous shale streak option (NSHOPS = 1)

NSHOPS = 1

NTLAYR = 3

KT = 2

KT = 4

KT = 6

Explanation: In the above example, no flow (zero transmissibility due to presence of continuous shale streaks [NSHOPS = 1]) will occur across three interfaces [NTLAYR = 3] (See figure 1). These interfaces are:

(a) boundary between layer 1 and 2 (KT = 2);

(b) boundary between layers 3 and 4 (KT = 4); and

(c) boundary between layers 5 and 6 (KT = 6).

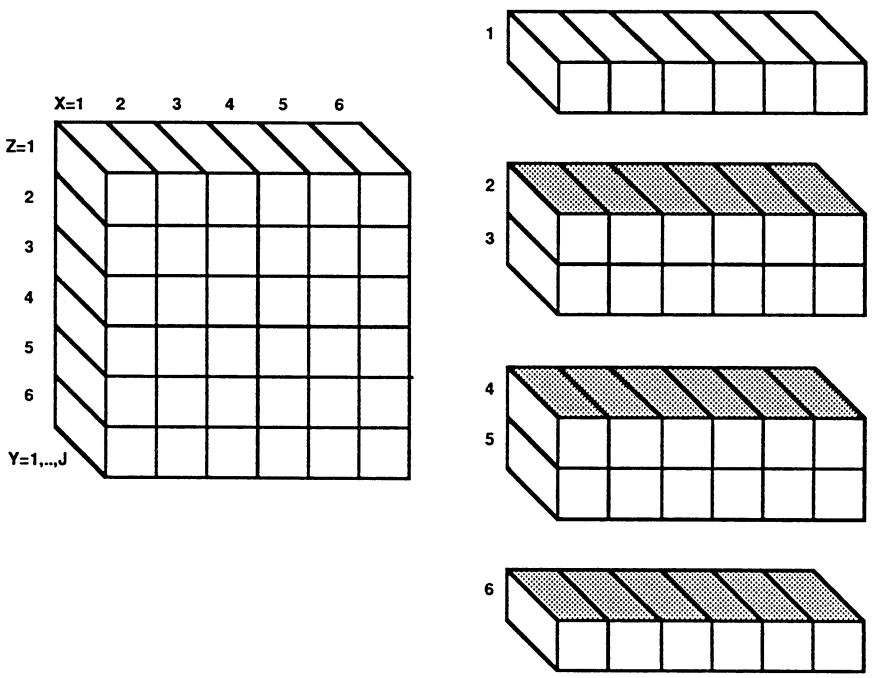

FIGURE 1. - Example of three continuous shale streaks across three interfaces.

Example 2: Discontinuous (broken) shale option (NSHOPS = 2)

NSHOPS = 2

NTLAYR = 3

KT,NUTM = 2,2

IGBL = 2

IGBL = 5

for NUTM = 2

for NTLAYR = 1

KT, NUTM = 3,3

IGBL = 1

IGBL = 3

IGBL = 4

for NUTM = 3

for NTLAYR = 2

KT NUTM = 5, 1

IGBL = 2 ⟩ for NTLAYR = 3

Explanation: In the above example, broken shale (discontinuous) streak occurs along three interfaces; between layers 1 and 2 (KT = 2) two (NUTM = 2) values of Z-direction transmissibility will be zeroed resulting in no flow between blocks (2,1,1) and (2,1,2) and no flow between blocks (5,1,1) and (5,1,2) (IGBL = 2 and 5). The remainder of the sequence zeros flow between blocks: (1,1,2) and (1,1,3); (3,1,2) and (3,1,3); (4,1,2) and (4,1,3); (2,1,4) and (2,1,5).

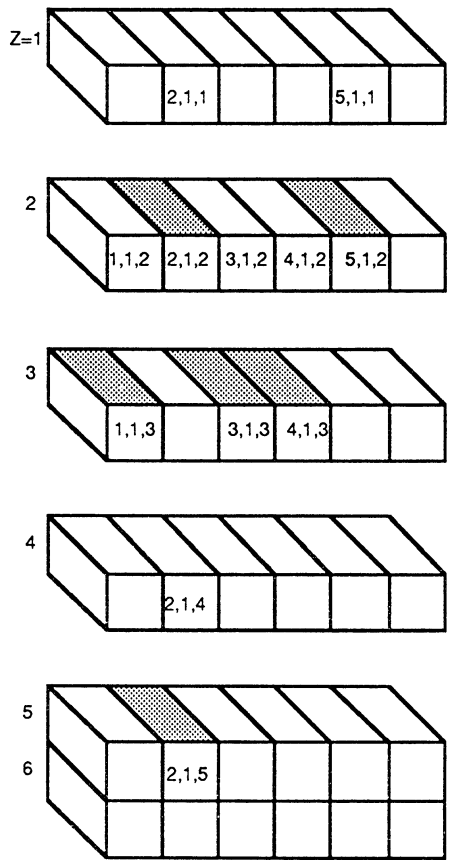

FIGURE 2. - Example of broken (discontinuous) shale streaks along three interfaces.

Line 7: Use this line to identify next set of data.

READ: Header (40A2)

Example: TRANSMISSIBILITY MODIFICATIONS

Line 8: This line is used to enter the number of grid blocks where transmissibilities are to be changed, and print code.

READ: NUMTX, NUMTY, NUMTZ, ITCODE

NUMTX = Number of grid blocks where X-direction transmissibility (TX) is to be changed

NUMTY = Number of grid blocks where Y-direction transmissibility (TY) is to be changed

NUMTZ = Number of grid blocks where Z-direction transmissibility (TZ) is to be changed

ITCODE = Print code for transmissibility modification

If ITCODE = 0, do not print the modified transmissibility distributions

If ITCODE = 1, print the modified transmissibility distributions

Example: 0 0 0 0

This specifies that no transmissibility modifications are to be made or printed.

Line 9: Use NUMTX sets of lines to enter the coordinates of the blocks in the X-direction where transmissibility (TX) is to be modified. Omit this line if NUMTX = 0.

READ: I, J, K, TX

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

TX = New value of X-direction transmissibility (TX) in md-ft for block (I, J, K)

Note: NUMTX lines must be read

Line 10: Use NUMTY sets of lines to enter the coordinates of the blocks in the Y-direction where transmissibility (TY) is to be modified. Omit this line if NUMTY = 0

READ: I, J, K, TY

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

TY = New value of Y-direction transmissibility (TY) for block (I, J, K)

Note: NUMTY lines must be read

Line 11: Use NUMTZ sets of lines to enter the coordinates of the blocks in the Z-direction where transmissibility (TZ) is to be modified. Omit this line if NUMTZ = 0.

READ: I, J, K, TZ

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

TZ = New value of Z-direction transmissibility (TZ) for block (I, J, K)

Note: NUMTZ lines must be read

5.9 Relative Permeability and Capillary Pressure Tables

Line 1: Use this line to input table headings.

READ: Header (40A2)

Example: SAT KRO KRW KRG PCOW PCGO

Line 2: Read relative permeability and capillary pressure tables.

READ: SAT1 KRO1 KRW1 KRG1 PCOW1 PCGO1

SAT2 KRO2 KRW2 KRG2 PCOW2 PCGO2

.....

SATn KROn KRWn KRGn PCOWn PCGOn

Note:
(1) SATn must be 1.1 or greater
(2) Read each saturation as a fraction in ascending order
(3) Read as many lines as there are table entries (Maximum number of table entries allowed is 25)
(4) KRO, KRW etc. are real variables

Example:

0.0	0.0	0.0	0.0	0.	0.	Begin the relative permeability/capillary pressure data with lowest saturation.
0.10	0.0	0.0	0.0	0.	0.0	
0.20	0.0015	0.0	0.075	0.	0.0	
0.30	0.0023	0.0122	0.190	0.	0.0	
0.40	0.0370	0.0244	0.410	0.	0.0	
0.50	0.0571	0.0336	0.72	0.	0.0	
0.60	0.134	0.0672	0.87	0.	0.0	
0.70	0.207	0.1344	0.94	0.	0.0	
0.80	0.604	0.2688	0.9667	0.	0.0	
0.90	1.00	0.4704	0.9933	0.	0.0	
1.10	1.0	0.5	1.0	0.	0.0	Saturation greater than or equal to 1.10 specifies the end of the relative permeability/capillary pressure data.

SAT = Phase saturation

KRO = Oil phase relative permeability, fraction

KRW = Water phase relative permeability, fraction

KRG = Gas phase relative permeability, fraction

PCOW = Oil-water capillary pressure, psi

PCGO = Gas-oil capillary pressure, psi

REMARKS: SAT refers to the saturation of each particular phase,

Example: In a data line following SAT = 0.3; KRO would refer to the oil relative permeability in the presence of 30% oil saturation, KRW would refer to the water relative permeability in the presence of 30% water saturation; KRG would refer to the gas relative permeability in the presence of 30% gas saturation; PCOW would refer to the oil-water capillary pressure in the presence of 30% water saturation, and PCGO would refer to the gas-oil capillary pressure in the presence of 30% gas saturation.

5.10 Oil-Water-Gas PVT Tables

Line 1: Use this line to input table headings for next line.

READ: Header (40A2)

Example: PBO VSLOPE BSLOPE RSLOPE PMAX IREPRS

Line 2: Use this line to enter the values of bubble-point pressure, undersaturated oil properties, and maximum PVT table pressure.

READ: PBO, VSLOPE, BSLOPE, RSLOPE, PMAX, IREPRS

PBO = Initial reservoir oil bubble-point pressure, psia

VSLOPE = Slope of the oil viscosity versus pressure curve for pressure above PBO (i.e., for under-saturated oil). This value is in cp/psi

BSLOPE = Slope of oil formation volume factor versus pressure curve for pressure above PBO (i.e., for under-saturated oil). This value is in RB/STB/psi.

RSLOPE = Slope of the solution gas-oil ratio versus pressure curve for pressure above PBO (i.e., for under-saturated oil). This value is in SCF/STB-psi

PMAX = Maximum pressure entry for all PVT tables, psia

IREPRS = Code for repressurization algorithm;
IREPRES = 0 means no repressurization will be performed,
IREPRES = 1 means repressurization will be performed.

Example: 4014.7 0.0 -0.000001 0. 9014.7 1

Notes: (1) VSLOPE, BSLOPE and RSLOPE are used only for under-saturated oil

(2) BSLOPE should be a negative number and is related to under-saturated oil compressibility, C_O by C_O = BSLOPE/BO

(3) Normally, RSLOPE will be zero

(4) If IREPRS = 0, a new bubble-point pressure will be calculated for each grid block containing free gas at the end of each time step.

(5) PMAX (9014.7 in this example data file) is used as a termination flag for other PVT input variables.

Line 3: Use this line to input oil-PVT table headings.

READ: Header (40A2)

Example: PRES VISCO BO RSO

Line 4: Read oil PVT data.

READ: P1 MUO1 BO1 RSO1

P2 MUO2 BO2 RSO2

.....

PMAX MUO @ PMAX BO @ PMAX RSO @ PMAX

P = Pressure, psia

MUO = Oil viscosity, cP

BO = Oil formation volume factor, RB/STB

RSO = Solution gas-oil ratio, SCF/STB

Example: 14.7 2.0 1.5 1.0

4014.7 2.0 1.5 1.0

9014.7 2.0 1.5 1.0 PMAX (9014.7) specifies end of oil PVT data

Note: (1) The last pressure entry must be PMAX as specified in line 2.

(2) Oil properties must be entered as saturated data over the entire pressure range. Laboratory saturated oil data will generally have to be extrapolated above the measured bubble-point pressure to cover the maximum pressure range anticipated during the simulation run. The saturated oil data are required because of the bubble-point tracking scheme used by BOAST-VHS.

(3) The saturated oil data above the initial bubble point pressure will only be used if the local reservoir pressure rises above the initial bubble point pressure and free gas is introduced. An example of this would be pressure maintenance by gas injection into the oil zone.

(4) Total number of table entries cannot exceed 25.

Line 5: Use this line to input water PVT table headings.

READ: Header (40A2)

Example: PRES VISW BW RSW

Line 6: Read water PVT data.

READ: P1 MUW1 BW1 RSW1

P2 MUW2 BW2 RSW2

.....

PMAX MUW @ PMAX BW @ PMAX RSW @ PMAX

P = Pressure, psia

MUW = Water viscosity, cp

BW = Water formation volume factor, RB/STB

RSW = Solution gas-water ratio, SCF/STB

Example: 14.7 1.00 1.0 0.0

4014.7 1.0 1.0 0.0

9014.7 1. 1.0 0.0 PMAX (9014.7) specifies end of water PVT data

Notes: (1) The last pressure entry must be PMAX as specified in line 2.

(2) The assumption is often made in black oil simulations that the solubility of gas in reservoir brine can be neglected. This model incorporates this water PVT table to handle such situations as gas production from geo-pressured aquifers, or any other case where gas solubility in water is considered to be of significance to the solution of the problem.

(3) Total number of table entries should be 25 or less.

Line 7: Use this line to input gas PVT table headings and rock compressibility.

READ: Header (40A2)

Example: PRES VISG BG CR

Line 8: Read gas PVT data and rock compressibility.

READ: P1 MUG1 BG1 CR1

P2 MUG2 BG2 CR2

.....

PMAX MUG @ PMAX BG @ PMAX CR @ P MAX

P = Pressure, psia

MUG = Gas viscosity, cp

BG = Gas formation volume factor, RCF/SCF

CR = Rock compressibility, psi^{-1}

Example:

14.7	0.0080	0.935800	0.000003	
264.7	0.0096	0.067902	0.000003	
514.7	0.0112	0.035228	0.000003	
1014.7	0.0140	0.017951	0.000003	
2014.7	0.0189	0.009063	0.000003	
2514.7	0.0208	0.007266	0.000003	
3014.7	0.0228	0.006064	0.000003	
4014.7	0.0268	0.004554	0.000003	
5014.7	0.0309	0.003644	0.000003	
9014.7	0.0470	0.002167	0.000003	PMAX (9014.7) specifies end of gas PVT data

Note: (1) The last pressure entry must be PMAX as specified in line 2.

(2) Total number of table entries should be 25 or less.

Line 9: Use this line to identify next set of input data.

READ: Header (40A2)

Example: RHOSCO RHOSCW RHOSCG

Line 10: Read stock tank fluid densities.

READ: RHOSCO, RHOSCW, RHOSCG

RHOSCO = Stock tank oil density, lb/cu ft

RHOSCW = Stock tank water density, lb/cu ft

RHOSCG = Gas density at standard conditions, lb/cu ft

Example: 46.244 62.238 0.0647

Note: (1) Stock tank conditions are 14.7 psia and 60° F

(2) If no gas exists, set RHOSCG = 0.0

5.11 Pressure and Saturation Initialization

BOAST-VHS contains two options for pressure and saturation initialization. Initial pressure and saturation distributions can be calculated based on equilibrium conditions using the elevations and pressure of the gas-oil and water-oil contacts (option 1). Alternatively, the initial pressure distribution can be read on a block-by-block basis, as in the case of a non-equilibrium situation (option 2). Saturations can either be read as constant values for the entire grid (option 1) or the entire S_o and S_w distributions are read on a block-by-block basis, and the program calculates the S_g distribution for each block as $SG = 1.0 - S_o - S_w$ (option 2).

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: OPTION 1: INITIAL PRESSURE & SATURATION BASED ON EQUILIBRIUM CONDITIONS.

Line 2: Use this line to enter the codes for pressure and saturation initialization.

READ: KPI, KSI

KPI = Code for controlling pressure initialization (see table 5-3)

KSI = Code for controlling saturation initialization (see table 5-3)

Example: 0 0

Line 3: Use this line to enter the equilibrium pressure initialization data.

Skip this line if KPI = 1 or 2.

If KIP = 0 then

READ: PWOC, PGOC, WOC, GOC

PWOC = Pressure at the water-oil contact, psia

PGOC = Pressure at the gas-oil contact, psia

WOC = Depth to the water/oil contact, in feet below datum

GOC = Depth to the gas/oil contact, in feet below datum

TABLE 5-3. - Options for initializing pressure and saturation

Code	Value	Pressure and saturation specifications
KPI	0	Use equilibrium pressure initialization. Input pressures at the oil/water contact and gas/oil contact and elevations to each contact.
KPI	1	Use non-equilibrium pressure initialization. Read pressures for each grid block on a block-by-block basis. NOTE: II x JJ x KK values must be read.
KPI	2	Use non-equilibrium pressure initialization. Read pressures for each layer.
KSI	0	Initial oil, water and gas saturations are constant over the entire model grid. NOTE: Read three values - SOI, SWI and SGI.
KSI	1	Read oil and water saturations for each grid block on a block-by-block basis. The gas saturations for each grid block will be calculated by the program. NOTE: II x JJ x KK values must be read for oil saturation; II x JJ x KK values must be read for water saturation.
KSI	2	Read oil and water saturation for each layer.

Example: 4806.6 0.0 8425.0 8300.0

Note: (a) Input this record only if KPI = 0

(b) PWOC and PGOC are used together with depth to calculate the initial oil phase pressure at each grid-block mid point.

Line 4: Use this line to enter the non equilibrium pressure initialization data.
Skip this line if KPI = 0.

(a) If KPI = 1, then

READ: P

P = Pressure for the entire grid, Psia

Note: (1) A value of 'P' must be read for each grid block in the model grid. Read a total of II x JJ x KK values. The order of input must be as indicated below with layer order K = 1,2, ..., KK

J = 1 I = 1,2, ... II
J = 2 I = 1,2, ... II
. . . . . .
J = JJ I = 1,2, ... II

(2) Input this record only if KPI = 1

a) If KPI = 1, then

READ: P

P = Initial pressure to be assigned to a layer in the model, Psia

Example: 4800. 4810. 4820.

Note: (1) A value of 'P' must be read for each layer in the model grid. Read a total of KK values in one row following the order of K = 1,2, ..., KK

(2) Input this record only if KPI = 1 or 2

Line 5: Use this line to initialize the saturation data for a constant saturation case.
If KSI=0, then see (a) below. If KSI = 1, then see (b) below. If KSI = 2, then see (c) below.

(a) If KSI = 0, then

READ: SOI, SWI, SGI

SOI = Initial oil saturation to be assigned to all grid blocks in the model
SWI = Initial water saturation to be assigned to all grid blocks in the model
SGI = Initial gas saturation to be assigned to all grid blocks in the model

Example: 0.8 0.2 0.0

Note: (1) Input all saturation values as a fraction.

(b) In a non-equilibrium case when KSI = 1, then

READ: SO, SW

SO = Initial oil saturation array

SW = Initial water saturation array

Note: (1) A value of SO must be read for each grid block in the model grid. Read a total of II x JJ x KK values. The order of input must be as indicated below with layer order K = 1,2, . . . KK

J = 1 I = 1,2, ..., II

J = 2 I = 1,2, ... II

.....

J = JJ I = 1,2, ... II

(2) A value of S_W must be read for each grid block in the model grid. Read a total of II x JJ x KK values. The order of input must be as indicated above (see note 1) with layer order K = 1,2, ..., KK

(3) Input this record only if KSI = 1

(c) If KSI = 2, then

READ: SO

READ: SW

SO = Initial oil saturation to be assigned to a layer in the model

SW = Initial water saturation to be assigned a layer in the model

Example: 0.8 0.5 0.9

0.2 0.5 0.1

Note: (1) Input all saturation values as a fraction.

(2) A value of SO must be read for each layer. Read a total of KK values in one row following the order of K = 1, 2, ..., KK.

(3) A value of SW must be read for each layer. Read a total of KK values in one row following the order of K = 1, 2, ..., KK.

5.12 Debug and Diagnostics Codes

Several codes for controlling diagnostics output for use in program debugging are provided. These codes should normally be set to zero. These codes will not provide information for debugging data input. Activating any of the codes will generate an extremely large volume of output!

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: KSN1 KSM1 KCO1 KTR KCOF

Line 2: Use this line to input diagnostics codes.

READ: KSN1, KSM1, KCO1, KTR, KCOF

KSN1 = LSOR parameter debug output control (see table 5-4)

KSM1 = Solution matrix debug output control (see table 5-4)

KCO1 = Compressibility and formation volume factors debug output control (see table 5-4)

KTR = Transmissibility debug output control (see table 5-4)

KCOF = Density and saturation debug output control (see table 5-4)

Example: 0 0 0 0 0

In the above example, all diagnostics codes are set equal to 0. This means no diagnostic output is to be printed.

TABLE 5-4. - Options for controlling diagnostics output

Code	Value	Diagnostics specifications
KSN1	0	No LSOR diagnostics output will be printed.
KSNn	n	The number of LSOR iterations required to convergence is printed at each nth time-step.
KSM1	0	No solution matrix will be printed.
KSMn	n	The solution matrix will be printed the first time-step and every n^{th} step thereafter.
KCO1	0	No compressibilities and formation volume factors will be printed.
KCOn	n	Oil, water and gas compressibilities and formation volume factors will be printed the first time and every n^{th} step thereafter.
KTR	0	No transmissibilities will be printed.
	1	Transmissibilities will be printed at the beginning of each simulation run and whenever transmissibilities are modified.
KCOF	0	No saturations, gravity terms and source terms are printed.
	1	Saturations, gravity terms etc. are printed in the main program each time step. Also component mobilities, grid block flow coefficients, formation volume factors and gravity terms are printed at each time step.

5.13 Run Control Parameters

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: NMAX FACT1 FACT2 TMAX WORMAX GORMAX PAMIN PAMAX

Line 2: Use this line to enter run time control parameters.

READ: NMAX, FACT1, FACT2, TMAX, WORMAX, GORMAX, PAMIN, PAMAX

NMAX = Maximum number of time steps allowed before run is terminated

FACT1 = Factor for increasing time step size under automatic time step control; set FACT1 = 1.0 for fixed time step size

FACT2 = Factor for decreasing time step size under automatic time step control; set FACT2 = 1.0 for fixed time step size

TMAX = Maximum simulation run time, days (run will be terminated when time exceeds TMAX)

WORMAX = Limiting maximum field water-oil ratio, in STB/STB; simulation will be terminated if total producing WOR exceeds WORMAX

GORMAX = Limiting maximum field gas-oil ratio, in SCF/STB; simulation will be terminated if total producing GOR exceeds GORMAX

PAMIN = Limiting minimum field average pressure, psia; simulation will be terminated if average reservoir pressure falls below PAMIN

PAMAX = Limiting maximum field average pressure, psia; simulation will be terminated if average reservoir pressure exceeds PAMAX

Example: 500 1.2 0.5 365.0 20.0 500000.0 14.7 10000

The above example specifies automatic time step control and the simulation is to be terminated if:

(a) simulation time steps exceed 500 or

(b) simulation run time exceeds 1 year (365 days) or

(c) total producing water-oil ratio exceeds 20 STB/STB or

(d) total producing gas-oil ratio exceeds 500,000 SCF/STB or

(e) average reservoir pressure falls below 14.7 psia or

(f) average reservoir pressure exceeds 10,000 psia.

Note: (1) Time-step size cannot be less than DTMIN nor greater than DTMAX as specified in the recurrent data section

(2) For fixed time-step size, specify FACT1 = 1.0 and FACT2 = 1.0 and/or specify DTMIN = DTMAX = DT in the recurrent data section

(3) For automatic time-step control, set FACT1 > 1.0 and FACT2 < 1.0; suggested values are FACT1 = 1.25 and FACT2 = 0.5

(4) Automatic time-step control means the following:

(a) If at the beginning of a time-step, the maximum grid-block pressure and saturation changes from the previous step are less than DPMAX and DSMAX, respectively (DPMAX and DSMAX are defined in Section 5.14), the size of the current time-step will be increased by FACT1

(b) If at the beginning of a time-step, the maximum grid-block pressure or saturation change from the previous step is greater than DPMAX or DSMAX, respectively, the size of the current time-step will be decreased by FACT2

(c) If at the end of one iteration (after new pressures and saturations are calculated), the maximum pressure change exceeds DPMAX or the maximum saturation change exceeds DSMAX, and FACT2 < 1.0, the size of the current time-step will be decreased by FACT2 and the iteration will be repeated.

5.14 Solution Method Control Parameters

Line 1: Use this line to identify next set of data.

READ: Header (40A2)

Example: MITR OMEGA TOL TOL1 DSMAX DPMAX

Line 2: Use this line to specify various parameters for controlling LSOR solution method.

READ: MITR, OMEGA, TOL, TOL1, DSMAX, DPMAX

MITR = Maximum number of LSOR iterations for convergence; a typical value is 100

OMEGA = Initial LSOR acceleration parameter. The initial value for OMEGA must be in the range 1.0 < OMEGA < 2.0. A typical initial value for OMEGA is 1.20. The model will attempt to optimize OMEGA as the solution proceeds if TOL is greater than zero

TOL = Maximum acceptable pressure change for LSOR convergence; a typical value is 0.1 psi

TOL1 = Parameter for determining when to change (i.e. optimize) OMEGA; a typical value is 0.0005. If TOL1 = 0.0 the initial value of OMEGA will be used for the entire simulation

DSMAX = Maximum saturation change (fraction) permitted over a time-step. The time-step size will be reduced by FACT2 if FACT2 < 1.0 and the

saturation change of any phase in any grid-block exceeds DSMAX and the current step-size is greater than DTMIN. If the resulting step-size is less than DTMIN, the time-step will be repeated with the step-size DTMIN. A typical value of DSMAX is 0.05

DPMAX = Maximum pressure change (psi) permitted over a time-step. The time-step size will be reduced by FACT2 if FACT2 < 1.0 and the pressure change in any grid-block exceeds DPMAX and the current step-size is greater than DTMIN. If the resulting step-size is less than DTMIN, the time-step will be repeated with step-size DTMIN. A typical value of DPMAX is 50 psi.

Example: 100 1.70 0.1 0.0 0.05 50.0

VI. RECURRENT DATA

6.1 Introduction

During the course of a simulation run, it is generally desirable to be able to (1) add or delete injection/production wells, (2) control injection/production rates or bottomhole pressures at all existing wells, and (3) specify the types and frequency of output information. These types of controls and output specifications are accomplished in this model via "recurrent data" records. That is, as the simulation proceeds, well specification and print control information is input at preselected times.

Recurrent data record pairs are input which control printed output and time-step size for a specified time period. The first parameter (IWLCNG) on the first recurrent data record specifies whether or not to read well information. If IWLCNG = 0, well information is not read. If IWLCNG = 1, well information is read immediately following the recurrent data record pair. In any case, the simulator advances through time-steps until the specified elapsed time (ICHANG times DT) has occurred. During this period, all print codes and the latest well information applies. At the end of this period, a new set of recurrent data records are read and the process is repeated.

Modification of the recurrent data records occasionally needs to be done under the restart option. This is because all of the recurrent data is written to the restart file. If a waterflood is begun under restart conditions after any given period of primary production during a phase 1 run, and then restarted and continued in a phase 2 period, the recurrent data records for the primary recovery must first be removed.

Line 1: Use this line to signify the start of the recurrent data.

READ: Header (40A2)

Example: RECURRENT DATA RECORDS

Note: This line is read only once.

6.2 Time-Step and Output Control Codes

Note: (a) Recurrent data record pairs are read at preselected times

(b) A recurrent data record 'pair' consists of one integer control record and one time-step size specification record

(c) Lines 1 and 2 below constitute a recurrent data record pair. These records may be read any number of times during a simulation run

(d) Well information records (section 6.3) must be read immediately following each pair of recurrent data records if and only if IWLCNG = 1

(e) If well information is read, all specified rates and pressures will be used this time-step and all subsequent time-steps until new well information is read

Line 1: This line is used to input time-step and output control codes.

READ: IWLCNG, ICHANG, IWLREP, ISUMRY, IPMAP, ISOMAP, ISWMAP, ISGMAP, IPBM

IWLCNG = Code to tell the program whether or not the well information lines should be read this time-step. If IWLCNG = 0, well information is not read this step. If IWLCNG = 1, well information is read this step

ICHANG = A number for calculating the time period "ITIME" (see note 2 below) for which this recurrent data record pair will apply

IWLREP = Output code for printing well report

ISUMRY = Output code for printing summary report

IPMAP = Output code for printing pressure distribution

ISOMAP = Output code for printing oil saturation distribution

ISWMAP = Output code for printing water saturation distribution

ISGMAP = Output code for printing gas saturation distribution

IPBMAP = Output code for printing bubble-point pressures (normally set IPBMAP = 0)

Example: 1 1 1 1 0 0 0 0 0

The above example specifies that:

(a) Well information is read at this step;

(b) 1 is to be used as the number for calculating the time period for which this recurrent data will apply;

(c) well report and summary reports are to be printed at this step; and

(d) no pressure or saturation maps are to be printed at this step.

Note: (1) If IWLCNG = 1, well information lines must be read. The new well information will apply during the next time-step.

(2) If 'ETI' is the time at the beginning of the current step, then this recurrent data record pair will apply from ETI until FTMAX = ETI + ITIME where ITIME = ICHANG times DT. DT is the initial time-step size for this period as read in line 2 below.

(3) The actual number of time-steps for which ICHANG is used will likely be different from ICHANG if automatic time-step control is 'on.' Whenever the calculated simulation time exceeds 'FTMAX,' the current step-size is reduced to give an elapsed time of exactly FTMAX. Whenever FTMAX is reached, another recurrent data record pair is read.

(4) If the output code value = 0, the information will not be printed.

(5) If the output code value = 1, the information will be printed for each time-step during this period from ETI days to ETI + ITIME days.

Line 2: This line is used to input time-step control information.

READ: DT, DTMIN, DTMAX, HR, MIN, SEC

DT = Initial time-step size (days) for this period

DTMIN = Minimum time-step size (days) for this period

DTMAX = Maximum time-step size (days) for this period

Example: 3.0 3.0 3.0 0. 0. 0.

In the above example DT = DTMIN = DTMAX = 3.0, so the automatic time step control is overridden.

Note: (a) The time period referred to is the time for which this recurrent data pair will be used. This period is from the current simulation time (ETI) to an elapsed time of ETI + ITIME, where ITIME = ICHANG times DT.

(b) Common (suggested) values for DTMIN and DTMAX are 0.1 and 30.0 days, respectively.

(c) Automatic time-step control can be overridden by specifying DTMIN = DTMAX = DT.

(d) If automatic time-step control is not specified (i.e. FACT1 = FACT2 = 1.0) it is convenient to specify DTMIN = 0.0 and DTMAX = DT.

REMARK: Lines 1 and 2 above constitute a "recurrent data record pair". If IWLCNG = 1, well data as described in the next section must be read. IF IWLCNG = 0, well data is not read. Recurrent data records should be input until the cumulative time as given by the summation of ICHANG times DT for each pair exceeds the maximum desired simulation time (TMAX). The simulation will terminate if EOF (end of file) is encountered due to no more recurrent data.

6.3 Well Information Records

Line 1: Use this line to describe well activities.

READ: Header (40A2)

Example: NUMBER OF WELLS

Line 2: Total number of vertical/horizontal/slanted wells for which well information is to be read

READ: NVQN , NVQNH, NVQNS

NVQN = Number of vertical wells

NVQNH = Number of horizontal wells

NVQNS = Number of slanted wells

Example: 1 1 1; specifies 1 vertical well, 1 horizontal well, and 1 slanted well

Note: (1) Must repeat lines 3, 4, 5 a total of NVQN times; must repeat lines 6, 7, 8 a total of NVQNH times; and must repeat lines 9, 10, 11, 12 a total of NVQNS times

(2) Wells may be added or recompleted at any time during the simulation. However, once a well has been specified, it must be included in each time-step that well information is read, even if the well is currently shut-in.

Line 3: Vertical well ID (Omit this line if NVQN = 0)

READ: WELLID = Five character well name

Example: VERT1; this indicates the vertical well name is VERT1

Line 4: Vertical Well Information (Omit this line if NVQN = 0)

READ: I, J, PERFI, NLAYER, KIP, QO, QW, QG, QT

I = X-coordinate of grid-block containing this well

J = Y-coordinate of grid-block containing this well

PERFI = Layer number of the uppermost layer completed.

NLAYER = Total number of consecutive completion layers, starting with and including PERFI.

KIP = Code for specifying both well type and whether the well's production (injection) performance is determined by specifying rates or specifying flowing bottomhole pressure and also whether an explicit or implicit pressure calculation is to be made. For most cases, the implicit pressure calculation is recommended. See Table 6-1 for the code details. For more information on KIP see the notes at the end of this section.

QO = Oil rate, STB/D (nonzero only if KIP = 1 and QT = 0.0)

QW = Water rate, STB/D (nonzero only if KIP = 2)

QG = Gas rate, MCF/D (nonzero only if KIP = 3)

QT = Total fluid rate (nonzero only if KIP = 1 and QO = 0.0)

Example: 10 1 1 1 1 600. 0. 0. 0.

The above example specifies that the well PROD1 is located in the grid block (10,1,1); completed in one layer and produces oil at the rate of 600 STB/D.

Note: (1) Table 6-1 summarizes all well control options

(2) NLAYER must include all layers from PERFI to the lower most layer completed. For example, in a 5-layer model, if a well is completed in layers 2, 3, & 5, set PERFI = 2 and NLAYER = 4. Note that in this, layer 4 must be included in NLAYER even though layer 4 is not perforated. Layer 4 may be shut in by specifying the PID value for layer 4 as zero in line 4 below.

(3) Exactly NLAYER lines must be read for each WELLID (even if the well is rate controlled). Each of these lines specify a layer flow index (PID) and flowing bottomhole pressure (FBHP) for one completion layer; thus, NLAYER of these lines must be read. The first line read applies to the uppermost completion layer (PERFI); additional lines apply to succeeding layers. If rates are specified for this well (KIP = +1, +2, or +3), PWF will not be used and should be read as zero; however, PID will be used to calculate a FBHP for the well. This FBHP will be printed out on the well report, but it will not be used in any way to control the well performance.

(4) Negative rates indicate fluid injection; positive values indicate fluid production.

(5) The total fluid rate given by QT is the oil plus water plus gas production for the well or the total reservoir voidage at stock tank conditions.

(6) Only one of the four values (QO, QW, QG, or QT) may be nonzero. If KIP < 0, all four values should be zero.

(7) For most applications, implicit pressure calculations are recommended.

(8) If KIP = 2, -2 or -12, only water will be produced or injected; if KIP = 3, -3, or -13, only gas will be produced or injected; solution gas is not considered; therefore, these options are only recommended for water or gas injection wells. If KIP = 1, -1, or -11, oil, water, and gas will be produced in proportion to fluid mobilities and pressure constraints.

(9) If KIP > 0, the specified rate will be allocated to layers based on total layer mobilities; e.g. if QW is specified and there are two layers QW1 = QW * TM1/(TM1 + TM2) and QW2 = QW * TM2/(TM1 + TM2), where TM1 = total mobility for layer 1 and TM2 = total mobility for layer 2.

TABLE 6-1. - Options for controlling well performance

Code	Value	Rate or pressure specifications
KIP	1	Production (oil) well; specify rate, QO or QT
KIP	2	Water well; specify injection rate, QW
KIP	3	Gas well; specify injection rate, QG
KIP	-1	Oil well; oil, water & gas production rates will be calculated based on fluid mobilities and PID and PWF for each layer. Well will be shut-in if block pressure <PWF. Explicit pressure calculations are used.
KIP	-2	Water well; Water injection rate will be calculated based on total mobility of oil, water, and gas and PID and PWF for each layer. Well will be shut-in if block pressure >PWF. Explicit pressure calculations are used.
KIP	-3	Gas well; Gas injection rate will be calculated based on total mobility of oil, water, and gas and PID and PWF for each layer. Well will be shut-in if block pressure >PWF. Explicit pressure calculations are used.
KIP	-11	Oil well; Oil, water, and gas rates will be calculated based on fluid mobilities and PID and PWF for each layer. Implicit pressure calculations are used.
KIP	-12	Water well; Water injection rate will be calculated based on water mobility and PID and PWF for each layer. Implicit pressure calculations are used.
KIP	-13	Gas well; Gas injection rate will be calculated based on gas mobility and PID and PWF for each layer. Implicit pressure calculations are used.

Line 5: Use this line to enter flowing bottomhole pressure and productivity index information for vertical well.

READ: PID, PWF

PID = Layer productivity index

PWF = Layer flowing bottomhole pressure, psia

Example: 10.0 2500.0

Note: (1) If rates are specified (i.e. KIP > 0) for this well, PWF is not required and should be specified zero.

(2) If rates are specified (i.e. KIP > 0) for this well and PID is specified nonzero, the specified rate and PID will be used to calculate and print a flowing bottomhole pressure. However, the calculated pressure will not be used to control well performance.

(3) Once a well has been specified in any layer, that well and that layer must be specified each time well information lines are read.

(4) To shut in a layer, set the layer PID = 0.0; to shut in a well, simply set all its layer PID's = 0.0.

(5) The layer PID may be calculated from the following equation:

$$PID = \left(\frac{0.00708\ kh}{\ln (r_e/r_w) + S}\right)$$

where -

r_e = equivalent grid-block radius, ft

r_w = wellbore radius, ft

h = Z-dimension (layer thickness) of the block, ft

k = mean X-Y permeability in md

S = layer skin factor

The radius r_e may be calculated from Peaceman's formula:

$$r_e = 0.28 \frac{\left[\left(\frac{k_y}{k_x}\right)^{\left(\frac{1}{2}\right)} dx^2 + \left(\frac{k_x}{k_y}\right)^{\left(\frac{1}{2}\right)} dy^2\right]^{\left(\frac{1}{2}\right)}}{\left(\frac{k_y}{k_x}\right)^{\left(\frac{1}{4}\right)} + \left(\frac{k_x}{k_y}\right)^{\left(\frac{1}{4}\right)}}$$

where:

K_x = permeability in x-direction

K_y = permeability in y-direction

dx = X-direction grid-block dimension, ft

dy = Y-direction grid-block dimension, ft

(6) Formation damage or stimulation at any point in time can be handled on a layer-by-layer basis by changing the layer PID.

(7) Line 5 must be read NLAYER times

Example This illustrates the well information for well 2, INJ1

1 1 1 1 2 0 -900.0 0.0 0.0

10.0 7500.0

The above example specifies that well number 2 is an injection well (INJ1), is located in the grid block (1,1,1), completed in one layer; the well is a water injection well (KIP=2) and the injection rate is 900 STB/D. The layer productivity index for this well is 10.0 and the flowing bottomhole pressure 7500 psia will not be used in calculations.

Line 6: Horizontal Well ID (Omit this line if NVQNH = 0)

READ: WELID = Five character horizontal well name

Example: HORZ1

Line 7: Horizontal Well Information (Omit this line if NVQNH = 0)

READ: LAYER, KIP, QVO, QVW, QVG, QVT, COND

LAYER = Total number of consecutive well bore blocks

KIP, QVO, QVW, QVG, QVT = same definitions as KIP, QO, QW, QG and QT in line 4, respectively

COND = code for specifying type of wellbore conductivity in well rate calculations

When COND = 1, infinite conductivity is used

When COND = 2, "uniform flux" is chosen

Example: 5 - 1 0 0 0 0 1; specifies all 3 horizontal wellbore block will be produced under infinite conductivity and explicit pressure constraint

Line 8: Horizontal Well Information (Omit this line if NVQNH = 0) LAYER lines must be read for each wellbore block of WELID

READ: IQH1, IQH2, IQH3, PID, PWF

IQH1 = X - coordinate of grid block containing this well

IQH2 = Y - coordinate of grid block containing this well

IQH3 = Z - coordinate of grid block containing this well

PID = grid block productivity index, Peaceman's formula in line 5 is suggested except that kx (or ky) is replaced by kz when the horizontal wellbore is parallel to the y (or x) axis.

PWF = grid block flowing bottomhole pressure

Example: 3 5 1 4.5 500

4 5 1 4.5 500

5 5 1 4.5 500 specifies horizontal wellbore block at (3, 5, 1), (4, 5, 1), and (5, 5, 1)

Line 9: Slanted Well ID (Omit this line if NVQNS = 0)

READ: WELID = Five character slanted well name

Example: SLAN1

Line 10: Slanted Well Information (Omit this line if NVQNS = 0)

READ: IFLAG, KIP, QVO, QVW, QVG, QVT, COND

IFLAG = Code for specifying ways to define the geometric location of slanted well in reservoir grid blocks. Two options are defined in line 11.

KIP, QVO, QVW, QVG, QVT, COND - See definitions in line 7

Example: 1 -11 0 0 0 0 1; slanted wellbore, produced under infinite conductivity and implicit pressure condition, will be defined by option 1

Line 11: Slanted Well Information (Omit this line if NVQNS = 0)

(a) If IFLAG in line 10 is 1, then enter

IS, JS, KS, WELENGTH, THETA, ALPHA, IS1, IS2, IS3

where

IS = X - coordinate of starting grid block for defining this well

JS = Y - coordinate of starting grid block for defining this well

KS = Z - coordinate of starting grid block for defining this well

WELENGTH = Total wellbore length in feet of this well

THETA = Slant angle in degree which wellbore deviated from the downward direction as shown in figure 3, i.e. vertical well downward has a THETA of 0 ($0 \leq THETA \leq 180$)

ALPHA = Area angle in degree which wellbore departed from the increasing direction of x-axis from the plan view as shown in figure 4 ($0 \leq ALPHA \leq 360$)

IS1 = X - coordinate of starting grid block of the producing wellbore, i.e., wellbore grid blocks of x - coordinate from IS to IS1-1 are not productive.

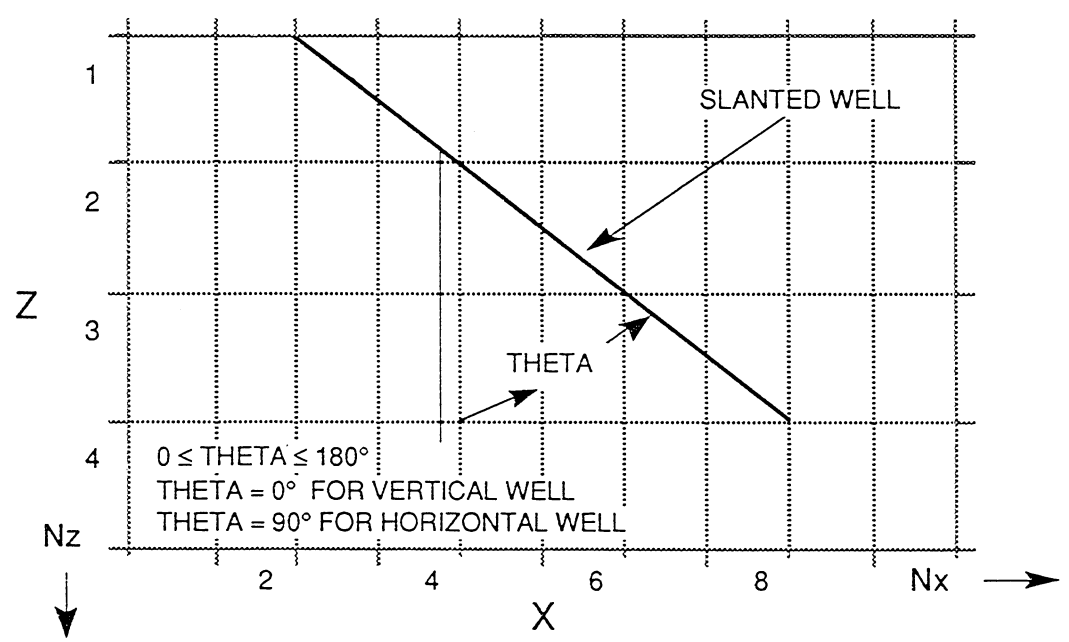

FIGURE 3. - Side view of grid to show angle theta.

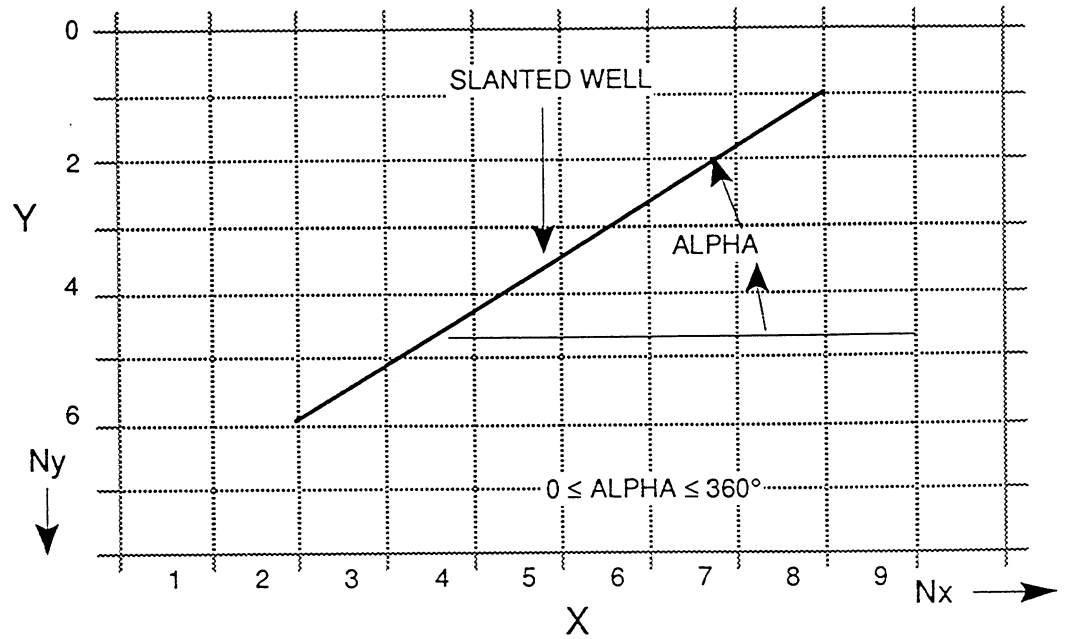

FIGURE 4. - Top view of grid to show angle alpha.

JS1 = Y - coordinate of starting grid block of the producing wellbore. Wellbore grid blocks of Y - coordinate from JS to JS1-1 are not productive.

JS1 = Z - coordinate of starting grid block of the producing wellbore. Wellbore grid blocks of Z - coordinate from KS to KS1-1 are not productive.

Example: 1 1 1 1000 60 315 1 1 1; indicates a slanted wellbore starting from (1, 1, 1) is 1000 ft long and 60 degrees from the downward direction and 315 degrees from the X-axis. This slanted well has productive wellbore block starting from (1, 1, 1).

(b) If IFLAG in line 10 is 2, then

READ: IS, JS, KS, IE, JE, KE, IS1, JS1, KS1

where

IE = X - coordinate of ending grid block of this well

JE = Y - coordinate of ending grid block of this well

JE = Z - coordinate of ending grid block of this well

IS, JS, KS, IS1, JS1, KS1 are defined same as those in option (a) when IFLAG = 1.

Example: 3 1 1 8 1 5 5 1 2; indicates a slanted wellbore starting from (3, 1, 1) and ending at (8, 1, 5). The productive wellbore block starts from (5, 1, 2) as shown in figure 5.

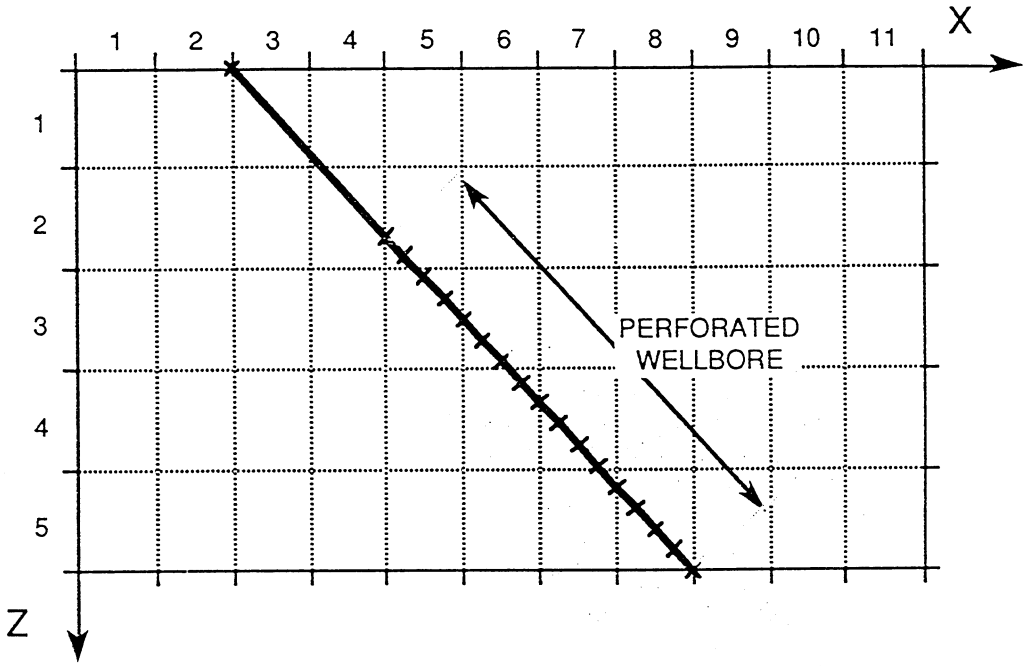

FIGURE 5.- Side view to show a slanted wellbore position in x-z axis.

Line 12: Slanted Well Information (Omit this line if NVQNS = 0)

READ: RW, S, PWF, JFLAG

where

RW = wellbore radius, ft

S = wellbore skin factor

PWF = grid block flowing bottom hole pressure

JFLAG = code for specifying ways to initialize wellbore pressure

when JFLAG = 1, PWF will be assigned to all wellbore blocks

when JFLAG = 2, wellbore pressure will be calculated for each wellbore block based on hydraulic gradient and PWF as wellbore pressure of the starting wellbore block.

Example: 0.3 0 100 1; specifies the wellbore has a radius of 0.3 ft with 0 skin and a flowing pressure of 100 psi which will be assigned to all wellbore blocks.

VII. INTERPRETATION OF MODEL OUTPUT

7.1 Model Start Up

This section provides a brief description of the BOAST-VHS program output. The program always writes the initialization data to the output file at model start up. The program also writes the initial well locations and well control information to this file. In addition to providing a complete report, this gives the user an excellent opportunity to quickly check for input data errors.

The information printed prior to the first summary report consists of the following items, in the order given:

(1) Grid-block sizes;
(2) Node midpoint elevations;
(3) Porosity distribution;
(4) Permeability distribution;
(5) Relative permeability and capillary pressure table;
(6) Oil-water-gas PVT table;
(7) Slopes calculated from PVT data for use in determining fluid compressibilities;
(8) Solution method parameters and time-step control data;
(9) Initial well locations and well control information;
(10) Initial fluids in place by layer; and
(11) Initial pressure and saturation distributions.

Other output can be obtained at the user's command. For example, whenever a modification option is activated, the user may print out the altered array. It is worthwhile to do this as a check on the input modifications.

7.2 Recurrent Data:

Using the output codes, the user can print out the following information during the course of a simulation run:

1. Well report;
2. Summary report;
3. Pressure and saturation distribution arrays; and
4. Bubble-point pressure distributions.

7.2.1 Well Report:

A well report may be specified at any time during the simulation run. Each time a well report is specified, production and injection rates and cumulatives for each layer of each well are tabulated and summarized. For oil producers, oil, water, and gas production is printed on the well report.

7.2.2 Summary Report:

The summary report is the single most useful report and can also be obtained at any desired time. The summary report contains a concise summary of field injection and production performance information including (a) average reservoir pressure, (b) total reservoir oil, water, and

gas production rates and cumulative production, (c) total reservoir water, and gas injection rates and cumulative injection, (d) total reservoir current and cumulative water-oil, and gas-oil ratios, (e) time-step and material balances for oil, water, and gas, (f) and maximum pressure, and saturation changes for the current time-step, and where these changes are occurring in the reservoir model.

The summary report serves two major purposes by permitting the user to (1) quickly review total reservoir performance and (2) determine if the model is functioning properly. As a general rule, maximum saturation changes nearly always should be less than 10%, and time-step material balance errors should normally be less than 0.1%.

Material balances or saturation changes that are excessive do not necessarily mean that the model cannot handle the problem at hand. However, it does mean that adjustments are needed to some of the input parameters. Normally, the first adjustment is reduction of time-step size. If this modification does not completely solve the problem, reduce injection and/or production rates to determine if well controls are excessive based on existing flow capacity and reservoir pressure. By making full use of automatic time-step control and being careful not to over-pressure or overproduce the reservoir, most reservoir engineering problems can be successfully simulated with BOAST-VHS.

7.2.3 Distribution Arrays:

The user may output pressure, saturation, and bubble-point pressure arrays at any time-step desired. For large two-dimensional or three-dimensional problems, an enormous output file can result if all these arrays are frequently printed. Therefore, these distributions should only be printed when absolutely needed. Normally, the bubble-point pressure array need not ever be printed out. This array provides mainly diagnostic information.

The pressure and saturation arrays should always be checked carefully at discrete times during the simulation to assure that overall pressure and saturation trends are as they should be. Also, if a material balance problem exists, these maps may help to isolate the problem.

VIII. SIMULATION PLANNING

8.1 Introduction

This section briefly outlines the major steps involved in conducting a reservoir simulation study. It must be emphasized at the outset that a reservoir simulator is an engineering tool and, as such, a great deal of engineering judgement is involved in its proper use. Reservoir simulators do not provide answers; they provide estimates of performance for user defined reservoir and vertical/horizontal/slanted well models. These performance estimates, together with economic evaluations, can then be used to make the required operating or field development decisions.

Because of the complexity and the volume of data needed for a simulation, it is almost always wise to begin a simulation study using the simplest model and coarsest reservoir description. If the results of the simulation run are not adequate, further runs should be made using a finely gridded model. The rule is to keep the simulation simple. The accuracy of the simulation depends upon the input and not upon the sophistication of the model.

The major steps in the conduct of a simulation study are:

1. Input data gathering
2. History matching
3. Performance prediction

8.2 Input Data Gathering

The initial phase of every simulation study is the gathering of data to be used in the simulator. Values for the physical quantities must be specified before a simulation can begin. The particular data needed will depend on the nature and complexity of the study. The required data can be classified into three groups: reservoir rock properties, fluid properties, and field performance history. Ascertaining the reliability of the available data and information is vital for the success of modeling a reservoir. Also, conventional reservoir engineering analysis of the past and prevailing producing mechanisms will greatly aid in the selection of the proper model to simulate reservoir performance. A list of minimum data required for a reservoir simulation study is presented in table 8-1. The information needed to conduct a simulation study can be divided into four parts:

TABLE 8-1. - Minimum required information for a reservoir simulation study

A. Single Point Data

These data include the following:
- Number of layers, dimension of the grid
- The starting data (initial production data)
- Original reservoir pressure
- Rock compressibility

B. Empirical Data

Relative permeabilities, capillary pressure, and PVT data are required for a simulation; if we do not have these data they can be generated.

The following information is needed for the generation of relative permeability curves.
- Connate water saturation
- Residual oil saturation in water-oil system
- Residual oil saturation in gas-oil system
- Critical gas saturation

The following information is needed for the generation of PVT data.
- Reservoir temperature
- Gas and oil gravity
- Bubble-point pressure
- Water density, compressibility and viscosity at reservoir condition. Capillary pressure is determined from laboratory data.

C. Grid Data

The required data include the elevation, thickness, permeability, and porosity distributions for a reservoir. These data are compiled from:
- Structure map
- Gross and net sand isopach maps
- Isopermeability map
- Isoporosity map

If these contour maps are not available, they can be constructed from well data (such as drill-stem tests, log data, drilling records, etc.)

D. Production Data

The production data include the following:
- Location and perforation intervals of wells
- Oil, water, and gas production rates for each well as a function of time
- Pressure history

1. Single point data (general information for field)
2. Empirical data (rock and PVT data)
3. Grid data (data for each grid block)
4. Production data

The source of common reservoir data required for a simulation study are given in table 8-2.

In many cases, the only rock property data available are those obtained near well sites. The following procedures, along with well site rock property data and reservoir geology, are then used to infer reservoir rock data.

a. Collect all available rock property data; namely, permeability, porosity, formation thickness and formation elevation. Plot these data by well location on a plan map of the region or field being modeled.
b. Contour the data points to obtain an overall distribution within the reservoir limits. In evaluating and contouring these rock parameters, the engineer must use good engineering judgement and the known geological interpretation of the region.
c. In a simulation study, the reservoir is divided into several cells by superimposing a rectangular grid over the region. Within any given cell, the rock data are assumed to be uniform. The contoured data are then digitized to obtain the required value at each cell. The digitizing step is performed after the grid has been selected.

TABLE 8-2. - Sources of Common Reservoir Data Required for Simulation Studies

Property	Sources
Permeability	Pressure transient testing, core analyses, correlations
Porosity	Core analyses, well log data
Relative permeability	Laboratory core flow tests, correlations
Capillary pressures	Laboratory measurements
Saturations	Well log data, conventional core analyses, pressured core analyses, single well tracer tests
PVT data (Formation volume factors, gas solubility, viscosity, density)	Laboratory analyses of reservoir fluid samples (subsurface or recombined surface samples), correlations

Reservoir fluid properties (PVT data) include initial bubble point pressure, fluid viscosities, densities, formation volume factors, solution gas-oil ratio, solution gas-water ratio, etc. These data are usually obtained from laboratory measurement of samples of the reservoir fluid. Usually the PVT data are not known over the entire range of pressures and correlations are used to extend the laboratory data to the desired range.

The rock and PVT data, together with the relative permeability and capillary pressure data, constitute the initialization data for the model. Other initialization data include the reservoir model grid dimensions and geometry, and the initial pressure and saturation distribution within the reservoir. This information is read only once at the beginning of the simulation.

The remaining data that must be input are called the recurrent data. These data are read repeatedly during the course of the simulation run. The recurrent data include the location and specification of wells in the model, changes in well completions and field operations over time, a schedule of well rate and/or pressure performance over time, etc. The simulator calculates production and pressure performance based on the input data provided.

Since the accuracy of the simulation results depend upon the quality of input data, ascertaining the reliability of the available data and information is vital for the success of modeling a reservoir. Simulation models are often used to do sensitivity analyses on selected parameters. By varying each of several selected parameters over a reasonable range of uncertainty and observing the effect on simulator performance, the critical parameters controlling the performance can be identified. Further efforts should then be expended in improving the quality of these critical parameters.

8.3 History Matching

The objective of history matching is to reproduce, with the simulator, the past reservoir performance. This is achieved by adjusting the reservoir parameters of a model, until the simulated performance matches the observed behavior. Thus, history matching is the process of determining the values of poorly known or unknown physical parameters which are needed as input to the mathematical reservoir model.

Since history matching is a qualitative procedure, the reliability of a history match depends, in large part, on the knowledge and experience of the engineer performing the simulation. The engineer must identify the reservoir parameters which should be adjusted, and then determine the degree to which adjustments should be made. Some reservoir data are known with a greater degree of accuracy than others. It is usually assumed, for example, that the fluid properties are

valid, provided careful laboratory measurements were made. On the other hand, reservoir formation properties, i.e., porosity, permeability, and capillary pressure, etc. are known only at the points where the wells have pierced the formation, and even these may be subject to significant errors. In the interwell regions, the rock properties must be inferred from geological and petrophysical correlations. If these values are not precise or the correlation techniques inappropriate, then the results of the simulation may be inaccurate as well. History matching provides a way of using the historical performance of the reservoir to adjust these values.

Normally observed reservoir behavior such as pressure, production rates, water-oil ratios, and gas-oil ratios are compared with model results. Modifications of saturations, porosities, and permeabilities are then made to improve the match. History matching is a complicated process and many problems encountered during a history matching process can result in inexact performance projections. Some of the typical problems encountered are described below.

1. Nonuniqueness of Parameter Sets:
   Frequently, a set of reservoir parameters modified to obtain a good match is not unique. By selecting and modifying another set of parameters, it is possible to obtain as good a match as the accepted set; however, the two sets will not yield the same future performance predictions.
2. Incorrect Field Data:
   Lack of reliable field data is another typical problem faced by a simulation engineer. The reported field data may be inaccurate or incomplete. Use of such data without caution will result in a history match that may characterize the reported data, but may not characterize the reservoir.
3. Numerical Dispersion:
   Often the simulation results may not be reasonable due to what is known as numerical dispersion. Numerical dispersion or truncation errors arise due to the approximation employed to solve the mathematical formulations of the model. Numerical dispersion can cause a correct set of parameters to yield incorrect results.

An engineer should be aware that these and other potential problems result in inexact performance projections. One should carefully analyze the simulation results and draw conclusions based on his experience with the type of reservoir, the area, and the production systems being used in the field.

History matching should not be attempted without a systematic plan. A step-wise history matching procedure is described below.

Step I - Initialization:

The first step in any history matching process is to verify the reliability and completeness of the field data. Problems encountered in these areas must be corrected as necessary. It may be necessary to check:

- Data errors
- Pressure distribution at the initial time, and equilibration
- Saturation distribution at the initial time
- Original oil, gas, and water in place

Step II - Pressure Match:

Experience indicates it is wiser to match pressures (reservoir and individual wells) before attempting to match production rates. By specifying the total production rates for wells, the correct effect of the individual well rate on reservoir pressure can be approximated. A pressure match can be achieved by adjusting:

- Size of the aquifer
- Rock compressibility
- Permeability distribution
- Thickness and porosity effecting the original oil in place

Step III - Saturation Match:

Once the pressure match has been achieved with sufficient accuracy for all of the wells, the engineer should then match water-oil and gas-oil ratios. These are matched by adjusting

- Vertical permeabilities
- Relative permeability curves
- Water-oil and gas-oil contacts
- Thickness of water or gas zones
- Permeability

If the pressure match is disturbed, repeat step II with the new data from step III. These two steps might have to be repeated a number of times to match both P and S.

Step IV - Productivity Index Match:

Finally, the well flowing pressures must be matched. The well flowing pressures can be matched by modifying the productivity index. If there are multiple-node wells, with commingled production, it might be necessary to make some runs with flowing well pressures.

Once these steps are taken, chances are that the reservoir simulation model will predict valid future production performance.

8.4 Prediction Runs

The final phase of a reservoir simulation study is the prediction runs. Prediction runs are made (1) to predict the future performance of the reservoir under existing operating conditions; (2) evaluate and compare a number of alternative field operations or development plans. The main objective is to determine the optimum operating condition in order to maximize economic recovery of hydrocarbon from the reservoir. Examples of the type of problems tackled in this stage could be:

1. Do we need pressure maintenance for the reservoir? And, if we do need it, what kind of pressure maintenance project is optimal?
2. What kind of infill drilling program should we choose?
3. What type of wells should we drill - vertical, horizontal, or slanted well? Where are these wells drilled? And, in the case of horizontal or slant wells, what are their optimal length in the reservoir?
4. What would be the effect of installing more powerful pumps on the producing wells?

Since there are no field results against which to compare simulation results during the prediction phase, an engineer must carefully analyze the results using experience and engineering judgment before arriving at a decision.

IX. EXAMPLE INPUT DATA FILES AND OUTPUT

9.1 Introduction

This section provides three example problems which illustrate the capability of the model to simulate a wide range of problems in vertical, horizontal, or slant wells. The reservoir and PVT data used for the example problems are not intended to represent any specific reservoir or fluid system. The input files should be considered as "sample data" and their sole purpose is to illustrate the capabilities of the simulator. Users can consider these input data as a guide for building their own input data files.

Complete input files and output summary tables are presented for each problem in appendices. Complete output files also are included on the program diskettes.

9.2 Problem Description

A brief description of each example problem is given below. The input file, summary report and partial output file for each example are in the appendices and complete files are on the program diskette.

Test Problem 1:

This example is a two-dimensional, pressure depletion production of 10 years from a horizontal well of 1200 ft in 160 acres. This calculation provides a test of the saturation calculations performed by BOAST-VHS.

A two-dimensional grid model with NX=11, NY=9 and NZ=1 has been constructed. The input and two output files for test problem 1, TSTPBM1.DAT, TSTPBM1.OUT, and TSTPBM1.SUM, respectively, are on the program diskette. Files TSTPBM1.DAT, TSTPBM1.SUM, and part of TSTPBM1.OUT are presented in appendix A.

Test Problem 2:

This example is a two-dimensional homogeneous model showing waterflooding from a vertical producer in the middle of one reservoir edge and a horizontal water injector penetrated through the other edge of the reservoir.

A two-dimensional grid with NX=9, NY=9 and NZ=1 has been constructed. Vertical and horizontal permeabilities of 195 md are used. The input and two output files for test problem 2, TSTPBM2.DAT, TSTPBM2.SUM, and TSTPBM2.OUT, respectively, are on the program diskette. Files TSTPBM2.DAT and TSTPBM2.SUM are presented in appendix B.

Test Problem 3:

This example is a three-dimensional homogeneous reservoir model showing pressure depletion production from a 739-ft slant well. The reservoir is 40 acres.

The rectangular reservoir model was dimensioned with NX=9, NY=9, and NZ=3. Located in the middle of the reservoir, the slanted well penetrates the reservoir from the top to the bottom of the formation at a slant of 83°. Both the pressure and oil saturation show larger depletion near the well bore with production time as compared to the formation away from the well bore. This test problem demonstrates the capability of this model for simulating production from slant wells. The input and two output files for test problem 3, TSTPBM3.DAT, TSTPRBM3.SUM, and TSTPBM3. OUT, respectively, are on the program diskette. Files TSTPBM3.DAT and TSTPRBM3.SUM are presented in appendix C.

9.3 Program Validation

While BOAST-VHS has been tested on a variety of problems, the program has not been tested exhaustively in all of its options and features against every possible combination of factors

and conditions. Complete comprehensive validation is not practical due to the complexity of the simulator and the great time and cost involved. Consequently, we strongly recommend that results from any simulation be examined carefully and checked for "reasonableness" before accepting them.

The program has been checked by comparing its results with those of the Seventh SPE Comparative Solution[4] for modeling horizontal well production in a reservoir where coning tendency is important and reported in another report[5]. It was found that BOAST-VHS predicted well performance, including oil rate, cumulative oil production, and water-oil-ratio in the same range as those in the project. Pressure changes and saturation changes were limited to 10 psi and 1%, respectively at each time step in the BOAST-VHS simulations.

The specific changes to the BOAST program to allow simulation of horizontal and slant wells are detailed by Chang in two previous publications[2,6].

9.4 BOAST-VHS Diskette

The BOAST-VHS simulator and related files on the BOAST-VHS diskette are:

BOASTVHS.EXE - BOAST-VHS simulator program that uses a math coprocessor for those computers with math coprocessor chips (Intel™ XX87 series or equivalent).

BOSTVHSM.EXE - BOAST-VHS simulator program that has an emulator built in for those computers without a math coprocessor. This is designed for use on "386 machines" and is not recommended for a 286AT based machine because the simulation run times will be long.

TSTPBM1.DAT - The data input file for test problem 1 described in section 9.
TSTPBM2.DAT - The data input file for test problem 2 described in section 9.
TSTPBM3.DAT - The data input file for test problem 3 described in section 9.
TSTPBM1.SUM - The summary report file from test problem 1.
TSTPBM2.SUM - The summary report file from test problem 2.
TSTPBM3.SUM - The summary report file from test problem 3.
TSTPBM1.OUT - The full simulation report file from test problem 1.
TSTPBM2.OUT - The full simulation report file from test problem 2.
TSTPBM3.OUT - The full simulation report file from test problem 3.

X. REFERENCES

1. Fanchi, J.R., K. J. Harpole, and S. W. Bujnowski. BOAST - A Three-Dimensional, Three-Phase Black Oil Applied Simulation Tool. U.S. Dept. of Energy Report No. DOE/BC 10033-3, Sept 1982.

2. Chang, M-M., L. Tomutsa, and M. K. Tham. Predicting Horizontal/Slanted Well Production by Mathematical Modeling. Pres. at the SPE Production Operation Symposium, Oklahoma City, OK, March 13-14, 1989. SPE 18854.

3. Fanchi, J.R., J.E. Kennedy, and D. L. Dauben. BOAST II: A Three-Dimensional, Three-Phase Black Oil Applied Simulation Tool (Release 1.0), U.S. Dept. of Energy Report No. DOE/BC 88/2/SP, Dec. 1987.

4. Nghiem, L., D.A. Collins, and R. Sharma. Seventh SPE Comparative Solution Project: Modeling of Horizontal Wells in Reservoir Simulation. Presented at the 11th SPE symposium on Reservoir Simulation, Anahiem, CA, Feb. 17-20, 1991. SPE 21221.

5. Quarterly Technical Report for July 1 - September 30, 1991. U.S. Dept of Energy Report No. NIPER-576, December 1991.

6. Chang, M-M. Simulation of Production from Wells with Horizontal /Slanted Laterals.U.S. Dept. of Energy Report No. NIPER-326, March 1989.

XI. GLOSSARY

B - formation volume factor

Free-field format - input format in which an item of data need not appear in a specific location in a line.

GOC - depth at the gas/oil contact

II - the number of blocks in the x-direction on the input-value grids

IMPES - Implicit pressure/explicit saturation model used by BOASTVHS to solve finite difference approximations to partial differential equations

JJ - The number of blocks in the y-direction on the input-value grids

KK - The number of blocks in the z-direction on the input-value grids

KR - Relative permeability

LSOR - Line-successive, over-relaxation solution technique used by BOASTVHS to solve systems of pressure equations

Mu - viscosity

PBO - bubble-point pressure

PC - capillary pressure

PID - productivity index

PGOC - pressure at the gas/oil contact

PWOC - pressure at the water/oil contact

Q - production rate

RSO - solution gas-oil ratio

SAT - phase saturation

SO - oil saturation

WOC - depth at the water/oil contact

APPENDIX A. TEST PROBLEM 1

Input Data for Test Problem 1

(TSTPBM1.DAT)

```
HORIZONTAL WELL(1200 FT), 160 ACRES, 10md
   10     9     1
 SO  SHALE  RESTART  DT (SWITCH)
  0    0      1      7
GRID BLOCK LENTTH
  0   -1   -1
  240.00  240.00  240.00  300.00  300.00  300.00  300.00  240.00  240.00  240.00
  293.33
   50.00
GRID BLOCK LENGTH MODIFICATION (NONE)
    0    0    0    0
CAPROCK BASE DEPTH TO TOP OF SAND
    0
 3000.00
POROSITY AND PERMEABILITY DISTRIBUTIONS
   -1   -1   -1   -1
    0.25
   10.00
   10.00
   10.00
POROSITY AND PERMEABILITY MODIFICATION (NONE)
    0    0    0    0    0
TRANSMISSIBILITY MODIFICATIONS (NONE)
    0    0    0    0
    SAT     KRO     KRW     KRG     PCOW     PCGO
    0.00    0.00    0.00    0.00  904.00  904.00
    0.10    0.00    0.00    0.00  784.00  784.00
    0.20    0.00    0.00    0.03  664.00  664.00
    0.30    0.02    0.00    0.09  544.00  544.00
    0.40    0.06    0.00    0.19  424.00  424.00
    0.50    0.15    0.02    0.34  304.00  304.00
    0.60    0.32    0.06    0.53  184.00  184.00
    0.70    0.59    0.15    0.75   64.00   64.00
    0.80    1.00    0.32    1.00    4.00    4.00
    0.90    1.00    0.59    1.00    4.00    4.00
    1.10    1.00    1.00    1.00    4.00    4.00
    PBO      MUSLOPE      BSLOP    RSLOPE   PMAX  IREPRS
   1500.0   0.0000460  -0.0000232      0.0   6000.0    0
    P       MUO      BO      RSO
     15.    10.50    1.039     2.0
    500.     5.35    1.078    93.1
   1000.     3.39    1.123   198.6
   1500.     2.46    1.171   309.5
   2000.     1.92    1.220   424.0
   2500.     1.58    1.270   541.1
   3000.     1.34    1.321   660.6
   3500.     1.17    1.373   781.9
   4000.     1.04    1.426   904.8
```

```
   4500.      0.94     1.479  1029.2
   5000.      0.85     1.533  1154.9
   5500.      0.78     1.587  1281.8
   6000.      0.72     1.642  1409.8
    P       MUW       BW       RSW
    0       1.0       1.0       0.
  6000.     1.0       1.0       0.
    P       MUG        BG         CR
     15.    0.01092  1.081322 0.0000030 0.9966967
    500.    0.01171  0.028204 0.0000030 0.8842395
   1000.    0.01347  0.012231 0.0000030 0.7669402
   1500.    0.01664  0.007180 0.0000030 0.6753116
   2000.    0.02100  0.005131 0.0000030 0.6434640
   2500.    0.02548  0.004210 0.0000030 0.6600009
   3000.    0.02949  0.003729 0.0000030 0.7014127
   3500.    0.03295  0.003439 0.0000030 0.7546549
   4000.    0.03597  0.003244 0.0000030 0.8135868
   4500.    0.03864  0.003102 0.0000030 0.8753091
   5000.    0.04105  0.002993 0.0000030 0.9383891
   5500.    0.04326  0.002906 0.0000030 1.0020770
   6000.    0.04530  0.002833 0.0000030 1.0659600
 RHOSCO  RHOSCW  RHOSCG
  54.651  62.300   0.068
EQUILIBRIUM PRESSURE INITIALIZATION/CONSTANT SATURATION
    0    0
 1500.00 1420.00 3000.00 2800.00
    0.75    0.25    0.00
KSN1 KSM1 KCO1  KTR KCOF
    0    0    0    0    0
NMAX  FACT1  FACT2  TMAX  WORMAX  GORMAX   PAMIN   PAMAX
 1000  1.2    .5   3660.0   50.   100000.    0.   10000
MITR   OMEGA   TOL   TOL1   DSMAX  DPMAX
3000    1.7    .1     0.     .05     50.
RECURRENT DATA
    1    1    1    1    1    1    1    1    0
  .01   .001   3.   0.  0.  0.
RATES --
    0    1    0
PROD1
    4  -11      1000.0  0   0   0   2
    4    5    1    4.152    500.0
    5    5    1    4.152    500.0
    6    5    1    4.152    500.0
    7    5    1    4.152    500.0
   0      30.0    0    0    0    0    0    0    0
  1.  .01   30.   0.   0.   0.
   0    1    1    1    1    1    1    1    0
  1.  .01   3.   0.   0.   0.
   0     150.0    0    0    0    0    0    0    0
  1.  .01   30.   0.   0.   0.
   0    1    1    1    1    1    1    1    0
  1.  .01   3.   0.   0.   0.
   0     180.0    0    0    0    0    0    0    0
  1.  .01   30.   0.   0.   0.
```

```
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0     365.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0     365.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0     365.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0     365.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0     730.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0    1095.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
 0    1    1    1    1    1    1    1    0
1.  .01   3.   0.   0.   0.
 0    1095.0    0    0    0    0    0    0    0
1.  .01   30.   0.   0.   0.
```

Summary Report for Test Problem 1

(TSTPBM1.SUM)

```
*            U.S. Department of Energy:                          *
*      VERTICAL/HORIZONTAL/SLANT WELL RESERVOIR SIMULATOR        *
*                        (VERSION 1.2)                           *
*******************************************************************************
*                                                                             *
*HORIZONTAL WELL(1200 FT), 160 ACRES, 10md                                    *
*                                                                             *
*******************************************************************************
```

N (T.S.)	PROD TIME (DAY)	AVG PRESS (PSI)	OIL RATE (B/D)	CUM OIL (BBL)	GAS RATE (MCF/D)	CUM GAS (MCF)	GAS OIL RATIO (MCF/B)	WATER RATE (B/D)	CUM WATER (BBL)	WATER OIL RATIO (B/B)
7	5.97	1500.71	1000.00	5968.	974.29	6843.	0.97	0.00	0.	0.00
14	29.11	1483.99	1000.00	29108.	500.83	21679.	0.50	0.00	0.	0.00
21	39.94	1478.88	1000.00	39940.	406.18	26357.	0.41	0.00	0.	0.00
28	78.51	1465.02	1000.00	78507.	283.18	38986.	0.28	0.00	0.	0.00
35	121.08	1448.56	735.64	117156.	1680.24	80722.	2.28	0.00	0.	0.00
42	183.21	1431.47	478.14	152146.	1725.36	191900.	3.61	0.00	0.	0.00
49	201.81	1427.07	445.43	160675.	1614.33	222803.	3.62	0.00	0.	0.00
56	268.45	1412.76	371.78	187249.	1202.71	314333.	3.23	0.00	0.	0.00
63	365.65	1394.97	332.53	220363.	615.71	400018.	1.85	0.00	0.	0.00
70	387.97	1391.35	328.06	227724.	543.13	412806.	1.66	0.00	0.	0.00
77	467.94	1379.48	321.00	253566.	341.59	446367.	1.06	0.00	0.	0.00
84	666.75	1354.81	319.50	317311.	152.50	486771.	0.48	0.00	0.	0.00
91	733.38	1347.19	317.22	338500.	166.36	496879.	0.52	0.00	0.	0.00
98	760.16	1344.01	316.63	346987.	173.05	501444.	0.55	0.00	0.	0.00
105	856.13	1332.66	314.59	377264.	175.32	518391.	0.56	0.00	0.	0.00
112	1062.75	1308.01	289.58	439918.	317.34	567846.	1.10	0.00	0.	0.00
119	1101.45	1303.04	277.92	450841.	385.62	581571.	1.39	0.00	0.	0.00
126	1133.59	1298.92	270.43	459634.	405.62	594344.	1.50	0.00	0.	0.00
133	1248.75	1284.61	240.17	488774.	441.86	644035.	1.84	0.00	0.	0.00
140	1458.75	1262.92	197.37	533443.	320.84	726167.	1.63	0.00	0.	0.00
147	1469.94	1262.02	197.72	535661.	288.51	729440.	1.46	0.00	0.	0.00
154	1508.51	1258.76	194.62	543213.	255.62	739830.	1.31	0.00	0.	0.00
161	1644.75	1248.13	193.48	569485.	146.94	765916.	0.76	0.00	0.	0.00
168	1826.01	1235.60	209.25	606078.	50.93	781187.	0.24	0.00	0.	0.00
175	1838.93	1234.80	210.25	608788.	49.86	781836.	0.24	0.00	0.	0.00
182	1885.21	1231.90	213.55	618609.	49.34	784115.	0.23	0.00	0.	0.00
189	2040.75	1222.53	218.46	652399.	89.86	795042.	0.41	0.00	0.	0.00
196	2250.75	1210.26	216.95	698069.	107.39	817416.	0.49	0.00	0.	0.00
203	2460.75	1196.87	218.56	743922.	130.77	840433.	0.60	0.00	0.	0.00
210	2560.65	1190.19	212.97	765509.	187.99	856338.	0.88	0.00	0.	0.00
217	2582.97	1188.72	211.50	770243.	196.07	860639.	0.93	0.00	0.	0.00
224	2662.94	1183.40	205.05	786867.	222.00	877559.	1.08	0.00	0.	0.00
231	2861.75	1170.65	187.26	825563.	252.48	926045.	1.35	0.00	0.	0.00
238	3071.75	1157.41	177.07	863515.	247.58	978461.	1.40	0.00	0.	0.00
245	3281.75	1144.70	169.50	899831.	259.44	1031578.	1.53	0.00	0.	0.00
252	3491.75	1133.03	160.01	934296.	270.25	1087649.	1.69	0.00	0.	0.00
259	3654.01	1124.21	153.55	959619.	263.63	1131092.	1.72	0.00	0.	0.00

PART OF THE OUTPUT FILE FOR TEST PROBLEM 1
(TSTPBM1.OUT)

```
*****************************************************************
*                                                               *
*                                                               *
*            U.S. Department of Energy:                         *
*          VERTICAL/HORIZONTAL/SLANT WELL RESERVOIR SIMULATOR   *
*                          (VERSION 1.2)                        *
*                                                               *
*                                                               *
*****************************************************************


*******************************************************************************
*                                                                             *
*HORIZONTAL WELL(1200 FT), 160 ACRES, 10md                                    *
*                                                                             *
*******************************************************************************


GRID SIZE (DX) IN COLUMN    1 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    2 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    3 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    4 IS INITIALLY SET AT  300.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    5 IS INITIALLY SET AT  300.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    6 IS INITIALLY SET AT  300.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    7 IS INITIALLY SET AT  300.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    8 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN    9 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID SIZE (DX) IN COLUMN   10 IS INITIALLY SET AT  240.00 FOR ALL NODES

GRID BLOCK WIDTH  (DY) IS INITIALLY SET AT  293.3300 FOR ALL NODES

GRID BLOCK DEPTH  (DZ) IS INITIALLY SET AT   50.0000 FOR ALL NODES

********** NODE MIDPOINT ELEVATIONS **********

K = 1

 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025.
 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025.
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 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025. 3025.
```

POROSITY (PHI) IS INITIALLY SET AT 0.2500 FOR ALL NODES

PERMEABILITY (KX) IS INITIALLY SET AT 10.0000 FOR ALL NODES

PERMEABILITY (KY) IS INITIALLY SET AT 10.0000 FOR ALL NODES

PERMEABILITY (KZ) IS INITIALLY SET AT 10.0000 FOR ALL NODES

***** EMPIRICAL DATA TABLE *****

SAT	KRO	KRW	KRG	PCOW	PCGO
0.0000	0.0000	0.0000	0.0000	904.00	904.00
0.1000	0.0000	0.0000	0.0000	784.00	784.00
0.2000	0.0000	0.0000	0.0300	664.00	664.00
0.3000	0.0200	0.0000	0.0900	544.00	544.00
0.4000	0.0600	0.0000	0.1900	424.00	424.00
0.5000	0.1500	0.0200	0.3400	304.00	304.00
0.6000	0.3200	0.0600	0.5300	184.00	184.00
0.7000	0.5900	0.1500	0.7500	64.00	64.00
0.8000	1.0000	0.3200	1.0000	4.00	4.00
0.9000	1.0000	0.5900	1.0000	4.00	4.00
1.1000	1.0000	1.0000	1.0000	4.00	4.00

PBO	MUSLOPE	BSLOP	RSLOPE	PMAX	IREPRS
1500.00	0.460E-04	-0.232E-04	0.00	6000.00	0

P	MUO	BO	RSO
15.0	10.5000	1.0390	2.00
500.0	5.3500	1.0780	93.10
1000.0	3.3900	1.1230	198.60
1500.0	2.4600	1.1710	309.50
2000.0	1.9200	1.2200	424.00
2500.0	1.5800	1.2700	541.10
3000.0	1.3400	1.3210	660.60
3500.0	1.1700	1.3730	781.90
4000.0	1.0400	1.4260	904.80
4500.0	0.9400	1.4790	1029.20
5000.0	0.8500	1.5330	1154.90
5500.0	0.7800	1.5870	1281.80
6000.0	0.7200	1.6420	1409.80

P	MUW	BW	RSW
0.0	1.0000	1.0000	0.00
6000.0	1.0000	1.0000	0.00

P	MUG	BG	CR
15.0	0.0109	0.1081E+01	0.300E-05
500.0	0.0117	0.2820E-01	0.300E-05
1000.0	0.0135	0.1223E-01	0.300E-05
1500.0	0.0166	0.7180E-02	0.300E-05
2000.0	0.0210	0.5131E-02	0.300E-05
2500.0	0.0255	0.4210E-02	0.300E-05
3000.0	0.0295	0.3729E-02	0.300E-05
3500.0	0.0329	0.3439E-02	0.300E-05
4000.0	0.0360	0.3244E-02	0.300E-05
4500.0	0.0386	0.3102E-02	0.300E-05
5000.0	0.0410	0.2993E-02	0.300E-05
5500.0	0.0433	0.2906E-02	0.300E-05
6000.0	0.0453	0.2833E-02	0.300E-05

RHOSCO	RHOSCW	RHOSCG
54.6510	62.3000	0.0680

***** SLOPES FOR COMPRESSIBILITY CALCULATIONS ****

P	BO	DBO/DP	RSO	DRSO/DP
500.0	1.0780	0.8041E-04	16.6	0.3345E-01
1000.0	1.1230	0.9000E-04	35.4	0.3758E-01
1500.0	1.1710	0.9600E-04	55.1	0.3950E-01
2000.0	1.2200	0.9800E-04	75.5	0.4078E-01
2500.0	1.2700	0.1000E-03	96.4	0.4171E-01
3000.0	1.3210	0.1020E-03	117.6	0.4256E-01
3500.0	1.3730	0.1040E-03	139.2	0.4320E-01
4000.0	1.4260	0.1060E-03	161.1	0.4377E-01
4500.0	1.4790	0.1060E-03	183.3	0.4431E-01
5000.0	1.5330	0.1080E-03	205.7	0.4477E-01
5500.0	1.5870	0.1080E-03	228.3	0.4520E-01
6000.0	1.6420	0.1100E-03	251.1	0.4559E-01

P	BW	DBW/DP	RSW	DRSW/DP
6000.0	1.0000	0.0000E+00	0.0	0.0000E+00

P	BG	DBGDP
500.0	0.2820E-01	-0.2171E-02
1000.0	0.1223E-01	-0.3195E-04
1500.0	0.7180E-02	-0.1010E-04
2000.0	0.5131E-02	-0.4098E-05
2500.0	0.4210E-02	-0.1842E-05
3000.0	0.3729E-02	-0.9620E-06
3500.0	0.3439E-02	-0.5800E-06
4000.0	0.3244E-02	-0.3900E-06
4500.0	0.3102E-02	-0.2840E-06
5000.0	0.2993E-02	-0.2180E-06
5500.0	0.2906E-02	-0.1740E-06
6000.0	0.2833E-02	-0.1460E-06

MAXIMUM NUMBER OF TIME-STEPS = 1000
FACTOR FOR INCREASING DELT = 1.200000 WHEN DSMAX AND DPMAX NOT EXCEEDED.
FACTOR FOR DECREASING DELT = 0.500000 WHEN DSMAX OR DPMAX IS EXCEEDED.

```
MAXIMUM SIMULATION TIME =3660.000000
MAXIMUM RESERVOIR WOR/TIME-STEP =     50. STB/STB
MAXIMUM RESERVOIR GOR/TIME-STEP = 100000. SCF/STB
MINIMUM AVERAGE RESERVOIR PRESSURE/TIME-STEP =      0.
MAXIMUM AVERAGE RESERVOIR PRESSURE/TIME-STEP =  10000.


SOLUTION METHOD IS LSOR:
     MAXIMUM NUMBER OF ITERATIONS       (MITR) =       3000
     INITIAL ACCELERATION PARAMETER     (OMEGA) =     1.7000
     MAXIMUM PRESSURE RESIDUAL           (TOL) =     0.1000
     PARAMETER FOR CHANGING OMEGA       (TOL1) =     0.0000

AUTOMATIC TIME STEP CRITERIA:
     MAXIMUM ALLOWED SATURATION CHANGE (DSMAX) =     0.0500
     MAXIMUM ALLOWED PRESSURE CHANGE   (DPMAX) =    50.0000


RESERVOIR CONTAINS FOLLOWING RATE NODES              (FOR HORIZONTAL OR SLANT WELLS)

  NODE        OIL(STBD)   WATER(STBD)   GAS(MCFD)   TOTAL(RBD)   BHFP(PSIA)   PID
 4  5  1      1000.00        0.00        0.00        0.00        500.00  4.152000
 5  5  1      1000.00        0.00        0.00        0.00        500.00  4.152000
 6  5  1      1000.00        0.00        0.00        0.00        500.00  4.152000
 7  5  1      1000.00        0.00        0.00        0.00        500.00  4.152000


     HORIZONTAL OR SLANT WELL PROD1 IS AN IMPLICIT PRESSURE SPECIFIED PRODUCING WELL WHICH CONTAINS:
          BLOCK   4  5  1
          BLOCK   5  5  1
          BLOCK   6  5  1
          BLOCK   7  5  1

LAYER  1 INITIAL FLUID VOLUMES:
        OIL IN PLACE (MILLION STB)                          9.9394
        WATER IN PLACE (MILLION STB)                        3.8789
        SOLUTION GAS IN PLACE (BILLION SCF)                 3.0762
        FREE GAS IN PLACE (BILLION SCF)                     0.0000


TOTAL INITIAL FLUID VOLUMES IN RESERVOIR:
        OIL IN PLACE (MILLION STB)                          9.9394
        WATER IN PLACE (MILLION STB)                        3.8789
        SOLUTION GAS IN PLACE (BILLION SCF)                 3.0762
        FREE GAS IN PLACE (BILLION SCF)                     0.0000


          ******* INITIAL ARRAYS *******


          ***** RESERVOIR PRESSURE DISTRIBUTION *****

K = 1

    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
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    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
    1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511. 1511.
```

********* OIL SATURATION *********

K = 1

0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750

******** WATER SATURATION *********

K = 1

0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250

********* GAS SATURATION *********

K = 1

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

***** BUBBLE POINT PRESSURE DISTRIBUTION *****

K = 1

1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.

********** WELL REPORT FOR ALL ACTIVE WELLS ELAPSED TIME = 31.010000 DAYS FROM BEGINNING OF SIMULATION **********

WELL ID	LOCATION I	J	K	CALC BHFP	SPEC BHFP	SPEC PI	RATE OIL STB/D	RATE GAS MCF/D	RATE WATER STB/D	GOR	WOR	CUMULATIVE OIL MSTB	CUMULATIVE GAS MMCF	CUMULATIVE WATER MSTB
PROD1	4	5	1	828.	500.	4.152	257.	118.	0.	461.	0.000	8.	6.	0.
PROD1	5	5	1	828.	500.	4.152	243.	111.	0.	456.	0.000	8.	6.	0.
PROD1	6	5	1	828.	500.	4.152	243.	111.	0.	456.	0.000	8.	6.	0.
PROD1	7	5	1	828.	500.	4.152	257.	118.	0.	461.	0.000	8.	6.	0.
TOTALS							1000.	459.	0.			31.	23.	0.

```
*********************************************************************
*                                                                   *
*                                                                   *
*            SUMMARY REPORT: BOAST - VHS                            *
*                                                                   *
*                                                                   *
*********************************************************************
```

ELAPSED TIME (DAYS) = 31.01 TIME STEP NUMBER = 16 TIME STEP SIZE (DAYS) = 1.00

CURRENT AVG RES PRESSURE = 1483.0 PREVIOUS AVG RES PRESSURE = 1483.5 PRESSURE DPMAX(5, 5, 1) = -3.8

OIL DSMAX(5, 5, 1) = -0.00116 GAS DSMAX(5, 5, 1) = 0.00116 WATER DSMAX(5, 5, 1) = 0.00000

OIL MATERIAL BALANCE (%) = 0.000010 GAS MATERIAL BALANCE (%) = 0.006352 WATER MATERIAL BALANCE (%) = 0.000026

OIL PRODUCTION RATE (STB/D) = 1000.0 CUM. OIL PRODUCTION (STB) =0.3101E+05
GAS PRODUCTION RATE (MSCF/D)= 458.6 CUM. GAS PRODUCTION (MSCF) =0.2256E+05
WATER PRODUCTION RATE(STB/D)= 0.0 CUM. WATER PRODUCTION (STB) =0.0000E+00

GAS INJECTION RATE (MSCF/D) = 0.0 CUM. GAS INJECTION (MSCF) =0.0000E+00
WATER INJECTION RATE (STB/D)= 0.0 CUM. WATER INJECTION (STB) =0.0000E+00

PRODUCING WOR (STB/STB) = 0.000 CUM. WOR (STB/STB) = 0.000
PRODUCING GOR (SCF/STB) = 459. CUM. GOR (SCF/STB) = 727.

***** RESERVOIR PRESSURE DISTRIBUTION *****

K = 1

```
1510. 1510. 1509. 1509. 1508. 1508. 1509. 1509. 1510. 1510.
1509. 1509. 1507. 1506. 1505. 1505. 1506. 1507. 1509. 1509.
1508. 1506. 1502. 1498. 1498. 1498. 1498. 1502. 1506. 1508.
1505. 1501. 1494. 1465. 1461. 1461. 1465. 1494. 1501. 1505.
1503. 1497. 1460. 1181. 1169. 1169. 1181. 1460. 1497. 1503.
1505. 1501. 1494. 1465. 1461. 1461. 1465. 1494. 1501. 1505.
1508. 1506. 1502. 1498. 1498. 1498. 1498. 1502. 1506. 1508.
1509. 1509. 1507. 1506. 1505. 1505. 1506. 1507. 1509. 1509.
1510. 1510. 1509. 1509. 1508. 1508. 1509. 1509. 1510. 1510.
```

```
********* OIL SATURATION *********

K = 1

    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750
    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750
    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750
    0.750 0.750 0.749 0.744 0.743 0.743 0.744 0.749 0.750 0.750
    0.750 0.749 0.743 0.704 0.699 0.699 0.704 0.743 0.749 0.750
    0.750 0.750 0.749 0.744 0.743 0.743 0.744 0.749 0.750 0.750
    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750
    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750
    0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750 0.750


******** WATER SATURATION *********

K = 1

    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250
    0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250


********* GAS SATURATION *********

K = 1

    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    0.000 0.000 0.001 0.006 0.007 0.007 0.006 0.001 0.000 0.000
    0.000 0.001 0.007 0.046 0.051 0.051 0.046 0.007 0.001 0.000
    0.000 0.000 0.001 0.006 0.007 0.007 0.006 0.001 0.000 0.000
    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
    0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000

****************************************************** END OF REPORT ******************************************************
```

Complete output file has separate report sections for each time step. To conserve space, the last time-step was not included in the manual. The output file TSTPBM1.OUT includes output for all the time-steps. Many blank lines have been removed from the output for inclusion in this document.

APPENDIX B. TEST PROBLEM 2

Input Data for Test Problem 2

(TSTPBM2.DAT)

```
WATERFLOOD (HORIZ. INJECTOR, VERT. PRODUCER)
  9    9    1
SO  SHALE  RESTART  DT (SWITCH)
 0    0      0      10
GRID BLOCK LENTTH
 0   -1   -1
 114.32  114.32  114.32  114.32  114.32  114.32  114.32  114.32  114.32
 127.02
  92.00
GRID BLOCK LENGTH MODIFICATION (NONE)
   0    0    0    0
CAPROCK BASE DEPTH TO TOP OF SAND
   0
 1900.00
POROSITY AND PERMEABILITY DISTRIBUTIONS
  -1   -1   -1   -1
   0.25
 195.00
 195.00
 195.00
POROSITY AND PERMEABILITY MODIFICATION (NONE)
   0    0    0    0    0
TRANSMISSIBILITY MODIFICATIONS (NONE)
   0    0    0    0
   SAT     KRO     KRW     KRG     PCOW     PCGO
   0.00    0.00    0.00    0.00  470.63  470.63
   0.10    0.00    0.00    0.00  350.63  350.63
   0.20    0.00    0.00    0.003 230.63  230.63
   0.30    0.00    0.00    0.009 110.63  110.63
   0.40    0.10    0.10    0.02    4.00    4.00
   0.50    0.20    0.20    0.10    4.00    4.00
   0.60    0.40    0.40    0.30    4.00    4.00
   0.70    0.60    0.60    0.75    4.00    4.00
   0.80    0.90    0.90    1.00    4.00    4.00
   1.10    1.00    1.00    1.00    4.00    4.00
    PBO      MUSLOPE      BSLOP     RSLOPE   PMAX   IREPRS
   1000.0   0.0000460  -0.0000232    0.0   6000.0    0
    P       MUO      BO      RSO
     15.     8.80    1.022     1.4
    500.     4.66    1.064    89.5
   1000.     2.90    1.118   203.9
   1500.     2.07    1.177   329.9
   2000.     1.60    1.240   464.1
   2500.     1.30    1.306   604.9
   3000.     1.10    1.375   751.0
   3500.     0.95    1.445   901.8
   4000.     0.84    1.518  1056.7
   4500.     0.75    1.593  1215.3
```

```
  5000.     0.68    1.669  1377.2
  5500.     0.62    1.746  1542.1
  6000.     0.57    1.825  1709.9
   P       MUW      BW      RSW
   0       1.0      1.0      0.
 6000.     1.0      1.0      0.
   P       MUG       BG        CR
    15.   0.01084  1.053224 0.0000030 0.9968016
   500.   0.01160  0.027595 0.0000030 0.8883290
  1000.   0.01325  0.012054 0.0000030 0.7760914
  1500.   0.01617  0.007121 0.0000030 0.6877449
  2000.   0.02017  0.005082 0.0000030 0.6544081
  2500.   0.02435  0.004149 0.0000030 0.6678598
  3000.   0.02813  0.003658 0.0000030 0.7064928
  3500.   0.03143  0.003362 0.0000030 0.7575253
  4000.   0.03431  0.003163 0.0000030 0.8146929
  4500.   0.03687  0.003020 0.0000030 0.8749519
  5000.   0.03918  0.002910 0.0000030 0.9367676
  5500.   0.04128  0.002822 0.0000030 0.9993249
  6000.   0.04323  0.002750 0.0000030 1.0621740
 RHOSCO  RHOSCW  RHOSCG
  53.011  62.300   0.064
EQUILIBRIUM PRESSURE INITIALIZATION/CONSTANT SATURATION
    0    0
 1000.00  920.00 2000.00 1800.00
    0.80    0.20    0.00
KSN1 KSM1 KCO1  KTR KCOF
    0    0    0    0    0
NMAX   FACT1  FACT2  TMAX    WORMAX  GORMAX   PAMIN   PAMAX
 1000   1.2    .5   3650.0   50.   100000.    0.   10000
MITR   OMEGA   TOL   TOL1   DSMAX  DPMA
3000    1.7    .1     0.     .05     50.
RECURRENT DATA
    1    1    0    0    0    0    0    0    0
  .01   .001   3.   0.  0.  0.
RATES --
   1    0    0
PROD1
  5    1    1    1   -11   0   0   0   0
 28.78  450.
  0      30.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     150.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     180.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
   1    1    1    1    1    1    1    1    0
 .01   .001   3.   0.  0.  0.
RATES --
   1    1    0
```

```
PROD1
  5    1    1    1   -11   0   0   0   0
 28.78  450.
INJ1
  9   -12   0   0.   0   0   2
   1    9    1   35.265    1300
   2    9    1   35.265    1300
   3    9    1   35.265    1300
   4    9    1   35.265    1300
   5    9    1   35.265    1300
   6    9    1   35.265    1300
   7    9    1   35.265    1300
   8    9    1   35.265    1300
   9    9    1   35.265    1300
  0      30.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     150.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     180.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     365.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     365.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     365.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0     730.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
  0    1    1    1    1    1    1    1    0
 1.  .01   3.   0.   0.   0.
  0    1095.0    0    0    0    0    0    0    0
 1.  .01   30.   0.   0.   0.
```

Summary Report for Test Problem 2

(TSTPBM2.SUM)

```
*              U.S. Department of Energy:                          *
*          VERTICAL/HORIZONTAL/SLANT WELL RESERVOIR SIMULATOR      *
*                          (VERSION 1.2)                           *
*******************************************************************************
*                                                                             *
*WATERFLCOD (HORIZ. INJECTOR, VERT. PRODUCER)                                 *
*                                                                             *
*******************************************************************************
```

N (T.S.)	PROD TIME (DAY)	AVG PRESS (PSI)	OIL RATE (B/D)	CUM OIL (BBL)	GAS RATE (MCF/D)	CUM GAS (MCF)	GAS OIL RATIO (MCF/B)	WATER RATE (B/D)	CUM WATER (BBL)	WATER OIL RATIO (B/B)
10	12.49	973.03	1129.98	22691.	1542.47	13798.	1.37	0.00	0.	0.00
20	37.45	958.66	1179.48	50843.	583.48	35854.	0.49	0.00	0.	0.00
30	102.05	935.64	932.92	118418.	599.28	72520.	0.64	0.00	0.	0.00
40	190.94	916.74	872.68	200436.	505.95	116316.	0.58	0.00	0.	0.00
50	268.45	905.39	785.34	263295.	519.42	157340.	0.66	0.00	0.	0.00
60	362.58	898.41	780.62	336283.	410.12	201163.	0.53	0.00	0.	0.00
70	363.27	917.75	780.01	336820.	410.31	201445.	0.53	0.00	0.	0.00
80	365.14	923.92	778.40	338281.	411.58	202216.	0.53	0.00	0.	0.00
90	369.26	943.95	769.93	341470.	415.06	203920.	0.54	0.00	0.	0.00
100	387.23	998.49	730.59	354914.	427.82	211551.	0.59	0.00	0.	0.00
110	408.52	1026.43	720.86	370254.	367.36	220037.	0.51	0.00	0.	0.00
120	489.63	1066.33	1136.19	442136.	154.32	237507.	0.14	0.00	0.	0.00
130	548.39	1107.39	1494.45	519651.	264.79	252168.	0.18	0.00	0.	0.00
140	602.22	1153.92	1714.43	613626.	606.95	278382.	0.35	0.00	0.	0.00
150	718.16	1143.71	1605.74	813581.	535.56	337545.	0.33	0.00	0.	0.00
160	744.82	1148.59	1602.83	856103.	553.19	352352.	0.35	0.00	0.	0.00
170	836.05	1163.85	1350.00	995414.	228.42	399147.	0.17	0.00	0.	0.00
180	929.42	1183.87	1116.76	1107072.	194.99	436207.	0.17	376.37	15740.	0.34
190	1003.18	1172.43	1007.93	1182964.	170.39	457155.	0.17	497.00	45189.	0.49
200	1091.02	1173.35	802.23	1259628.	395.40	484989.	0.49	547.57	92914.	0.68
210	1122.17	1173.14	786.22	1284281.	303.95	494973.	0.39	663.80	112784.	0.84
220	1224.19	1173.91	717.24	1360615.	199.87	524046.	0.28	834.34	188909.	1.16
230	1298.83	1175.34	666.70	1411964.	261.98	542831.	0.39	906.98	254574.	1.36
240	1344.41	1175.06	635.76	1441715.	237.73	553241.	0.37	985.86	298321.	1.55
250	1438.54	1173.11	564.10	1498336.	204.59	575227.	0.36	1091.20	398422.	1.93
260	1463.46	1172.16	553.02	1512440.	219.65	579942.	0.40	1190.03	427638.	2.15
270	1528.06	1169.61	515.55	1546711.	203.90	593608.	0.40	1296.98	508430.	2.52
280	1654.71	1158.83	444.28	1606586.	71.91	615761.	0.16	1671.40	689954.	3.76
290	1737.21	1159.68	380.48	1641071.	60.93	626719.	0.16	1794.28	823408.	4.72
300	1822.02	1156.30	364.65	1673447.	99.22	636875.	0.27	1826.82	971021.	5.01
310	1847.98	1155.15	350.99	1682630.	135.31	640755.	0.39	1807.42	1017264.	5.15
320	1978.64	1151.78	279.67	1725871.	44.50	657464.	0.16	1866.46	1262175.	6.67

330	2037.04	1148.54	299.33	1743982.	96.70	661342.	0.32	2012.67	1381139.	6.72
340	2107.19	1144.45	291.39	1764182.	46.85	667027.	0.16	2125.75	1527120.	7.30
350	2190.22	1145.83	258.69	1786920.	42.19	674221.	0.16	2342.62	1702825.	9.06
360	2227.60	1145.33	253.07	1796495.	94.31	677466.	0.37	2189.64	1784535.	8.65
370	2286.94	1141.61	244.41	1811056.	39.90	682617.	0.16	2291.76	1916869.	9.38
380	2359.81	1141.56	218.54	1828077.	149.19	688699.	0.68	2040.89	2083816.	9.34
390	2394.47	1138.27	222.98	1835932.	79.25	690872.	0.36	2349.21	2165039.	10.54
400	2449.49	1135.56	215.75	1847801.	34.48	694866.	0.16	2448.93	2296569.	11.35
410	2532.55	1134.19	199.25	1864883.	63.43	700864.	0.32	2505.27	2499439.	12.57
420	2564.69	1131.30	198.15	1871273.	59.71	702378.	0.30	2483.07	2579464.	12.53
430	2615.70	1129.56	189.47	1880959.	30.01	705356.	0.16	2592.08	2708742.	13.68
440	2692.71	1128.31	174.96	1894906.	123.24	710971.	0.70	2437.37	2904415.	13.93
450	2707.61	1125.87	176.79	1897506.	27.82	711379.	0.16	2637.78	2946056.	14.92
460	2799.87	1124.85	160.76	1912892.	25.44	716228.	0.16	2795.81	3191582.	17.39
470	2835.58	1120.52	162.15	1918641.	33.60	717513.	0.21	2664.62	3287037.	16.43
480	2878.46	1119.65	151.82	1925214.	23.69	719065.	0.16	2790.88	3404631.	18.38
490	2922.66	1119.74	143.86	1931786.	51.12	720824.	0.36	2757.65	3526095.	19.17
500	2967.52	1119.20	139.08	1938116.	52.12	723097.	0.37	2782.81	3650544.	20.01
510	3038.72	1112.95	132.48	1947606.	19.87	726313.	0.15	3015.04	3853108.	22.76
520	3109.48	1113.23	117.32	1956759.	19.85	728113.	0.17	2738.50	4055814.	23.34
530	3151.07	1110.92	121.29	1961846.	18.73	728894.	0.15	2904.37	4177818.	23.95
540	3217.10	1107.64	113.06	1969374.	16.94	730820.	0.15	3110.56	4373309.	27.51
550	3316.76	1107.43	100.31	1980118.	15.48	732891.	0.15	3086.96	4670810.	30.77
560	3336.04	1106.34	101.51	1982079.	15.57	733423.	0.15	3012.09	4728053.	29.67
570	3414.65	1105.77	87.66	1989594.	12.94	735664.	0.15	2832.85	4965222.	32.32
580	3460.86	1102.18	89.84	1993873.	14.37	736317.	0.16	3035.66	5106435.	33.79
590	3508.66	1100.55	83.04	1997913.	12.42	738028.	0.15	3294.39	5253072.	39.67
600	3564.02	1099.38	78.93	2002466.	22.45	738869.	0.28	3067.03	5423840.	38.86
610	3621.29	1097.30	76.54	2006778.	11.55	740328.	0.15	3105.46	5602176.	40.57

APPENDIX C. TEST PROBLEM 3

Input Data for Test Problem 3

(TSTPBM3.DAT)

```
 SLANT PRODUCER
  9    9    3
SO  SHALE  RESTART  DT  (SWITCH)
 0    0      0      3
GRID BLOCK LENGTH
 -1   -1   -1
 146.67
 146.67
  30.0
GRID BLOCK LENGTH MODIFICATION (NONE)
   0    0    0    0
CAPROCK BASE DEPTH TO TOP OF SAND
   0
 1900.00
POROSITY AND PERMEABILITY DISTRIBUTIONS
  -1   -1   -1   -1
   0.25
 195.00
 195.00
  30.00
POROSITY AND PERMEABILITY MODIFICATION (NONE)
   0    0    0    0    0
TRANSMISSIBILITY MODIFICATIONS (NONE)
   0    0    0    0
   SAT    KRO      KRW     KRG     PCOW     PCGO
   0.00   0.00     0.00    0.00  470.63  470.63
   0.10   0.00     0.00    0.00  350.63  350.63
   0.20   0.00     0.00    0.003 230.63  230.63
   0.30   0.00     0.00    0.009 110.63  110.63
   0.40   0.10     0.10    0.02    4.00    4.00
   0.50   0.20     0.20    0.10    4.00    4.00
   0.60   0.40     0.40    0.30    4.00    4.00
   0.70   0.60     0.60    0.75    4.00    4.00
   0.80   0.90     0.90    1.00    4.00    4.00
   1.10   1.00     1.00    1.00    4.00    4.00
    PBO     MUSLOPE        BSLOPE    RSLOPE   PMAX   IREPRS
   1000.0  0.0000460   -0.0000232      0.0   6000.0    0
    P       MUO      BO      RSO
     15.     97.75   1.019     1.3
    500.     47.55   1.046    60.6
   1000.     27.24   1.077   129.2
   1500.     17.90   1.109   201.4
   2000.     12.86   1.142   275.8
   2500.      9.81   1.177   352.1
   3000.      7.82   1.211   429.7
   3500.      6.44   1.247   508.7
   4000.      5.43   1.283   588.7
   4500.      4.68   1.319   669.6
   5000.      4.09   1.356   751.4
   5500.      3.62   1.393   833.9
   6000.      3.25   1.430   917.2
```

```
   P         MUW     BW       RSW
   0         1.0     1.0       0.
  6000.      1.0     1.0       0.
   P         MUG      BG         CR
    15.      0.01084 1.053224 0.0000030
   500.      0.01160 0.027595 0.0000030
  1000.      0.01325 0.012054 0.0000030
  1500.      0.01617 0.007121 0.0000030
  2000.      0.02017 0.005082 0.0000030
  2500.      0.02435 0.004149 0.0000030
  3000.      0.02813 0.003658 0.0000030
  3500.      0.03143 0.003362 0.0000030
  4000.      0.03431 0.003163 0.0000030
  4500.      0.03687 0.003020 0.0000030
  5000.      0.03918 0.002910 0.0000030
  5500.      0.04128 0.002822 0.0000030
  6000.      0.04323 0.002750 0.0000030
 RHOSCO  RHOSCW  RHOSCG
  53.011  62.300   0.064
EQUILIBRIUM PRESSURE INITIALIZATION/CONSTANT SATURATION
   0    0
 1000.00  920.00 2000.00 1800.00
   0.80    0.20    0.00
KSN1 KSM1 KCO1  KTR KCOF
   0    0    0    0    0
NMAX  FACT1  FACT2  TMAX   WORMAX  GORMAX  PAMIN  PAMAX
 1000  1.2    .5    1100.   50.    100000.    0.   10000
 MITR  OMEGA   TOL   TOL1  DSMAX  DPMAX
 1000   1.7    1.      0.   .05    50.
RECURRENT DATA
   1    0    0    0    0    0    0    0    0
  .1   .01   3.   0.  0.  0.
RATES --
   0    0    1
SLANT
  2   -1    0    0    0    0    2
  3  5  1   7  5  3   3  5  1
  0.25   0.  500.  2
  0       30.0    0    0    0    0    0    0    0
 1.  .2   10.   0.    0.    0.
  0   1   1   1   1   1   1   1   0
 .1   .1   3.   0.   0.   0.
  0      335.0    0    0    0    0    0    0    0
 1.  .5   30.   0.    0.    0.
  0   1   1   1   1   1   1   1   0
 .1   .1   3.   0.   0.   0.
  0      730.0    0    0    0    0    0    0    0
 1.  .5   30.   0.    0.    0.
  0   1   1   1   1   1   1   1   0
 .1   .01   3.   0.   0.   0.
  0      364.0    0    0    0    0    0    0    0
 1.  .01  30.   0.    0.    0.
  0   1   1   1   1   1   1   1   0
 .1  .01  3.   0   0   0
```

Summary Report for Test Problem 3

(TSTPBM3.SUM)

```
*              U.S. Department of Energy:                          *
*           VERTICAL/HORIZONTAL/SLANT WELL RESERVOIR SIMULATOR     *
*                          (VERSION 1.2)                           *
*******************************************************************************
*                                                                             *
* SLANT PRODUCER                                                              *
*                                                                             *
*******************************************************************************
```

N (T.S.)	PROD TIME (DAY)	AVG PRESS (PSI)	OIL RATE (B/D)	CUM OIL (BBL)	GAS RATE (MCF/D)	CUM GAS (MCF)	GAS OIL RATIO (MCF/B)	WATER RATE (B/D)	CUM WATER (BBL)	WATER OIL RATIO (B/B)
3	2.74	978.33	1212.94	3632.	146.13	448.	0.12	0.00	0.	0.00
6	9.03	975.73	984.58	10173.	114.04	1213.	0.12	0.00	0.	0.00
9	19.90	972.53	831.31	19680.	94.37	2298.	0.11	0.00	0.	0.00
12	30.20	969.85	695.37	27493.	92.72	3180.	0.13	0.00	0.	0.00
15	34.57	968.78	678.82	30488.	155.58	3728.	0.23	0.00	0.	0.00
18	42.12	966.96	640.38	35418.	332.34	5805.	0.52	0.00	0.	0.00
21	55.16	963.59	578.34	43227.	521.64	12046.	0.90	0.00	0.	0.00
24	77.70	958.03	510.17	55132.	386.00	22139.	0.76	0.00	0.	0.00
27	116.64	949.96	489.11	74289.	174.01	31000.	0.36	0.00	0.	0.00
30	183.94	939.26	467.51	106353.	155.73	41528.	0.33	0.00	0.	0.00
33	273.94	928.28	427.96	145954.	220.66	57644.	0.52	0.00	0.	0.00
36	363.94	919.74	386.85	181525.	90.10	74522.	0.23	0.00	0.	0.00
39	366.50	919.44	390.82	182525.	42.47	74630.	0.11	0.00	0.	0.00
42	371.74	919.13	391.80	184578.	46.22	74865.	0.12	0.00	0.	0.00
45	380.80	918.46	392.70	188132.	54.02	75332.	0.14	0.00	0.	0.00
48	396.45	917.42	392.58	194278.	63.54	76284.	0.16	0.00	0.	0.00
51	423.50	915.65	390.47	204858.	71.31	78117.	0.18	0.00	0.	0.00
54	470.23	912.69	383.36	222908.	116.87	82979.	0.30	0.00	0.	0.00
57	549.04	907.75	369.16	252348.	158.42	94218.	0.43	0.00	0.	0.00
60	639.04	902.27	343.07	284134.	203.00	112317.	0.59	0.00	0.	0.00
63	729.04	897.39	329.24	314058.	165.55	128051.	0.50	0.00	0.	0.00
66	819.04	893.01	313.75	342794.	162.80	142922.	0.52	0.00	0.	0.00
69	909.04	889.36	306.91	370499.	113.22	154197.	0.37	0.00	0.	0.00
72	999.04	886.13	299.33	397673.	112.68	164723.	0.38	0.00	0.	0.00
75	1089.04	883.22	296.32	424396.	104.70	174041.	0.35	0.00	0.	0.00
78	1096.60	882.89	293.29	426620.	111.60	174882.	0.38	0.00	0.	0.00