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MODIFICATION OF BOAST II-PC - BOAST III

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ABSTRACT

A readily available public reservoir simulation model BOAST II was modified to simulate accurately the conditions encountered in steeply dipping high permeability reservoirs. The modifications also involved the development and integration of post processing programs. The modified model was evaluated, modified, and validated against commercial reservoir models.

EXECUTIVE SUMMARY

A readily available public reservoir simulation model BOAST II was modified to simulate accurately the conditions encountered in steeply dipping high permeability reservoirs. The modified model, named BOAST3-PC, is a Black Oil Applied Simulation Tool used for performing evaluation and design work in modern petroleum reservoir engineering. Many features were added to improve the versatility of the model.

BOAST3-PC, a modified, PC-version of BOAST II, is more efficient than its predecessor and is designed to run in a 386/486 PC-based environment. Streamlined code and use of a 32-bit Fortran compiler makes BOAST3 3.7 times faster than BOAST II.

BOAST3-PC simulates isothermal, darcy flow in three dimensions. It assumes that reservoir fluids can be described by three fluid phases (oil, gas, and water) of constant composition with physical properties that depend on pressure only. This PC version of BOAST is limited by a maximum grid dimension of 30x28x7 or 30x7x28 in the X, Y, and Z directions.

BOAST3-PC has a wide range of applicability. It can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and capillary imbibition mechanisms.

In addition, BOAST3-PC includes two post processors: B3PLOT and COLORGRID. B3PLOT is a line graphics package used to plot data, such as production, pressure, and saturation, versus time. COLORGRID is used to view the finite-difference grid on the screen in plan or elevation view. The grid is color based on the range of the parameter selected.

BOAST3-PC - A MODIFICATION OF THE PC VERSION OF BOASTII

BOAST3-PC is a Black Oil Applied Simulation Tool used routinely for performing evaluation and design work in modern petroleum reservoir engineering. In 1982 the U.S. Department of Energy released the original black oil model called BOAST. BOAST II, released in 1987, was designed to provide more flexibility and to overcome some of the limitations of the original BOAST. Many features were added to improve the versatility of the model.

BOAST3-PC, a modified, PC-version of BOAST II, is more efficient than its predecessor and is designed to run in a 386/486 PC-based environment. Streamlined code and use of a 32-bit Fortran compiler makes BOAST3 3.7 times faster than BOAST II.

BOAST3-PC simulates isothermal, darcy flow in three dimensions. It assumes that reservoir fluids can be described by three fluid phases (oil, gas, and water) of constant composition with physical properties that depend on pressure only. This PC version of BOAST is limited by a maximum grid dimension of 30x28x7 or 30x7x28 in the X, Y, and Z directions.

BOAST3-PC has a wide range of applicability. It can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and capillary imbibition mechanisms. Some of the typical field production problems that can be handled by BOAST3 include but are not limited to:

- Primary depletion studies;
- Pressure maintenance by water and/or gas injection; and
- Evaluation of waterflooding, operations.

BOAST3-PC is a finite-difference, implicit pressure/explicit saturation (IMPES) numerical simulator. It includes options for both direct and iterative solution techniques for solving systems of algebraic equations. The main features of BOAST3-PC are exhibited in Figure 1. Some of the features and options of the BOAST3 model include:

- An option for simulating steeply dipping reservoirs;
- Allowances for multiple rock and PVT regions;
- A bubble point tracking scheme;
- An automatic time step control method;
- Material balance check on solution stability;
- Allowances for multiple wells per grid block; and
- An option for rate or pressure constraints on well performance.

In addition, BOAST3-PC includes two post processors: B3PLOT and COLORGRID. B3PLOT is a line graphics package used to plot data, such as production, pressure, and saturation, versus time. The package has two modes:

- Plotting simulated data, allowing comparison of the results from up to five different simulation runs; and
- History matching, using oil, water, or gas production data, GOR, or WOR; the average reservoir pressure or bottomhole well pressure can also be matched.

COLORGRID is used to view the finite difference grid on the screen as either a plan or elevation. The range of the parameter selected determines the color of the grid. Various arrays (maps) of input or output data may be represented by a 12 band color legend. An annotation option, which displays the numerical values of the parameter selected within each grid block, is provided. Any portion of the grid may be expanded to fill the entire screen.

Currently, the simulator is being used in the industry by Mr. Karl Lang, formerly ICF Resources and now with Hart Publications, and Darien O'Brien of Solutions Engineering in Lakewood, Colorado. Indications are that the simulator is functioning as designed. As the simulator is used more, any comments will be directed to Louisiana State University. A manual for the use of BOAST3-PC has been included in Appendix A. Diskettes containing the source code as well as executables have also been included at the back of this report.

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APPENDIX A
User's Guide and Documentation Manual for BOAST3-PC - A Modified Version of BOASTII with Post Processors B3PLOT and COLORGRID

USER'S GUIDE

and

DOCUMENTATION MANUAL

for

"B O A S T 3"

A Modified Version of BOASTII
with
Post Processors B3PLOT and COLORGRID

Version 1.50 June 06, 1995

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BOAST3

Version 1.50 June 06, 1995

Release Notes

1. Version 1.50 contains a very convenient restart option which is fully documented on pages 16 to 18b.

2. Versions 1.50 has been converted to MS PowerStation Fortran and therefore is 100 percent Windows compatible.

3. The maximum number of wells permitted in Version 1.50 is 60.

4. The maximum number of time-steps permitted is 4000.

5. To facilitate both large areal simulations as well as cross sectional studies, two versions of the simulator and COLORGRID are provided. Maximum grid dimensions for the two versions are as follows:

   MODEL A: BOAST3.EXE----------30 x 28 x 7
   COLORGRD.EXE-----30 x 28 x 7

   MODEL B: BOAST3XZ.EXE-----30 x 7 x 28
   COLORXZ.EXE-------30 x 7 x 28

   To run MODEL A or MODEL B, use the following Batch Files:

   MODEL A: Type "B3 filename" to execute BOAST3.EXE
   Type "COLOR filename" to execute COLORGRD.EXE

   MODEL A: Type "B3XZ filename" to execute BOAST3XZ.EXE
   Type "COLXZ filename" to execute COLORXZ.EXE

   CAUTION: Both COLORGRD and COLORXZ will process a maximum of 230 maps! Check your recurrent data to be sure this limit is not exceeded!

6. B3PLOT has the following restrictions regarding the number of time-steps and the actual number of points plotted.
   (a) Simulated data - maximum number of time-steps = 5000
   - maximum number of points plotted =600

   (b) Historical data - maximum number of time-stepa = 3000
   - maximum number of points plotted = 1800

   CAUTION: For plotting simulated data, if more than 600 time-steps are used in a run, you must specify a time-interval, DT, such that TMAX/DT≤ 600

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1.1 INTRODUCTION TO BOAST3

Black oil simulators are used routinely for performing evaluation and design work in modern petroleum reservoir engineering. In 1982, the U.S. Department of Energy released the original black oil model called BOAST (Reference 1).

BOASTII, released in 1987, was designed to provide more flexibility and to overcome some of the limitations of the original BOAST. Many features were added to improve the versatility of model.

This manual describes a modified version of BOASTII -- called BOAST3 -- which is more efficient than BOASTII and is designed to run in a 386/486 PC-based environment. As a result of streamlining the code and using a 32-bit Fortran compiler, BOAST3 is 3.7 times faster than BOASTII.

This manual is intended as a guideline for the use of BOAST3. For detailed discussions regarding theory, solution methods, etc. see Reference 2.

1.2 ENHANCEMENTS--BOAST TO BOAST3

The following are the major enhancements of the PC version of BOAST3 relative to the original BOAST.

User-Friendly Enhancements:

Free format data entry on most data cards
Restructured recurrent data input to allow separate specification of time step size and output frequency
Restart capability
One-line time step summary
Summary table of program output

Output pressure map corrected to user-specified datum
Gas PVT default option

Reservoir Engineering Features:

Optional three-phase relative permeability algorithm
Multiple rock regions allowed
Multiple PVT regions allowed
Bubble point pressure can vary with depth and PVT region
Several different analytic aquifer models
Direct input of noncontiguous layers
Net and gross thicknesses allowed

Well Model Features:

Individual well gas/oil ratio (GOR) and water/oil ratio (WOR) constraints
Minimum oil production and maximum liquid withdrawal well constraints
Multiple wells per grid block
Gas well model using a laminar-inertial-turbulent analysis
Maximum water/gas injection rates

Numerical Features:

Two new iterative matrix solution methods: y and z direction line successive over-relaxation (LSOR) methods

Zero pore volume (inactive) grid blocks allowed

Optional two-point upstream weighting for reducing numerical dispersion

1.3 GENERAL PROGRAM OVERVIEW

The BOAST3 program simulates isothermal, darcy flow in three dimensions. It assumes reservoir fluids can be described by three fluid phases (oil, gas, and water) of constant composition with physical properties that depend on pressure only. These reservoir fluid approximations are acceptable for a large percentage of the world's oil and gas reservoirs. Consequently, BOAST3 should have a wide range of applicability. For example, BOAST3 can simulate oil and/or gas recovery by fluid expansion, displacement, gravity drainage, and capillary imbibition mechanisms. Some of the typical field production problems which can be handled by BOAST3 include: primary depletion studies, pressure maintenance by water and/or gas injection, and evaluation of secondary recovery waterflooding operations.

BOAST3 is a finite-difference, implicit pressure/explicit saturation (IMPES) numerical simulator. It contains both direct and iterative solution techniques for solving systems of algebraic equations. The well model in BOAST3 allows specification of rate or pressure constraints on well performance, and the user is free to add or recomplete wells during the simulation. Multiple rock and PVT regions may be defined, and three aquifer models are available as options. BOAST3 contains flexible initialization capabilities, a bubble point tracking scheme, an automatic time step control method, and a material balance check on solution stability.

1.4 COMPUTER SYSTEM REQUIREMENTS

The computer system used to test BOAST3 was a Compaq 386/20 with an 80387 math coprocessor and 6 Megs of 32-bit RAM. The Microway 32-bit NDP Fortran-386 Compiler and Linker were used.

The Microway NDP software is very efficient compared to the Microsoft compiler used for BOASTII. Before any significant code modifications, it was found that the NDP compiler reduced computation time on the BOASTII example problem #1 from 33 minutes to 20 minutes.

By removing solution gas in water and adding arrays to avoid redundant table lookups and calculations regarding viscosities, densities and relative permeabilities, computation time was further reduced by more than 50 percent. BOAST3 will run example #1 (ODEH.SIM) in just 9 minutes!

2.1 SUMMARY OF BOAST3 FORTRAN CODE

Fortran Module	Brief Description
PARAMS.FOR	Contains maximum dimensions - used as an INCLUDE file
MAIN.FOR	Main program, block data subroutine and functions for aquifers
NODES.FOR	Routine for establishing well locations, rates and constraints
BLOCK1.FOR	Routines for aquifers and material balance (AQIN, AQOUT, AQUI and MATBAL)
CODES.FOR	Routine for reading general codes and run controls
GRIDSZ	Routine for determining grid dimensions & elevations
BLOCK2.FOR	Routines for linear interpolation and solution of linear equations (INTCOM, INTERP, INTPVT, LSORX, LSORY, LSORZ)
BLOCK3.FOR	Routines for block properties, post-run table, and time-step output (BEGIN, PORPRM, POSTP, PRTPS, OUTX, UNSAT)
BLOCK4.FOR	Routines for gas pseudo-pressure, repressurization algorithm and solution of 1D problems (PSEUDO, REPRS1, GAUS1D)
QRATE.FOR	Routine for calculation of production/injection at all well blocks
BLOCK6.FOR	Routines for input tables, transmissibilties, three-phase relative permeabilities, initial conditions, gas PVT properties, and aquifer functions (TABLE, TRANS, TRIKRO, VISCY, XLGR4, ZANDC, functions)
UINITL	Routine for establishing initial pressure & saturation
SOLWKS.FOR	Routine for setting up matrix for solution of pressure pressure equation (single-point upstream weighting)
SOLTWO.FOR	Routine for setting up matrix for solution of pressure equation (two-point upstream weighting)
CGDB3.FOR	Routines for identifying nodes for each well and writing arrays to binary file for COLORGRID (WELLS, OUTMAP, WRTMAP)
WRTBPD.FOR	Routine for writing binary file of production data for B3PLOT

2.2 FILE STRCTURE AND EXECUTION OF BOAST3

MODEL EXECUTION

The file structure for BOAST3 is given on the following page. There is only one input file - "fname.SIM".

To execute BOAST3, type "B3" followed by the name of the .SIM file you wish to run (without extension).

For example, to run BOAST3 using input file BIGFRAC.SIM, type

B3 BIGFRAC

This invokes the Batch Command File B3.BAT and the file BIGFRAC.SIM is copied to B.SIM, the generic model input file name. The BOAST3 simulator is run and the following generic output files are created:

1. B.OUT ---------- Output listing
2. B.SCR ---------- Screen output
3. B.WEL ---------- Well production summary
4. B.TAB ---------- Field production summary
5. B.GWN ---------- Grid & wellblock data for B3PLOT
6. B.BPD ---------- Binary production data for B3PLOT
7. B.CGD ---------- Grid & well data for COLORGRID
8. B.MAP ---------- Binary file of 3D arrays for COLORGRID

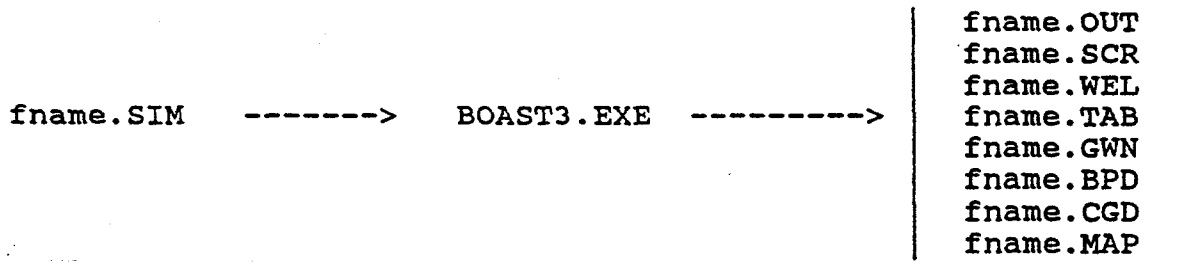
At the completion of the simulation run, these files are renamed to fname.OUT, fname.SCR, etc. Hence, the final output files would be as follows:

BIGFRAC.OUT
BIGFRAC.SCR
BIGFRAC.WEL
BIGFRAC.TAB
BIGFRAC.GWN
BIGFRAC.BPD
BIGFRAC.CGD
BIGFRAC.MAP

FILE STRUCTURE FOR BOAST3

Batch Command File

B3.BAT



Once a run has been completed you may use either of the post-processors - B3PLOT or COLORGRID. Since COLORGRID will display the finite-difference grid and some important input data arrays such as elevation, thickness, grid dimensions, porosity, permeability, pressure, and saturation, it is often useful to run through one time-step and check your input data by using COLORGRID before attempting a long run. **To use COLORGRID after running the simulator using BIGFRAC.SIM, type "COLOR BIGFRAC".** The .CGD and .MAP files are used and you can check any of the above arrays over the entire grid by selecting different layers and cross-sections. More information on COLORGRID is given in the section on Post Processors.

The line graphics package B3PLOT may also be used after a simulation run has been completed. **To run B3PLOT after running the simulator using BIGFRAC.SIM, type either "B3PLOT SIM" to plot only simulated data or "B3PLOT HIS" to plot both simulated and historical data.** You will immediately be prompted for a file name. After entering the filename "BIGFRAC", simply answer the questions asked to select the data you wish to plot. More information on B3PLOT is given in the section on Post Processors.

NOTE

Pages 1 to 10 of the BOASTII Manual (January, 1989) have been replaced with pages 1 to 6b.

Beginning with page 11, most page numbers are identical to the BOASTII Manual. Please note that some pages are no longer appropriate and have been removed.

3.1 DATA INPUT/OUTPUT

The data input file should be set up according to the specifications described in Section 3.3. Each variable is explained in that section. With the exception of a few instances in Recurrent Data, all input data is in free format.

Minor changes are required to input data in converting from BOASTII to BOAST3 as follows:

(1) Five identification records must be present at the beginning of each input data file.

(2) In the relative permeability table, SAT must now begin at 0.0 and end at 1.00.

(3) Pressure and saturation initialization data may now be input by layer (see pages 40 and 41).

(4) In Recurrent Data, parameters IWLCNG and IOMETH are input in the reverse order from BOASTII. IOMETH is now first since it is the most used option. Also, additional output codes have been added for relative permeability and capillary pressure - see page 51.

(5) A constant dip option has been added - see pages 24 & 24a.

(6) IPCODE has been replaced by four write codes (KPHIMP, KXMP, KYMP, KZMP) - see page 27.

(7) Two new output control switches, KSKIP & KOUT, have been added - see page 43.

(8) In addition to the normal output listing file (___.OUT), BOAST3 has seven other output files as discussed in Section 2.2.

(9) A new section "WELL and NODE DATA" has been added before Recurrent data - see page 48a.

3.2 INPUT DATA -- GENERAL REQUIREMENTS

The data input section is divided into two parts: an initialization data section and a recurrent data section. The initialization data include restart record and post-run control parameters, the reservoir model grid dimensions and geometry, the distribution of porosity and permeability within the reservoir, fluid PVT data, rock relative permeability and capillary pressure data, initial pressure and saturation distributions within the reservoir, specification of solution method, and various run control parameters. 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 rate 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.

Very Important! The following comments concerning data input format conventions, especially with regard to reading of arrays of data, apply to all of the input data.

1. Throughout this documentation, input data lines will be referred to as "cards". This can mean either physical computer input cards, in the case of card input, or individual lines in an input data set as entered on a CRT or line-printing terminal.

2. Title cards are read before each major and many minor sections of input data. A card must be read in each case unless specified otherwise in the documentation. These cards are designed to serve as delineators to make the input data file easier to read and edit. Title cards may include up to 80 characters.

3. In many cases, codes are read which will specify the type of input to follow and the number of values which will be read. This is necessary in order to provide some flexibility in the options available for data input.

4. All data (except as noted) are entered as free-field format. Free-field format means that an input datum required for a particular card need not appear in a particular location on that card. Input data must be entered in sequence, and a value must be specified for each input datum. If more than one datum appears on a card, each datum must be separated from neighboring data by at least one space.

As an example of free-field format, suppose we want to read an integer value of 5 and a real value of 120.5 on one card. This may be entered as

```
   5    120.5
or 5                 120.5
or
   5     1.205E+2
```

It may <u>not</u> be entered as 5120.5

An example of an input data set is given in section 3.5.

5. If a full grid of input values (II x JJ x KK) must be read for a particular parameter, the following input order <u>must</u> be followed:

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.

A Fortran input algorithm, as used by the program, might look like:

```
      DO 100 K = 1, KK
      DO 200 J = 1, JJ
  200 READ (5,*) (Parameter (I,J,K), I = 1, II)
  100 CONTINUE
```

6. BOAST3 uses a right-handed coordinate reference. Thus, each layer will be laid out as shown below, and z-direction values will increase going down.

```
        I = 1     I = 2     . . .


    J = 1

    J = 2
```

7. Parameter modifications by region are allowed for grid block dimensions, porosities, permeabilities, and transmissibilities. New parameter values are input using the following algorithm:

```
        DO 10 L = 1, NUMREG
        READ (20,*) I1, I2, J1, J2, K1, K2, REGVAL
        DO 10 K = K1, K2
        DO 10 J = J1, J2
        DO 10 I = I1, I2
        Parameter (I, J, K) = REGVAL
10 CONTINUE
```

where NUMREG = number of regions where parameter is modified
REGVAL = value of parameter in region defined by I1, I2, J1, J2, K1, K2:

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction

3.3 INITIALIZATION DATA -- FORMAT AND DEFINITIONS

Initialization data cards specify

- restart and post-plot options (3.3.1)

- reservoir model grid dimensions and geometry (3.3.2)
  - -grid dimensions
  - -modifications to grid dimensions
  - -depths to top of grid blocks

- porosity and permeability distributions (3.3.3)
  - -porosity and permeability
  - -modifications to porosity and permeability distribution
  - -transmissibility modifications

- rock and PVT regions (3.3.4)
- relative permeability and capillary pressure tables (3.3.5)

- fluid PVT data tables (3.3.6)

- pressure and saturation initializations (3.3.7)

- debug and diagnostics output control (3.3.8)

- run control parameters (3.3.9)

- solution method specifications (3.3.10)

- aquifer model (3.3.11)

These cards 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.

3.3.1 RESTART AND POST-RUN OPTIONS

1. Title card

2. Four run identification records

3. Restart and Post-Run Codes

```
IREOPT  ------ Restart switch
               -1 - initialization run; no restart records written
                0 - initialization run; restart records will be written
                1 - restart run; new restart records may be written

IPOSTP -------- Post-Run Table switch
               -1 - No Post-Run Table
                0 - Post-Run Table is written to output file and
                    also to ____.TAB file
```

(IF IREOPT = -1, GO TO SECTION 3.3.2)

4. Restart Parameters (to be read for IREOPT = 0 or 1)

```
IRNUM -------  Number of Restart Records to be written (max of 3)
IRSTRT ------  Starting time-step number for Restart Run
NN ----------  Maximum (cumulative) number of time-steps for Restart Run
TMAX --------  Maximum (cumulative) simulation time for Restart Run
```

5. Input and output Restart file names

```
RESIN.SIM ---- MS-DOS input file name   (used only for IREOPT=1)
RESOUT.SIM --- MS-DOS output file name  (used for IREOPT=0 or 1)
```

6. Times at which Restart Records are to be written

```
RSTIME ------- Restart Times (days)
               Specify IRNUM values; specify 0.0 if IRNUM=0.

               NOTE:  Each RSTIME must correspond to an interrupt
                      time in Recurrent Data!
```

========== ADDITIONAL REMARKS FOR RESTART RUNS ==========

(a) Although three restart records are permitted, only one is recommended (each restart record requires about 1.7 megs).

(b) For an initialization run with IREOPT=0, a restart input file is not used; therefore it is convenient to use DUMMY.RIN as the input file name in No. 5.

(c) For a restart run in which no restart records are to be written (i.e. IRNUM=0), it is convenient to specify DUMMY.ROT as the output file name in No. 5.

(d) Prior to an initialization run in which restart records are to be written (IREOPT=0), any previous input or output restart files should be deleted using the following two MS-DOS commands:

```
ERASE *.RIN
ERASE *.ROT
```

(e) Following an initialization run (with IREOPT=0) and before a restart run (IREOPT=1) it is necessary to reassign filenames using the following two MS-DOS given below.

```
ERASE *.RIN
RENAME *.ROT *.RIN
```

(f) Following a restart run and before a subsequent restart run, it is also necessary to reassign filenames using the two MS-DOS commands given above.

(g) A repeat restart run may be made without any reassignment of filenames. The same .RIN file will be used and the previous .ROT file will be overwritten.

To further explain the use of the Restart Option in BOAST3 the following three pages shows actual input data as follows:

(i) Page 18 shows the first part of an input data file for an initialization run in which one restart record is written.

(ii) Page 18a shows the complete input restart file (ODRST.SIM) used to make a restart run beginning at 1825 days (step 157) and terminating at TMAX=3650 days with another restart record written at 3650 days.

(iii) Page 18b shows the complete input restart file (ODRST1.SIM) used to begin at 3650 days (step 292) and terminate at 5000 days. No restart record is written.

Before making the initialization run (i), any previous .RIN or .ROT files were removed via (d) above.

Before making the first restart run (ii), files were "reassigned" as in (e) above.

Also, after the run in (ii) and before the final restart run (iii), files were again reassigned as in (e) above.

```
[ODEH553.SIM]  TESTING RESTART OPTION IN BOAST3 6/05/95
ID2:   INITIALIZATION RUN WITH IREOPT = 0
ID3:   ONE RESTART RECORD WRITTEN AT 1825 DAYS
ID4:   NO INPUT RESTART FILE IS NEEDED; HENCE USING "DUMMY.RIN"
ID5:   OUTPUT RESTART FILE IS NAMED "ODEH553.ROT"
RESTART AND POST-RUN CODES
 0  0           <--- IREOPT, IPOSTP
 1  0  0 0000.  <--- IRNUM,IRSTRT, NN,TMAX  (NN & TMAX used only for IREOPT=1)
DUMMY.RIN    <--- Input Restart File Name - used only for IREOPT=1
ODEH553.ROT  <--- Output Restart File Name-TO BE USED AS INPUT FOR RESTART RUN!
1825.      <--- Times @ which Restart Records are written
GRID DATA
 5  5  3
GRID BLOCK LENGTHS
-1 -1 0 0
2000.
2000.
20. 30. 50.
20. 30. 50.
GRID BLOCK LENGTH MODIFICATIONS
5*0
CONSTANT DEPTH TO TOP OF LAYER ONE
0  0.0     <---- KEL, ALPHA
8325.
POROSITY AND PERMEABILITY DISTRIBUTIONS
-1 0 0 0
.30
500. 50. 200.
500. 50. 200.
100. 37.5 20.83
POROSITY & PERMEABILITY MODS:  (IPCODE replaced by KPHIMP,KXMP,KYMP,KZMP)
0 0 0 0   1  1  1  1
TRANSMISSIBILITY MODIFICATIONS
4*0
 |           |
 |           |
 |           |
 |           |
```

```
[ODRST.SIM]  TESTING RESTART - ODEH553.SIM - 06/05/95
ID2:
ID3:  READING RESTART RECORD FROM FILE "ODEH553.RIN"
ID4:  RESTART TIME-STEP = 157   RESTART TIME = 1825.0 DAYS
ID5:  GO TO TMAX=3650 DAYS AND WRITE A RESTART RECORD TO "ODEN553.ROT"
RESTART AND POST-RUN CODES
 1  0
 1 157  999  3650.  <--IRNUM,IRSTRT, NN,TMAX (NN & TMAX used only for IREOPT=1)
ODEH553.RIN  <-- Input Restart File Name  [A12 Format]
ODEH553.ROT  <-- Output Restart File Name [A12 Format]
 3650.       <-- Times @ which Restart Records are written (enter 0 if IRNUM=0)
RECURRENT DATA
C===================== RECURRENT DATA SET FOR RESTART ====================
 0  6  1     [ICHANG  IOMETH  IWLCNG -> NOTE: ICHANG not used if IOMETH>0]
  1830.  2190.  2555.  2920.  3285.  3650.
1  1  0  1  1  0      [IPmap ISOmap ISWmap ISGmap IPBmap IAQmap]
1  0  1  1  0  0  1   [KROmap KRWmap KRGmap IRSOMP PCOWmap PCGOmap KPHImap]
1.0   0.1  15.0
HEADER -----> Beginning of data read by NODES - if IWLCNG=1]
2  0    [NWELLN=No. of new wells, NWELLO=No. of old wells]
---NEW WELLS---
INJ    1  1  1  1  1  [FORMATTED: A5,5I3 - WELLID, IDWELL, I, J, PERF1, NLAYER]
 9.85    (PID)
 0.0     (PWF)
INJ    1  3       0.        0.  -100000.        0.  [FORMATTED: A5,2I3,4F10.0]
PROD   2  5  5  3  1
 9.85   (PID)
1000.   (PWF)
PROD   2-11       0.        0.        0.        0. (Rates used if KIP > 0)
```

3.3.2 RESERVOIR MODEL GRID DIMENSIONS AND GEOMETRY

Grid Dimensions

If IREOPT = 1, go to Card 1 of RECURRENT DATA section, 3.4.1

1. Title card

2. Number of grid blocks in the model grid

   II = number of grid blocks in the x-direction
   JJ = number of grid blocks in the y-direction
   KK = number of grid blocks in the z-direction

3. Title card

4. Codes for type of input to be used

   KDX = code for controlling input of x-direction grid dimensions
   KDY = code for controlling input of y-direction grid dimensions
   KDZ = code for controlling input of z-direction gross grid block thicknesses
   KDZNET = code for controlling input of z-direction net grid block thicknesses

Code	Meaning — KDX =
-1	The x-direction grid dimensions are the same for all blocks in the grid (read only one value).
KDX = 0	The x-direction dimensions are read for each grid block in the first row (J = 1) of layer 1 (K =1). These same x-direction dimensions are assigned to all other rows and all other layers in the model grid. (NOTE: II values must be read.)

KDX = +1	The x-direction dimensions are read for every grid block in layer one (K = 1). These same x-direction dimensions are assigned to all other layers in the model grid. (NOTE: II x JJ values must be read - see section 3.2 for array input format convention.)
KDY = -1	The y-direction grid dimensions are the same for all blocks in the grid (read only one value).
KDY = 0	The y-direction dimensions are read for each grid block in the first column (I = 1) of layer one (K = 1). These same y-direction dimensions are assigned to all other columns and all other layers in the model grid. (NOTE: JJ values must be read.)
KDY = +1	The y-direction dimensions are read for every grid block in layer one (K = 1). These same y-direction dimensions are assigned to all other layers in the model grid. (NOTE: II x JJ values must be read - see section 3.2 for array input format convention.)
KDZ = -1	The z-direction grid dimensions (gross thicknesses) are the same for all blocks in the grid (read only one value).
KDZ = 0	A constant value of gross thickness is read for each layer in the grid. Each layer may have different, but constant value. (NOTE: KK values must be read.)
KDZ = +1	The z-direction grid dimensions (gross thicknesses) are read for every block in the model grid. (NOTE: II x JJ x KK values must be read - see section 3.2 for array input format convention.)
KDZNET = -1	The z-direction grid dimensions (net thicknesses) are the same for all blocks in the grid (read only one value).
KDZNET = 0	A constant value of net thickness is read for each layer in the grid. Each layer may have a different, but constant value. (NOTE: KK values must be read.)
KDZNET = +1	The z-direction grid dimensions (net thicknesses) are read for every block in the model grid. (NOTE: II x JJ x KK values must be read - see section 3.2 for array input format convention.)

5. x-direction grid dimension(s) (DX)

   If KDX = -1, only one constant value is read.
   If KDX = 0, II values are read (one for each row).
   If KDX = +1, (II x JJ) values are read (one for each grid block in layer one).

6. y-direction grid dimension(s) (DY)

   If KDY = -1, only one constant value is read.
   If KDY = 0, JJ values are read (one for each row).
   If KDY = +1, (II x JJ) values are read (one for each grid block in layer one).

7. z-direction gross grid block thicknesses (DZ)

   If KDZ = -1, only one constant value is read.
   If KDZ = 0, KK values are read (one for each layer).
   If KDZ = +1, (II x JJ x KK) values are read (one for each block in the model grid).

8. z-direction net grid block thicknesses (DZNET)

   If KDZNET = -1, only one constant value is read.
   If KDZNET = 0, KK values are read (one for each layer).
   If KDZNET = +1, (II x JJ x KK) values are read (one for each block in the model grid).

Modifications to Grid Dimensions

1. Title card

2. Number of regions where grid dimensions are to be changed, and print code

   NUMDX = number of regions where x-direction grid dimension (DX) is to be changed

NUMDY = number of regions where y-direction grid dimension (DY) is to be changed

NUMDZ = number of regions where z-direction gross grid block thickness (DZ) is to be changed

NUMDZN = number of regions where z-direction net grid block thickness (DZNET) is to be changed

IDCODE = print code:

IDCODE = 0 means do <u>not</u> print the modified grid dimensions

IDCODE = 1 means print the modified grid dimensions

NOTE: See section 3.2, item 7 for modification input algorithm.

3. x-direction grid dimension (DX) modification.

<u>Omit this card if NUMDX = 0.</u>

I1 = coordinate of first region block in I-direction;
I2 = coordinate of last region block in I-direction;
J1 = coordinate of first region block in J-direction;
J2 = coordinate of last region block in J-direction;
K1 = coordinate of first region block in K-direction;
K2 = coordinate of last region block in K-direction;
DX = new value of x-direction grid dimension (DX) for region.

NOTE: NUMDX cards must be read.

4. y-direction grid dimension (DY) modification.

<u>Omit this card if NUMDX = 0.</u>

I1 = coordinate of first region block in I-direction;
I2 = coordinate of last region block in I-direction;
J1 = coordinate of first region block in J-direction;
J2 = coordinate of last region block in J-direction;

K1 = coordinate of first region block in K-direction;
K2 = coordinate of last region block in K-direction;
DY = new value of y-direction grid dimension (DY) for region

NOTE: NUMDY cards must be read.

5. z-direction gross thickness (DZ) modification.

Omit this card if NUMCZ = 0.

I1 = coordinate of first region block in I-direction;
I2 = coordinate of last region block in I-direction;
J1 = coordinate of first region block in J-direction;
J2 = coordinate of last region block in J-direction;
K1 = coordinate of first region block in K-direction;
K2 = coordinate of last region block in K-direction;
DZ = new value of z-direction gross thickness (DZ) for region

NOTE: NUMDZ cards must be read.

6. z-direction net thickness (DZNET) modification.

Omit this card if NUMDZ = 0.

I1 = coordinate of first region block in I-direction;
I2 = coordinate of last region block in I-direction;
J1 = coordinate of first region block in J-direction;
J2 = coordinate of last region block in J-direction;
K1 = coordinate of first region block in K-direction;
K2 = coordinate of last region block in K-direction;
DZNET = new value of z-direction net thickness (DZNET) for region.

NOTE: NUMDZN cards must be read.

Depths to Top of Grid-Blocks

With the coordinate system used in BOAST3, z-direction values increase going down, as illustrated in Figure 1. Thus depths must be read as depths below the user-selected reference datum (negative values will be read as heights above the datum).

1. Title card

2. Code (KEL) for inputting depth values and dip angle (ALPHA)

   KEL

   ALPHA

   NOTES: (a) Specify ALPHA = 0.0 for no dip.
   Specify ALPHA > 0 for downward dip in x-direction.
   Specify ALPHA < 0 for upward dip in x-direction.

   (b) KEL = -1 means constant dip angle with contiguous layers. Read a single value of ELEV (ZT_1 in Figure 1) which is the elevation at the top left corner of grid-block (1,1,1). Other values (ZT_2, ZT_3, etc.) will be calculated.

   (c) KEL = -2 means constant dip angle with non-contiguous layers. Read KK depth values; $ELEV_1 = ZT_1$, $ELEV_2 = ZT_2$, etc. $ELEV_k$ is the elevation at the top left corner of grid-block (1,1,k).

   (d) KEL = 0 means no dip (ALPHA = 0.0) and contiguous layers; specify a single value of ELEV which is the elevation at the top of layer 1.

   (e) KEL = 1 means a separate depth value must be read for each grid-block in layer 1; II x JJ values must be read.

   (f) KEL = 2 means horizontal non-contiguous layers; Read KK depth values; $ELEV_k$ = elevation at top of layer k.

   (g) KEL = 3 means one depth value must be read for each grid-block; II x JJ x KK values must be read. See Section 3.2 for array input format conventions.

3. Depth value(s)

   ELEV ------ Depth to top of grid-block, ft

For KEL = -1, 0 and 1, layers are contiguous and depths (i.e. elevations) to the top of grid-blocks in layers below layer 1 will be calculated by adding the layer thickness to the preceding layer top; i.e.

$$Top(I,J,K+1) = Top(I,J,K) + DZ(I,J,K).$$

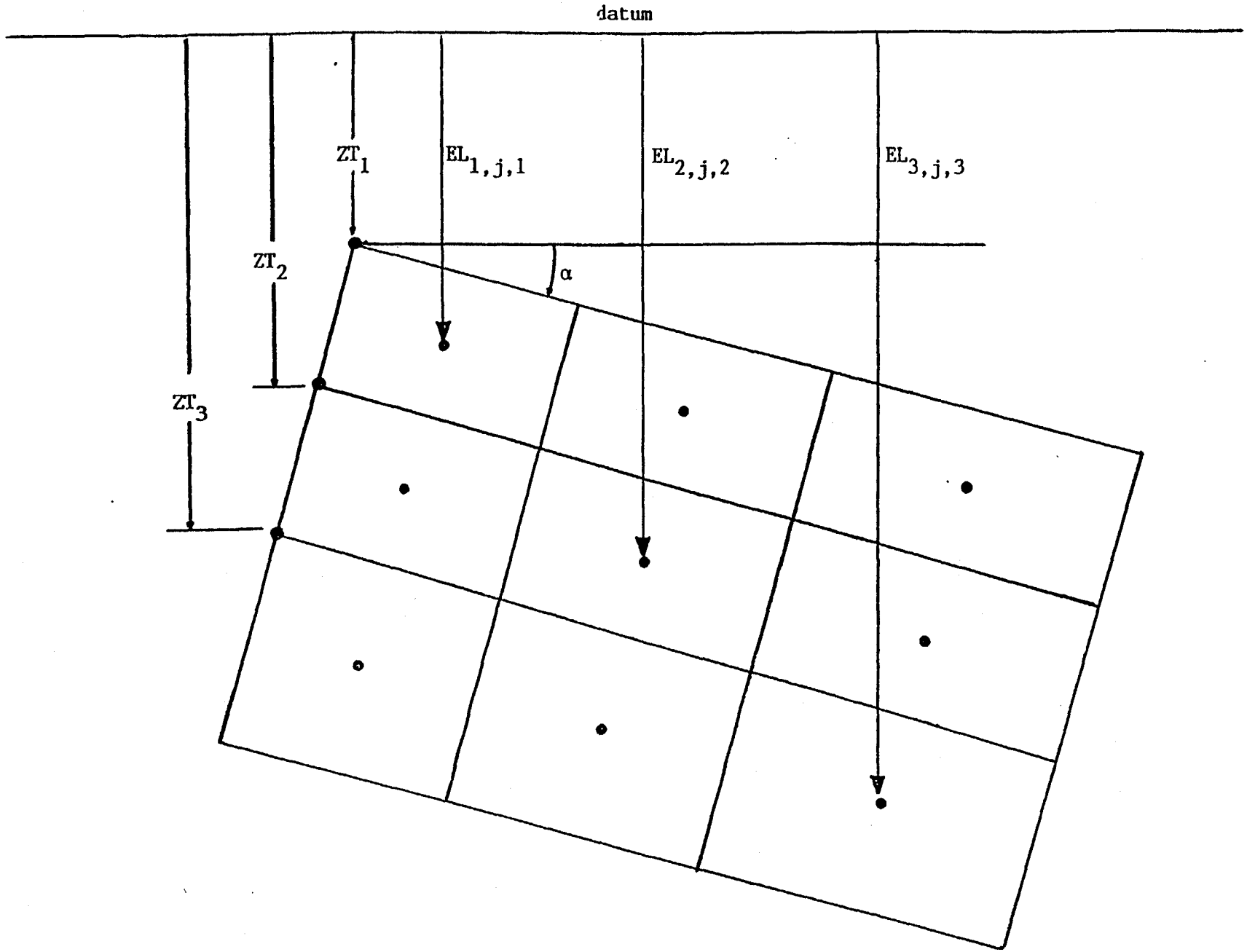


Figure 1 – Illustration of dipping reservoir: α positive means downward dip in positive x-direction; α negative means upward dip in positive x-direction

Midpoint locations (node locations in z-direction) are given by

$$EL(I,J,K) = Top(I,J,K) + 0.5 * DZ(I,J,K).$$

3.3.3 POROSITY AND PERMEABILITY DISTRIBUTIONS

Porosity and Permeability

1. Title card
2. Codes for type of input to be used

KPH = code for controlling porosity data input
KKX = code for controlling x-direction permeability data input
KKY = code for controlling y-direction permeability data input
KKZ = code for controlling z-direction permeability data input

Code	Meaning
-1	A single constant value is read and assigned to all blocks in the model grid (one value read).
0	A constant value is read for each of the KK layers in the grid; individual layers may have a different, but constant, value (KK values must be read).
+1	A separate value is read for each block in the grid (II x JJ x KK values must be read - see section 3.2. for array input format convention.)

3. Porosity value(s)

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

If KPH = -1, only one constant value is read
If KPH = 0, KK values are read (one for each layer)
If KPH = +1, (II x JJ x KK) values are read (one value for each block in the model grid)

4. x-direction (KX) permeability value(s)

   Permeability is read in millidarcies (md)

   If KKX = -1, only one constant value is read
   If KKX = 0, KK values are read (one for each layer)
   If KKX = +1, (II x JJ x KK) values are read (one value for each block in the model grid)

5. y-direction (KY) permeability value(s)

   Permeability is read in millidarcies (md)

   If KKY = -1, only one constant value is read
   If KKY = 0, KK values are read (one for each layer)
   If KKY = +1, (II x JJ x KK) values are read (one value for each block in the model grid)

6. z-direction (KZ) permeability value(s)

   Permeability is read in millidarcies (md)

   If KKZ = -1, only one constant value is read
   If KKZ = 0, KK values are read (one for each layer)
   If KKZ = +1, (II x JJ x KK) values are read (one value for each block in the model grid)

Modifications to Porosity and Permeability Distributions

1. Title card

2. Number of regions where porosity and/or permeability values are to be changed, and print code

   NUMP = number of regions where porosity values are to be changed

NUMKX = number of regions where x-direction permeability values (KX) are to be changed

NUMKY = number of regions where y-direction permeability values (KY) are to be changed

NUMKZ = number of regions where z-direction permeability values (KZ) are to be changed

KPHIMP = Porosity write code
KXMP = x-direction permeability write code
KYMP = y-direction permeability write code
KZMP = z-direction permeability write code

If code = 0, do not write map.
If code = 1, write input map to ___.OUT and ___.MAP files.

NOTE: See section 3.2, item 7 for modification input algorithm.

3. Porosity modifications.

Omit this card if NUMP = 0

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
PHI = new value of porosity for region, fraction

NOTE: NUMP cards must be read.

4. x-direction permeability (KX) modifications.

Omit this card if NUMKX = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
KX = new value of x-direction permeability (KX) for region in md

NOTE: NUMKX cards must be read.

5. y-direction permeability (KY) modifications.

Omit this card if NUMKY = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
KY = new value of y-direction permeability (KY) for region in md

NOTE: NUMKY cards must be read.

6. z-direction permeability (KZ) modifications.

Omit this card NUMKZ = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
KZ = new value of z-direction permeability (KZ) for region in md

NOTE: NUMKZ cards must be read.

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) refers to flow across the boundary between blocks I-1 and I,

TY(I,J,K) refers to flow across the boundary between blocks J-1 and J, and

TZ(I,J,K) refers to flow across the boundary between blocks K-1 and K.

1. Title card

2. Number of grid blocks where transmissibilities are to be changed, and print code

   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:

   ITCODE = 0 means do <u>not</u> print the modified transmissibility distributions

ITCODE = 1 means print the modified transmissibility distributions

3. x-direction transmissibility (TX) modifications.

Omit this card if NUMTX = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
TX = new value of x-direction transmissibility (TX) for region

NOTE: NUMTX cards must be read.

4. y-direction transmissibility (TY) modifications.

Omit this card if NUMTY = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
TY = new value of y-direction transmissibility (TY) for region

NOTE: NUMTY cards must be read.

5. z-direction transmissibility (TZ) modifications.

Omit this card if NUMTZ = 0.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction K2 = coordinate of last region block in K-direction
TZ = new value of z-direction transmissibility (TZ) for region

Note: NUMTZ cards must be read.

3.3.4 ROCKS AND PVT REGIONS

1. Title card

2. Number of regions

NROCK = number of distinct rock regions (up to five allowed). A separate set of saturation dependent data must be entered for each rock region.
NPVT = number of distinct PVT regions (up to five allowed). A separate set of pressure dependent data must be entered for each PVT region.

NOTE: All grid blocks are assigned to rock region 1 and PVT region 1 unless specified otherwise.

3. Title card

Omit this card if NROCK = 1.

4. Number of regions where the rock region value is changed.

Omit this card if NROCK = 1.

NUMROK = number of regions where the rock region default value of is changed.

5. Rock region specifications.

Omit this card if NROCK = 1.

If NUMROK = 0:

read II x JJ x KK rock region values -one value for each block in the model grid. See section 3.2 for array input format convention.
If NUMROK > 0:

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
IVAL = number of the saturation-dependent data set to be assigned to this rock region. IVAL must be less than or equal to NROCK..

NOTE: NUMROK cards must be read.

6. Title card

Omit this card if NPVT = 1.

7. Number of regions where the PVT region value is changed.

Omit this card if NPVT = 1.

NUMPVT = number of regions where the PVT region default value of 1 is changed.

8. PVT region specifications.

Omit this card if NPVT = 1.

If NUMPVT = 0:

Read II x JJ x KK PVT region values -- one value for each block in the model grid. See section 3.2 for array input format convention.

If NUMPVT > 0:

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
IVAL = number of the pressure dependent PVT data set to be assigned to this PVT region. IVAL must be less than or equal to NPVT.

NOTE: NUMPVT cards must be read.

3.3.5 RELATIVE PERMEABILITY AND CAPILLARY PRESSURE TABLES

The following saturation dependent data should be entered a total of NROCK times -- one set of data for each defined rock region.

1. Title card

2. Read relative permeability and capillary pressure tables

SAT1	KROW1	KRW1	KRG1	KROG1	PCOW1	PCGO1
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
SATn	KROWn	KRWn	KRGn	KROGn	PCOWn	PCGOn

SAT = value of phase saturation. NOTE: SAT1 must be 0.0 and SATn must be 1.0. Read each saturation as a fraction, in ascending order.

KROW = oil phase relative permeability, fraction
KRW = water phase relative permeability, fraction
KRG = gas phase relative permeability, fraction
KROG = oil phase relative permeability for gas-oil system, fraction
PCOW = oil/water capillary pressure, psi
PCGO = gas/oil capillary pressure, psi

SAT refers to the saturation of each particular phase, e.g. in a data line following SAT = 0.20: KROW would refer to oil relative permeability in presence of 20 percent oil saturation, KRW would refer to water relative permeability in the presence of 20 percent water saturation, KRG would refer to gas relative permeability in the presence of 20 percent gas saturation, KROG would refer to oil relative permeability in the presence of 20 percent total liquid (irreducible water plus oil) saturation, PCOW would refer to the oil/water capillary pressure in the presence of 20 percent water saturation, and PCGO would refer to the gas/oil capillary pressure in the presence of 20 percent gas saturation.

NOTE: KROG is used only when a three-phase oil relative permeability is calculated (Card 4 below). When ITHREE = 1, KROW and KRW represent a water-oil system while KROG and KRG represent a gas-oil system. See reference 2 for more information.

3. Title card

4. Three-phase relative permeability option code

ITHREE = code specifying desired relative permeability option

Code	Meaning
ITHREE = 0	Do not make three-phase calculation of oil relative permeability.
ITHREE = 1	Make three-phase calculation of oil relative permeability.

SWR = irreducible water saturation, fraction

3.3.6 FLUID PVT DATA TABLES

The following pressure dependent data should be entered a total of NPVT times -- one set of data for each defined PVT region.

1. Title card

2. Bubble point data

   PBO = initial oil bubble point pressure, psia
   PBODAT = depth at which PBO applies, ft
   PBGRAD = constant bubble point pressure gradient, psia/ft

   The bubble point pressure at grid block I, J, K is computed as

   PBOT(I,J,K) = PBO + (PBODAT - EL(I,J,K))*PBGRAD

   where the mid-point elevation EL(I,J,K) is defined in section 3.3.2.

3. Title card

4. Undersaturated oil properties, maximum PVT table pressure, and bubble point tracking algorithm.

   VSLOPE = slope of the oil viscosity (μ_o) versus pressure curve for undersaturated oil (i.e., for pressures above PBO). This value is $\Delta\mu_o/\Delta P$ in cp/psi.

   BSLOPE = slope of the oil formation volume factor (B_o) versus pressure curve for undersaturated oil (pressure above PBO). This value is $\Delta B_o/\Delta P$ in RB/STB·psi. (NOTE: BSLOPE should be a negative number and is <u>not</u> the same as the undersaturated oil compressibility!)

   RSLOPE = slope of the solution gas-oil ratio versus pressure curve for undersaturated oil (pressure above PBO). This value is ΔRSO/ΔP in SCF/STB psi. (It will normally be zero.)

   PMAX = maximum pressure entry in all PVT tables, psia

IREPRS = 0; repressurization algorithm on 1; repressurization algorithm off

NOTE: Inaccuracies in the calculated reservoir pressure distributions may result when using this repressurization algorithm (IREPRS = 0).

5. Title card

6. Oil PVT table

P1	MUO @ P1	BO @ P1	RSO @ P1
P2	MUO @ P2	BO @ P2	RSO @ P2
.	.	.	.
.	.	.	.
.	.	.	.
PMAX	MUO @ PMAX	BO @ PMAX	RSO @ PMAX

P = pressure, psia (NOTE: Pressures must be in ascending order from P1 (normally 14.7 psia) to PMAX. The last entry in the table must be PMAX as specified in the preceding read.)

MUO = saturated oil viscosity, cp

BO = saturated oil formation volume factor, RB/STB

RSO = saturated oil solution gas/oil ratio, SCF/STB

VERY IMPORTANT! The oil properties must be entered as saturated oil 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 routine used by BOAST II. Note that 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 there is free gas introduced into the region (an example of this would be pressure maintenance by gas injection into the oil zone).

7. Title card

8. Water PVT table

P1	MUW @ P1	BW @ P1	RSW @ P1
P2	MUW @ P2	BW @ P2	RSW @ P2
.	.	.	.
.	.	.	.
PMAX	MUW @ PMAX	BW @ PMAX	RSW @ PMAX

P = pressure, psia (NOTE: Pressures must be in ascending order from P1 (normally 14.7 psia) to PMAX. The last entry in the table must be PMAX as specified in the preceding read.)
MUW = water viscosity, cp
BW = water formation volume factor, RB/STB
RSW = water solution gas/water ratio, SCF/STB

Commonly, the assumption is made in black oil simulations that the solubility of gas in the water can be neglected. In this case, set RSW = 0.0 for all pressures. BOAST II incorporates this water PVT table to handle such situations as gas production from geopressured aquifers and for any case where gas solubility in water is considered to be of significance to the solution of the problem.

9. Title card

10. Gas properties code

KGCOR = 0 Read gas and rock properties table
1 Activate gas correlation option
read rock compressibility versus pressure table.

11. Title card

12. Gas PVT table and rock compressibility
    Omit this card if KGCOR = 1.

P1	MUG @ P1	BG @ P1	PSI @ P1	CR @ P1
P2	MUG @ P2	BG @ P2	PSI @ P2	CR @ P2
.	.	.	.	.
.	.	.	.	.
PMAX	MUG @ PMAX	BG @ PMAX	PSI @ PMAX	CR @ PMAX

    P = pressure, psia (NOTE: Pressures must be in ascending order from P1 (normally 14.7 psia) to PMAX. The last entry in the table (must be PMAX as specified in the preceding read.)
    MUG = gas viscosity, cp
    BG = gas formation volume factor, RCF/SCF
    PSI = gas pseudo-pressure, $psia^2/cp$
    CR = pressure dependent rock compressibility, psi^{-1}

13. Gas PVT correlation parameters
    Omit this card if KGCOR = 0.

    KODEA = gas composition option
    MPGT = number of gas PVT table entries; must be greater than 1 and less than or equal to 25
    TEM = reservoir temperature, °F
    SPG = gas specific gravity (air = 1.0)

14. Gas composition
    Omit this card if KGCOR = 0.

    FRCI (1) = H_2S mole fraction
    FRCI (2) = CO_2 mole fraction
    FRCI (3) = N_2 mole fraction
    FRCI (4) = C_1 mole fraction
    FRCI (5) = C_2 mole fraction
    FRCI (6) = C_3 mole fraction
    FRCI (7) = iC_4 mole fraction

FRCI (8) = nC_4 mole fraction

FRCI (9) = iC_5 mole fraction

FRCI (10) = nC_5 mole fraction

FRCI (11) = C_6 mole fraction

FRCI (12) = C_{7+} mole fraction

NOTE: Twelve entries must be read.

15. User specified C_{7+} properties
Omit this card if KGCOR =0 or if KODEA ≠ 4.

PRSCI = Critical pressure, psia

TEMCI = Critical temperature, ^{o}R

RMWTI = Molecular weight

16. Title card Omit this card if KGCOR = 0.

17. Rock compressibility Omit this card if KGCOR = 0.

- To specify a constant rock compressibility, input the following values

PMAX = maximum table pressure from Card 4, psia

CR = rock compressibility at PMAX, 1/psia

- To specify a pressure-dependent rock compressibility, read MPGT entries as follows:

P1	CR @ P1
P2	CR @ P2
.	.
.	.
PMAX	CR @ PMAX

18. Title card

19. Stock tank fluid densities

RHOSCO = stock tank oil density, lb/cu ft
RHOSCW = stock tank water density, lb/cu ft
RHOSCG = stock tank gas density, lb/cu ft

Repeat Cards 1 through 19 NPVT times.

3.3.7 PRESSURE AND SATURATION INITIALIZATION

BOAST3 contains three options for pressure and saturation initialization as follows:

Pressure Initialization Options

Option 1 - KPI=0 ------- Pressure at fluid-fluid contacts (WOC and GOC) is used to calculate hydrostatic equilibrium

Option 2 - KPI=1 ------- Pressure is input for entire grid

Option 3 - KPI=2 ------- Pressure is specified by layer

Saturation Initialization Options

Option 1 - KSI=0 ------- Saturations (Soi, Swi and Sgi) are specified by grid region

Option 2 - KSI=1 ------- Soi and Swi are input for entire grid

Option 3 - KSI=2 ------- Saturations (Soi, Swi and Sgi) are specified by layer

1. Title card

2. Codes for controlling pressure and saturation initialization (KPI and KSI values are used as given above)

   KPI
   KSI
   PDATUM = depth of pressure datum, ft
   GRAD = fluid gradient for pressure corrections to PDATUM, psia/ft. If GRAD is greater than zero, a map of pressures corrected to PDATUM will be printed whenever a pressure map is printed.

3. Title Card

4. Pressure and saturation by rock region (NROCK cards must be read)
   NOTE: Title card No. 3 and these cards must be read. However, they will be used only if KPI=0 and/or KSI=0.

   NR = rock region number
   PWOC = pressure at water-oil contact, psia
   WOC = depth to water-oil contatc, ft
   PGOC = pressure at gas-oil contact, psia
   GOC = depth to gas-oil contact, psia
   SOREG = initial oil saturation for region
   SWREG = initial water saturation for region
   SGREG = initial gas saturation for region

5. Title card

6. Pressure and saturation by layer (KK cards must be read)
   NOTE: Title card No. 5 and these cards must be read. However, they will be used only if KPI=2 and/or KSI=2.

   L = layer number
   PI = initial pressure for layer L, psia
   SOI = initial oil saturation for layer L, fraction
   SWI = initial water saturation for layer L, fraction
   SGI = initial gas saturation for layer L, fraction

7. Title card

8. Initial pressures for entire grid
   NOTE: Title card No. 7 and these records are read only if KPI=1

9. Title card

10. Initial oil saturation for entire grid
    NOTE: Title card No. 9 and these records are read only if KSI=1

11. Title card

12. Initial water saturation for entire grid
    NOTE: Title card No. 11 and these records are read only if KSI=1

3.3.8 DEBUG AND DIAGNOSTICS CODES

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

1. Title card

2. Codes for controlling diagnostic output

   KSN1 - SOR parameter debug output control

   KSM1 - solution matrix debug output control

KCO1 = compressibility and volume factor debug output control

KCOF = density and saturation debug output

KSKIP = Screen output control - Every KSKIP step one line of output will be written to the screen giving oil, gas and water production.

KOUT = Code to control size of ___.OUT file. If the ___.OUT file becomes excessively large, set KOUT to zero. This will suppress printing of all maps after the first time-step. All specified maps will still be written to the ___.MAP binary file as determined by KSKIP and FTIO in Recurrent Data.

3.3.9 RUN CONTROL PARAMETERS

1. Title card

2. Run control parameters

NMAX = maximum number of time steps allowed before run is terminated. NMAX must be greater than or equal to 1.

FACT1 = factor for increasing time step size under automatic time step control (set FACT1 = 1.0 for fixed time step size). A common value for FACT1 is 1.25.

FACT2 = factor for decreasing time step size under automatic time step control (set FACT2 = 1.0 for fixed time step size). A common value for FACT2 is 0.5.

TMAX = maximum real time to be simulated during this run, days (run will be terminated when time exceeds TMAX). TMAX must be greater than 0.

WORMAX = limiting maximum water/oil ratio for a producing oil well. See reference 2, Appendix G for details. WORMAX must be greater than or equal to 0.0 (see Card 3 below).

GORMAX = limiting maximum gas/oil ratio, SCF/STB, for a producing oil well. See reference 2, Appendix G for details. GORMAX must be greater than or equal to 0.0 (see Card 4 below).

PAMIN = limiting minimum field average pressure, psia (run will be terminated when average reservoir pressures fall below PAMIN). PAMIN must be greater than 0.

PAMAX = limiting maximum field average pressure, psia (run will be terminated when average reservoir pressure exceeds PAMAX). PAMAX must be greater than PAMIN.

NOTE: Additional discussion of the automatic time step control method and parameters FACT1 and FACT2 is contained in Appendix H of reference 2.

3. Variable maximum WOR

If WORMAX ≠ 0.0, go to Card 4.

WOROCK = maximum WOR allowed in the corresponding rock region; NROCK values must be entered.

NOTE: If a well is completed in more than one rock region, the largest maximum WOR which applies to the rock regions penetrated by the well will be used as the WOR control of that well.

4. Variable Maximum GOR

If GORMAX ≠ 0.0, go to the next section.

GOROCK = Maximum GOR allowed in the corresponding rock region; NROCK values must be entered.

NOTE: If a well is completed in more than one rock region, the largest maximum GOR which applies to the rock regions penetrated by the well will be used as the GOR control of that well.

3.3.10 SOLUTION METHOD SPECIFICATIONS

1. Title card

2. Solution method control parameter

KSOL = solution method code

KSOL	Method	
1	Direct solution - band algorithm (use with one-dimensional problems)	
2	LSORX	line successive over-relaxation method with x-direction tridiagonal algorithm
3	LSORY	line successive over-relaxation method with y-direction tridiagonal algorithm
4	LSORZ	line successive over-relaxation method with z-direction tridiagonal algorithm

NOTE: Use of a line SOR method is recommended when two or three-dimensional problems are being solved. See reference 1 for further discussion.

The PC version of BOAST II differs from the original in that only four methods of solution are provided: a direct one-dimensional solution method and three iterative solution methods.

MITER = maximum number of SOR iterations per time step. A typical value for MITER is 100. MITER must be greater than or equal to 1.

OMEGA = initial SOR acceleration parameter. Initial values for OMEGA should be in the range $1.0 \leq \omega \geq 2.0$. A typical initial value for OMEGA would be 1.7 for TOL1 = 0, or 1.5 for TOL1 $\neq$ 0. The program will optimize OMEGA as the solution proceeds.

TOL = maximum acceptable pressure change for convergence of SOR

TOL1 = parameter for determining when to change OMEGA. A typical value for TOL1 would be 0.001. (NOTE: If TOL1 = zero, the initial value entered as OMEGA above will be used for the entire run.)

DSMAX = maximum saturation change permitted over a time step, fraction. The time step size will be reduced by FACT2 if the saturation change of any phase in any grid block exceeds DSMAX during a time step. A typical value for DSMAX would be 0.05. DSMAX must be greater than 0, but cannot exceed 1.0.

DPMAX = maximum pressure change permitted over a time step, psi. The time step size will be reduced by FACT2 if the pressure change in any grid block exceeds DPMAX during a time step. A typical value for DPMAX would be 100 psi. DPMAX must be greater than 0.

3. Title card

4. Numerical dispersion and formulation control parameters

NUMDIS = numerical dispersion control code

NUMDIS	Meaning
0	One-point upstream weighting (standard)
1	Two-point upstream weighting (see reference 5)

IRK = formulation control code

IRK	Meaning
0	IMPES (standard)
1	Stabilized IMPES

THRUIN = maximum throughput per grid block for the stabilized IMPES (IRK=1) formulation; $0 < \text{THRUIN} \leq 1.0$ with a recommended value between 0.5 and 1.0.

3.3.11 AQUIFER MODEL

1. Title card
2. Aquifer model option; see reference 2, Appendix E for details

IAQOPT = aquifer model code

Code	Meaning
IAQOPT = 0	No aquifer model activated 1Pot aquifer model selected
1	Pot aquifer model selected
2	Steady-state aquifer model selected
3	Carter-Tracy aquifer model selected; r_e/r_w = 1.5
4	Carter-Tracy aquifer model selected; r_e/r_w = 2.0
5	Carter-Tracy aquifer model selected; r_e/r_w = 3.0
6	Carter-Tracy aquifer model selected; r_e/r_w = 4.0
7	Carter-Tracy aquifer model selected; r_e/r_w = 5.0
8	Carter-Tracy aquifer model selected; r_e/r_w = 6.0
9	Carter-Tracy aquifer model selected; r_e/r_w = 8.0
10	Carter-Tracy aquifer model selected; r_e/r_w = 10.0
11	Carter-Tracy aquifer model selected; r_e/r_w =

If IAQOPT = 0, go to the next section.
If IAQOPT = 1, go to Card 3.
If IAQOPT = 2, go to Card 5.
If IAQOPT 3;. go to Card 7.

NOTE: Only one aquifer model option (IAQOPT) may be selected for a given run. Different aquifer influx strengths may be specified for a given aquifer model.

3. NAQEN = number of regions containing a pot aquifer

4. POT aquifer parameters

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
POT = pot aquifer coefficient, SCF/psia

Repeat Card 4 a total of NAQEN times, then go to the next section.

5. NAQEN = number of regions containing a steady-state aquifer.

6. Steady-state aquifer parameters.

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction
SSAQ = steady-state aquifer coefficient, SCF/day psia

Repeat Card 6 a total of NAQEN times, then go to the next section.

7. NAQREG = number of distinct Carter-Tracy aquifer parameter regions.

8. Carter-Tracy aquifer parameters

AQCR = aquifer rock compressibility, 1/psia
AQCW = aquifer water compressibility, 1/psia
AQMUW = aquifer water viscosity, cp
AQK = aquifer permeability to water, md
AQPHI = aquifer porosity, fraction
AQH = aquifer net thickness, ft
AQS = aquifer/reservoir boundary interface, fraction ($0 \leq AQS \leq 1.0$)
AQRE = external aquifer radius, ft

9. NAQEN = number of regions containing a Carter-Tracy aquifer with the parameters given in Card 8.

10. Carter-Tracy aquifer region boundaries

I1 = coordinate of first region block in I-direction
I2 = coordinate of last region block in I-direction
J1 = coordinate of first region block in J-direction
J2 = coordinate of last region block in J-direction
K1 = coordinate of first region block in K-direction
K2 = coordinate of last region block in K-direction

Repeat Card 10 a total of NAQEN times.

Repeat Cards 8 through 10 a total of NAQREG times, then go to the next section.

3.3.12 WELL AND NODE DATA

1. Header

2. Header

3. Number of wells

   NWELLS ---- Total number of wells (must be same as total number of wells identified in first set of Recurrent Data)

4. Header

5. Well number, nodes/well and wellname

   NW ---------- Well number (must be numeric - 1 to 4 digits)
   NODES ------- Number of nodes or grid-blocks penetrated by well NW
   WELNAM ------ Well name (1 to 8 ASCII characters in single quotes)

   NOTE: Exactly NWELLS records must be read.

6. Header

7. Well, node and direction code

   NW ---------- Well number (same as in Item 4)
   I,J,K ------- Node or grid-block index (e.g. 10 5 2)
   DIR --------- Direction code: 1=vertical well
   2=horizontal x-direction well
   3=horizontal y-direction well
   4=vertical fracture in x-direction
   5=vertical fracture in y-direction
   6=horizontal fracture

   NOTES: (a) Repeat NW for each node of each well; exactly NODES records must be read for each well. Exactly NWELLS sets of records must be read, giving NWELLS x NODES total records.

   (b) DIR is only used by COLORGRID to determine the location and orientation of well and fracture symbols. The appropriate PI must be calculated and input (see RECURRENT DATA) for each type of well simulated.

   (c) THIS ENTIRE SECTION IS FOR USE BY COLORGRID AND B3PLOT. THE WELL LOCATION DATA HERE MUST BE CONSISTENT WITH THE WELL INFORMATION DATA IN SECTION 3.4.2.

3.4 RECURRENT DATA -- FORMAT AND DEFINITIONS

Recurrent data cards are read repeatedly during the course of the simulation run. These 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, time step control information for advancing the simulation through time, and controls on the type and frequency of printout information provided by the simulator. The examples on diskettes 3 and 4 show a variety of recurrent data sets.

1. Title card. This card is read only once to signify the start of the recurrent data section.

3.4.1 TIME STEP AND OUTPUT CONTROL

1. Title card

2. Time step and output method codes

   ICHANG = number of time steps for which the output control and time step control information will apply when IOMETH = 0; otherwise ignored.

   IOMETH = code to specify output method used.

   IWLCNG = code to tell program whether or not the well information cards should be read this time step.

Code	Meaning
IOMETH = 0	Output based on time step number
IOMETH $\geq$ 1	Output based on elapsed time; see Card 4 below.

Code	Meaning
IWLCNG = 0	Do not read well information this time step
IWLCNG = 1	Read well information this time step

NOTE: When the automatic time step control is on and IOMETH = 0, the sole function of ICHANG is to determine, in conjunction with DT (Card 6), the length of the time interval during which the present recurrent data set will apply. This duration is always given by ICHANG x DT. If IOMETH > 0, the last FTIO entry on Card 4 below will determine the time interval during which the present recurrent data set applies.

If IOMETH $\geq$ 1, go to Card 4; otherwise proceed to Card 3.

3. Frequency of output for well report and summary report.

IWLREP = number of time steps between output of well report.
ISUMRY = number of time steps between output of time step summary report.

Go to Card 5.

4. Elapsed times when output is to be printed: up to 50 values may be entered during this time interval.

FTIO = array containing total elapsed times. The number of elapsed times input must equal IOMETH.

NOTE: When the elapsed time of a run equals an FTIO value, the well and basic summary reports will be printed. Maps will also be printed according to the instructions given in Card 5.

5. Map control codes for grid-block output arrays
(0=off - do not print; 1=on - print)

IPMAP = output code to control printing of pressure

ISOMAP = output code to control printing of oil saturation

ISWMAP = output code to control printing of water saturation

ISGMAP = output code to control printing of gas saturation

IPBMAP = output code to control printing of bubble point

IAQMAP = output code to control printing of aquifer influx

KROMAP = output code to control printing of k_{ro}

KRWMAP = output code to control printing of k_{rw}

KRGMAP = output code to control printing of k_{rg}

RSOMAP = output code to control printing of R_{so}

PCOWMAP= output code to control printing of P_{cow}

PCGOMAP= output code to control printing of P_{cgo}

PHIMAP = output code to control printing of porosity

6. Time step control information

DT = Initial time-step size in days (may be reduced by automatic time-step control if saturation or pressure limits are exceeded)

NOTE: When IOMETH=0, the total time for which information on Records 2 through 6 will apply is (ICHANG x DT), days.

DTMIN = Minimum time-step size to be taken during this period, days.

DTMAX = Maximum time-step size to be taken during this period, days.

3.4.2 WELL INFORMATION (see page 52a)

NOTE: The cards below are read only if IWLCNG = 1 in the preceding section (Card 2).

1. Title card

2. Well changes

NWELLN = number of new wells for which complete well information is to be read.

NWELLO = number of previously defined wells for which new rates and/or rate controls are to be read.

3. Title card
If NWELLN = 0, omit this card.

4. Well characteristics and rates (A5,5I3) ← Formatted
If NWELLN = 0, omit this card.

WELLID = five character well name. Subsequent parameters on this card should begin after column five.

IDWELL = well identification number. Each well should have a unique IDWELL number. If two or more wells have the same IDWELL number, the characteristics of the last well entered will be used. The format is I3, so the last digit of the IDWELL number should be in column 8.

I = x-coordinate of grid block containing this well. It is also of the I3 format and should end in column 11.

J = y-coordinate of grid block containing this well. It is also of the I3 format and should end in column 14.

PERF1 = layer number of the uppermost completion layer for this well. Should end in column 17.

NLAYER = total number of consecutive completion layers beginning with and including PERF1. Should end in column 20.

NOTE

When using B3PLOT, it is recommended to include all wells as new wells in each Recurrent Dataset. Also, you must specify P_{wf} = 0.0 at all rate controlled wells in order for the calculated P_{wf} to be plotted.

EXAMPLE CARD #4 INPUT:

```
PROD  .1 10  1  1  4
```

5. Well flow index

   If NWELLN = 0, omit this card.

   PID = layer flow index for each layer for rates in STB/D. Read NLAYER entries.

   Layer flow index can be estimated as follows:

$$PID = \left[\ln \left(\frac{\frac{0.00708\ Kh}{0.121\ \sqrt{DX*DY}}}{r_w} \right) + S \right]$$

   where, K = layer absolute permeability, md
   h = layer thickness, ft
   DX = x-direction grid block dimension, ft
   DY = y-direction grid block dimension, ft
   r_w = wellbore radius, ft
   S = layer skin factor

   Further discussion of the layer flow index (PID) is provided in Appendix G of reference 2.

6. Flowing bottom-hole pressures,

   If NWELLN = 0, omit this card.

   PWF = flowing bottom-hole pressure (FBHP) for each layer, psia. Read NLAYER entries. This value is used only if KIP is negative for this well.

   Important! Once a well has been completed in a certain layer, that layer must continue to be specified on all succeeding well information cards, even if the layer or well is shut in! To shut in a layer, set that layer PID = 0. To shut in a well, set in all of its layer PID's to zero.

7. Rate control and rate information. (A5,2I3,4F10.0) ← Formatted
If NWELLN = 0, omit this card.

WELLID = five character well name (see Card 4).
IDWELI = well identification number (see Card 4).
KIP = code for specifying both well type and whether the well's production (injection) performance is determined by specifying rates or by specifying flowing bottomhole pressure. For more details, see Appendix G of Reference 2. This number should end in column 11.

NOTE: THE REMAINING NUMBERS IN THIS CARD ARE OF FORMAT F10.0 AND SHOULD BE INPUT ACCORDINGLY.

Rate Controlled Well (KIP > 0):
QO = oil rate, STB/D
QW = water rate, STB/D
QG = gas rate, MCF/D
QT = total fluid voidage rate, RB/D

NOTE: The total fluid rate given by QT is the oil plus water plus gas production for the well or the total reservoir voidage rate at reservoir conditions. For multilayer systems, QT is a target rate.

BHP Controlled Production Well With Optional Rate Constraints (KIP = -1):
QO = minimum oil production rate required, STB/D.
QW = maximum oil production rate allowed, STB/D.
QG = 0.0
QT = maximum liquid withdrawal rate allowed, STB/D.

NOTE: Rate constraints are not activated if the corresponding rate is set equal to zero.

BHP Controlled Water Injection Well With Optional Rate Constraint (KIP = -2):

QO = 0.0

QW = maximum water injection rate allowed, STB/D.

QG = 0.0

QT = 0.0

NOTE: QW should be a negative number or zero. The rate constraint is not activated if QW = 0.0.

BHP Controlled Gas Injection Well With Optional Rate Constraint (KIP = -3):

QO = 0.0

QW = 0.0

QG = maximum gas injection rate allowed, MCF/D.

QT = 0.0

NOTE: QG should be a negative number or zero. The rate constraint is not activated if QG = 0.0.

KIP $\leq$ -4:

QO = 0.0

QW = 0.0

QG = 0.0

QT = 0.0

EXAMPLE CARD #7 INPUT:

```
PROD   1  1       0.        0.        0.        0.
```

Code	Meaning
KIP = 3	Gas well - injection rate specified
KIP = 2	Water well - injection rate specified
KIP = 1	Production well - rates specified
	-- Oil Rate Specified: QO > 0 (STB/D)
	QW = QG = QT = 0.
	-- Water Rate Specified: QW > 0 (STB/D)
	QO = QG = QT = 0.

NOTE: KIP = 1 works for oil injection; specify QO < 0

-- Gas Rate Specified: QG > 0. (MCF/D)
QO = QW = QT = 0.
-- Total Rate Specified: QT > 0. (RB/D)
QO = QW = QG = 0.

KIP = -1 Oil and/or water production well - PI and FBHP control (explicit pressure calculation)

KIP = -2 Water well - PI and FBHP control (explicit pressure calculation)

KIP = -3 Gas injection well - PI and FBHP control (explicit pressure calculation)

KIP = -4 Gas production well - LIT representation (explicit pressure calculation)

KIP = -11 Production well - PI and FBHP control (implicit pressure calculation)

KIP = -12 Water well - PI and FBHP control (implicit pressure calculation)

KIP = -13 Gas well - PI and FBHP control (implicit pressure calculation)

The sign conventions used when reading rates are as follows:
Negative rates indicate fluid injection
Positive rates indicate fluid production

8. Pressure constrained gas production well (A5,I3,2E12.5)
If NWELLN = 0 or KIP ≠ -4, omit this card.
WELLID = five character well name (see Card 4).
IDWELL = well identification number (see Card 4).
ALIT = "a" coefficient of LIT gas well analysis. MMSCF/D
Must be in an E12.5 format. $psia^2/cp$
BLIT = "b" coefficient of LIT gas well analysis, $(MMSCF/D)^2$
Must be in an E12.5 format. $psia^2/cp$

The parameters required for describing a gas production well are described in Appendix G of Reference 1. Values of ALIT and BLIT can be obtained from the program GASDEL. GASDEL is available through K&A Energy Consultants, Inc.

Cards 4 through 8 should be repeated a total of NWELLN times.

9. Title card

If NWELLO = 0, omit this card.

10. Rate control and rate information. (A5,2I3,4F10.0)

If NWELLO = 0, omit this card.

WELLID = five character well name. Subsequent parameters on this card should begin after column 5.

IDWELL = well identification number (see Card 3). Should end in column 8.

KIP = code for specifying both well type and whether the well's production (injection) performance is determined by specifying rates or by specifying flowing bottomhole pressure. For more details see Card 6 and Appendix G of Reference 1. Should end in column 11.

NOTE: THE REMAINING NUMBERS IN THIS CARD ARE OF FORMAT F10.0 AND SHOULD BE INPUT ACCORDINGLY.

Rate Controlled Well (KIP > 0):

QO = oil rate, STB/D.

QW = water rate, STB/D.

QG = gas rate, MCF/D.

QT = total fluid voidage rate, RB/D.

NOTE: The total fluid rate given by QT is the oil plus water plus gas production for the well or the total reservoir voidage rate at reservoir conditions. For multilayer systems, QT is a target rate.

BHP Controlled Production Well With Optional Rate Constraints (KIP = -1):

QO = minimum oil production rate required, STB/D.

QW = maximum oil production rate allowed, STB/D.

QG = 0.0

QT = maximum liquid withdrawal rate allowed, STB/D.

NOTE: Rate constraints are not activated if the corresponding rate is set equal to zero.

BHP Controlled Water Injection Well With Optional Rate Constraint (KIP = -2):

QO = 0.0

QW = maximum water injection rate allowed, STB/D.

QG = 0.0

QT = 0.0

NOTE: QW should be a negative number or zero. The rate constraint is not activated if QW = 0.0.

BHP Controlled Gas Injection Well With Optional Rate Constraint (KIP = -3):

QO = 0.0

QW = 0.0

QG = maximum gas injection rate allowed, MCF/D.

QT = 0.0

NOTE: QG should be a negative number or zero. The rate constraint is not activated if QG = 0.0.

KIP $\leq$ -4:

QO = 0.0

QW = 0.0

QG = 0.0

QT = 0.0

11. Pressure constrained gas production well (A5,I3,2E12.5)

<u>If NWELLO = 0 or KIP $\neq$ -4, omit this card</u>.

WELLID = five character well name (see Card 4)

IDWELL = well identification number (see Card 4) Should end on column 8.

ALIT = "a" coefficient of LIT gas well analysis, $\frac{\text{MMSCF/D}}{\text{psia}^2/\text{cp}}$
Should be of format E12.5

BLIT = "b" coefficient of LIT gas well analysis, $\frac{(\text{MMSCF/D})^2}{\text{psia}^2/\text{cp}}$
Should be of format E12.5

The parameters required for describing a gas production well are described in Appendix G of Reference 1. Values of ALIT and BLIT can be obtained from the program GASDEL. GASDEL is available through K&A Energy Consultants, Inc.

POST PROCESSORS

Two post processors are provided to assist in processing output data from the BOAST3 simulator. B3PLOT is a line graphics package used to plot production, pressure, saturation and other data vs time. It has two basic modes: (1) plotting simulated data and (2) history matching. In mode (1), results from five different simulation runs may be compared. In mode (2), historical data may be history matched using oil, water, or gas production, GOR, or WOR. Also, average reservoir pressure or bottomhole well pressure may be matched.

COLORGRID is used to view the finite-difference grid on the screen in plan or elevation view. The grid is colored based on the range of the parameter selected. Various arrays (maps) of input or output data may be represented by a 12-band color legend. An annotation option is provided which displays the numerical values of the parameter selected within each grid-block. Any portion of the grid may be expanded to fill the entire screen.

Detailed information on the use of B3PLOT and COLORGRID are given below.

B3PLOT

B3PLOT is used for preparing time plots of oil, gas or water production (by field, well or well-block), bottomhole well pressure, or average reservoir pressure. It may also be used to plot oil, gas or water saturation at each well-block. B3PLOT may be used for plotting only simulated data or for history matching. The .GWN and .BPD simulator output files are used as input. The .BPD (binary production data) file is unformatted to conserve disk space.

To run B3PLOT, type "B3PLOT SIM" to plot simulated data or "B3PLOT HIS" to plot historical data. In either case you will be prompted for a simulator file name. After specifying a simulator file name, follow directions per the menus presented. Default answers to yes/no questions are no and may be selected by the enter key. For most problems it is convenient to select a 30 or 60 day time interval.

The data you select for plotting will be saved in an ASCII file for viewing or subsequent analysis. When plotting simulated data, the ASCII file name is SIMPLT.ASC. When history matching, the ASCII file name is HISPLT.ASC.

When using the "HIS" option, one or more historical data files must be present. Each historical file must have the extension ".HIS". File naming conventions are as follows:

Total field data file:	FIELD.HIS
Total well data files:	wellname.HIS
Well-block data files:	nodename.HIS

Here 'wellname' is WNAME from the simulator input file and 'nodename' is a seven character name which identifies a particular well-block. For example, if a well is completed in block (7,6,2), nodename would be N070602 (the complete file name would be N070602.HIS).

The format of each historical data file consists of four header records followed by columns of numerical data as illustrated in Exhibit 1. For well files, pressure should be the arithmetic average of the bottomhole pressure at all producing horizons. For well-block files, pressure should be the bottomhole pressure corresponding to the simulator grid-block elevation. In the FIELD.HIS file, pressure should be a pore volume weighted average over the entire field.

Data is read in free format from historical files. Thus, all data must be present. As in Exhibit 1, simple enter zero for data that you do not wish to plot.

The "SIM" option allows for plotting data from multiple simulation runs. Up to five different runs are permitted, which is ideal for sensitivity studies.

Appendix A gives sample output from B3PLOT for both the "SIM" and "HIS" options.

EXHIBIT 1

SAMPLE HISTORICAL DATA FILE

BOAST3: History Match Plot Using B3PLOT (FIELD.HIS)

Time days	Gas Mcfd	Water stbd	Oil stbd	Gas MMcf	Water Mstb	Oil Mstb	GOR Mcf/stb	WOR	Pressure psia
365	25000	0	20000	0	0	0	1.27	0.0	5800
730	25000	0	20000	0	0	0	1.27	0.0	6650
1095	160000	0	20000	0	0	0	8.20	0.0	6450
1460	150000	0	14309	0	0	0	10.2	0.0	5400
1825	133441	0	12000	0	0	0	10.5	0.0	4700
2190	127000	0	10000	0	0	0	12.2	0.0	4400
2555	119000	0	8900	0	0	0	13.3	0.0	4150
2920	122000	0	7600	0	0	0	16.0	0.0	3900
3285	123000	0	6600	0	0	0	18.5	0.0	3800
3650	126000	0	5800	0	0	0	21.4	0.0	3700

COLORGRID

The .CGD and .MAP simulator output files are used as input to the ColorGrid package. The .MAP file is in binary form to conserve disk space.

Using a VGA monitor, various input and output arrays may be displayed by color legend and numerically on plan or elevation views of the finite-difference grid.

Input data that may be mapped include grid dimensions, elevations, thickness, porosity and permeability. Any of the arrays for which the output control code is nonzero (see Recurrent Data) may be mapped over time using COLORGRID. At each interrupt time (FTIO) each specified output array is written to the .MAP file.

To run ColorGrid type "COLOR xxxx", where "xxxx" is the name of a simulator file you wish to process. ColorGrid is very easy to use and is fully menu driven.

ColorGrid is written in Turbo Pascal and is a general purpose package that may easily be used with any finite-difference simulator.

REFERENCES

1. Franchi, J. R., Harpole, K. J., and Bujnowski, S. W.: BOAST: A Three-Dimensional, Three-Phase Black Oil Applied Simulation Tool, U.S. Department of Energy Report DOE/BC/1033-3, two volumes, 1982.

2. Franchi, J. R., Kennedy, J. E., and Dauben, D. L.: BOAST II: A Three Dimensional,Three-Phase Black Oil Applied Simulation Tool, U.S. Department of Energy Report DOE/BC-88/2/SP, 1987.

3. Odeh, A. S.: "Comparison of Solutions to a Three-Dimensional Black-Oil Reservoir Simulation Problem, paper SPE 9723, Journal of Petroleum Technology, January, 1981, pp. 13-25.

APPENDIX A

SAMPLE OUTPUT FROM B3PLOT

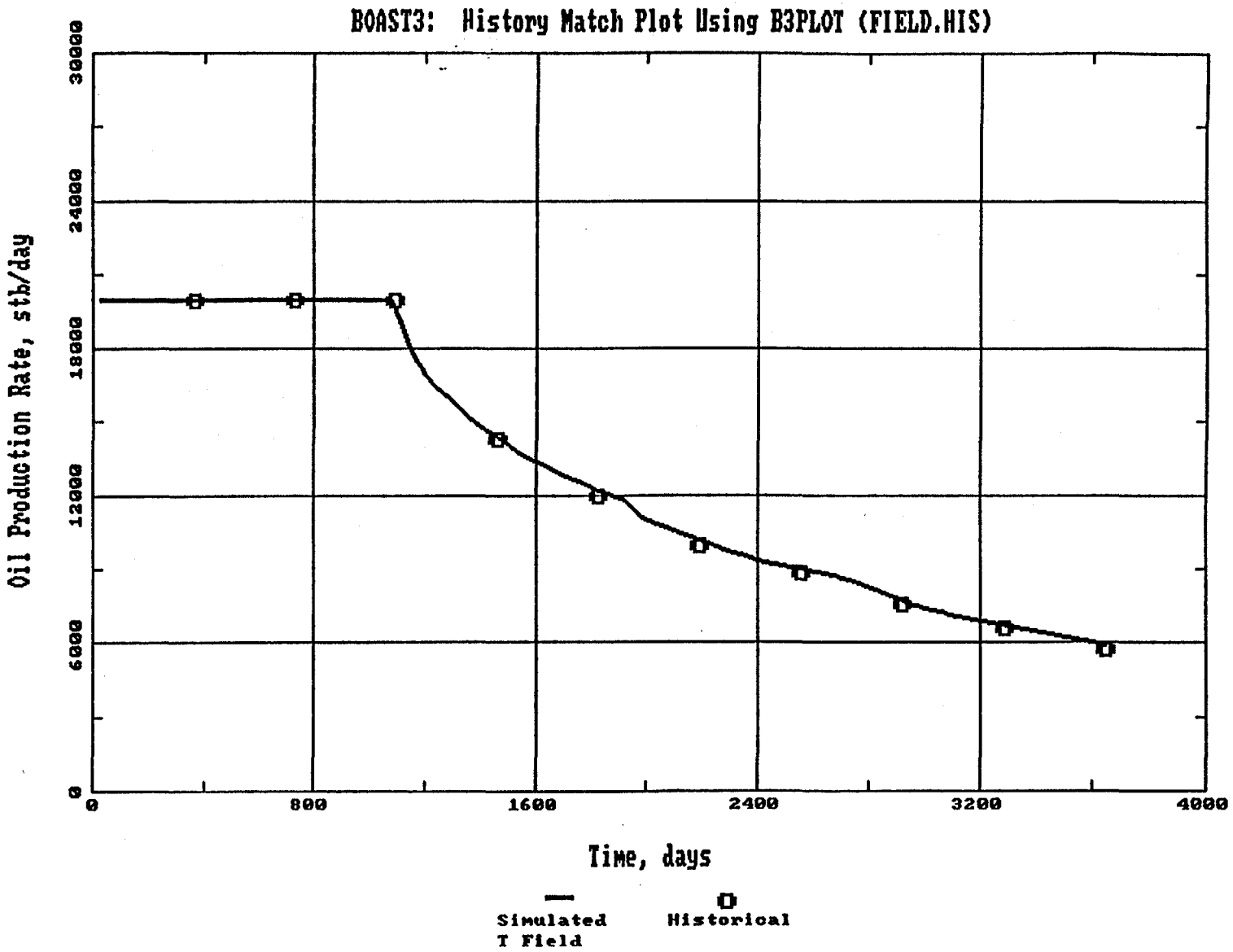


Figure A-1 - Oil Production Rate vs Time - Total Field

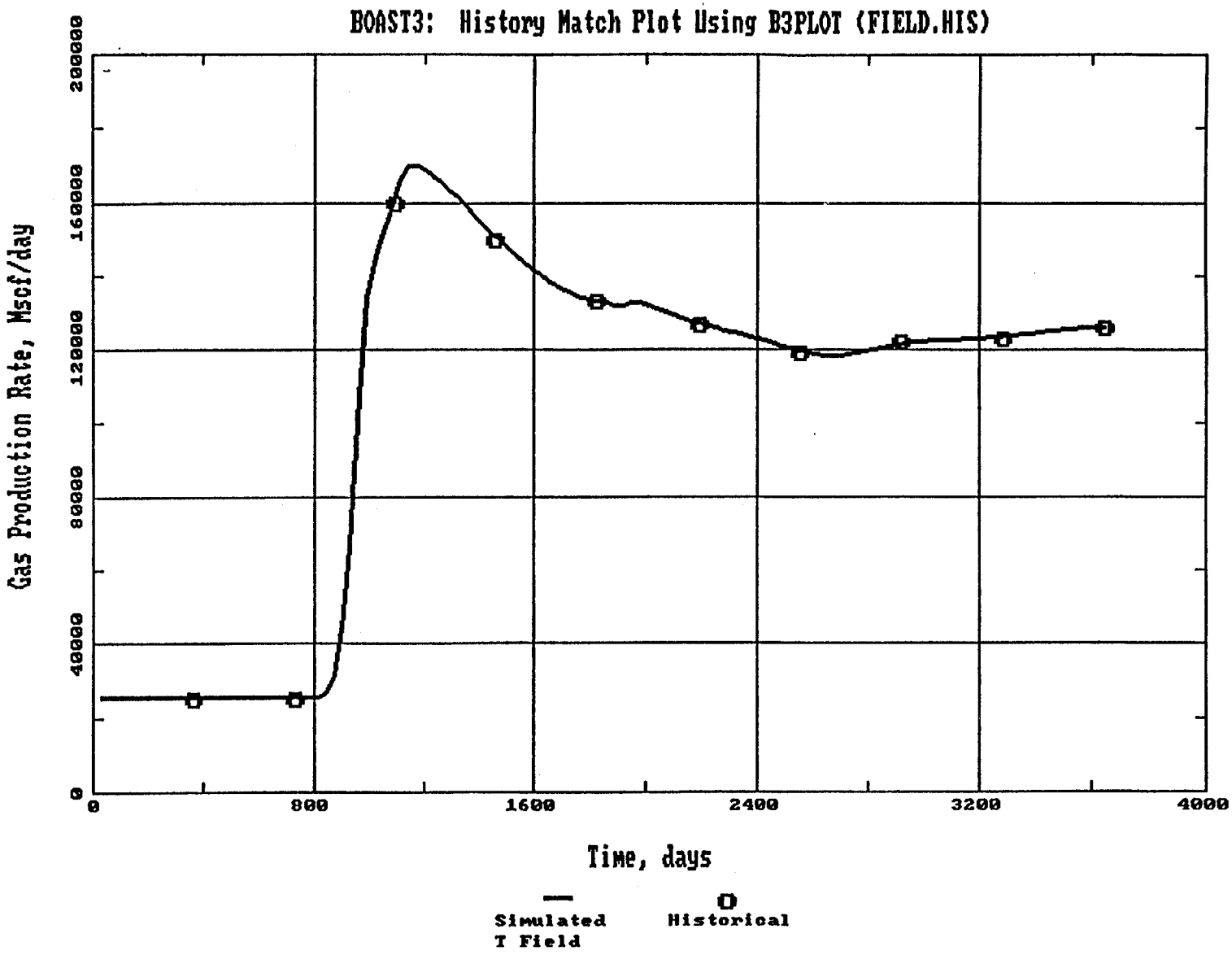


Figure A-2 - Gas Production Rate vs Time - Total.Field

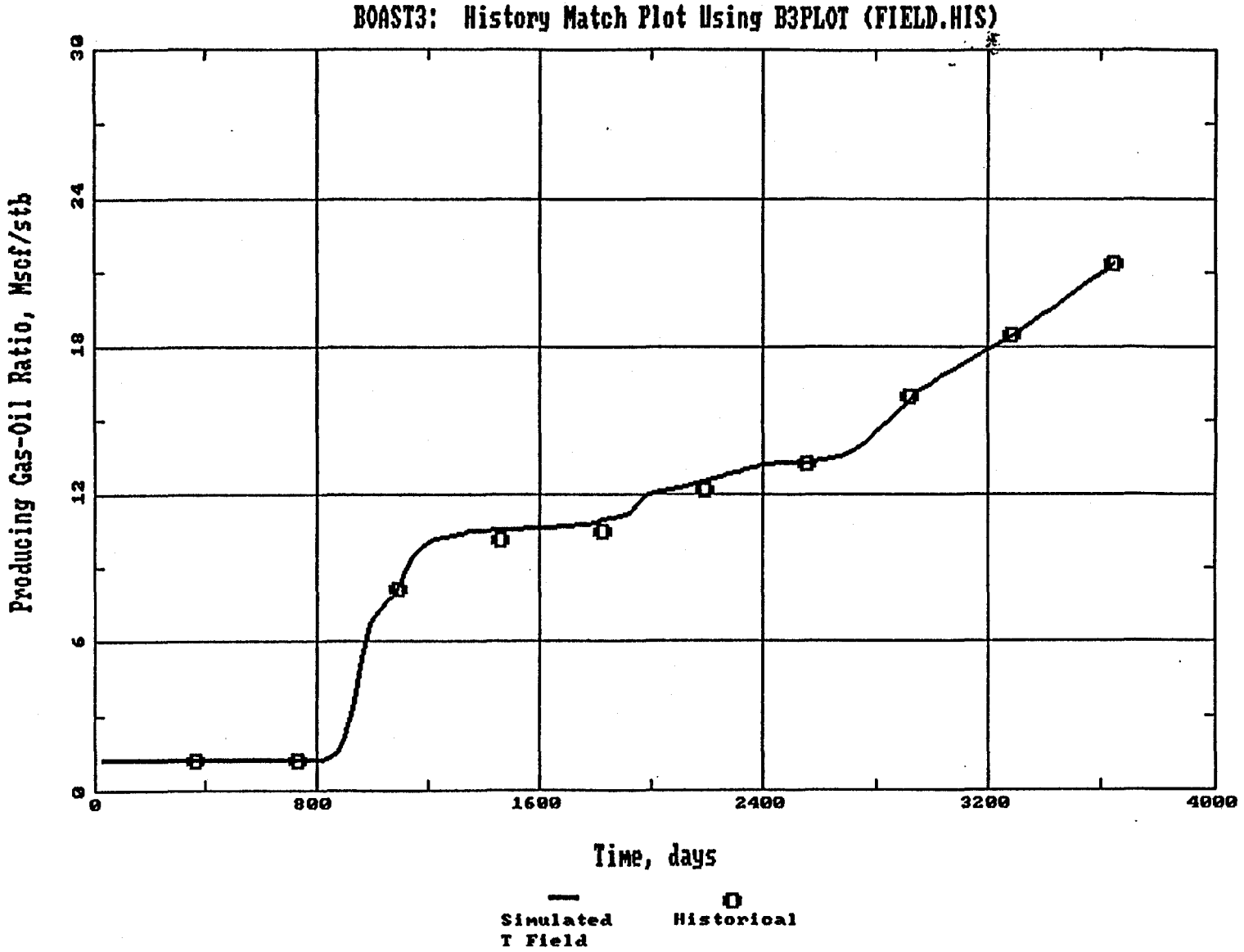


Figure A-3 - Producing GOR vs Time - Total Field

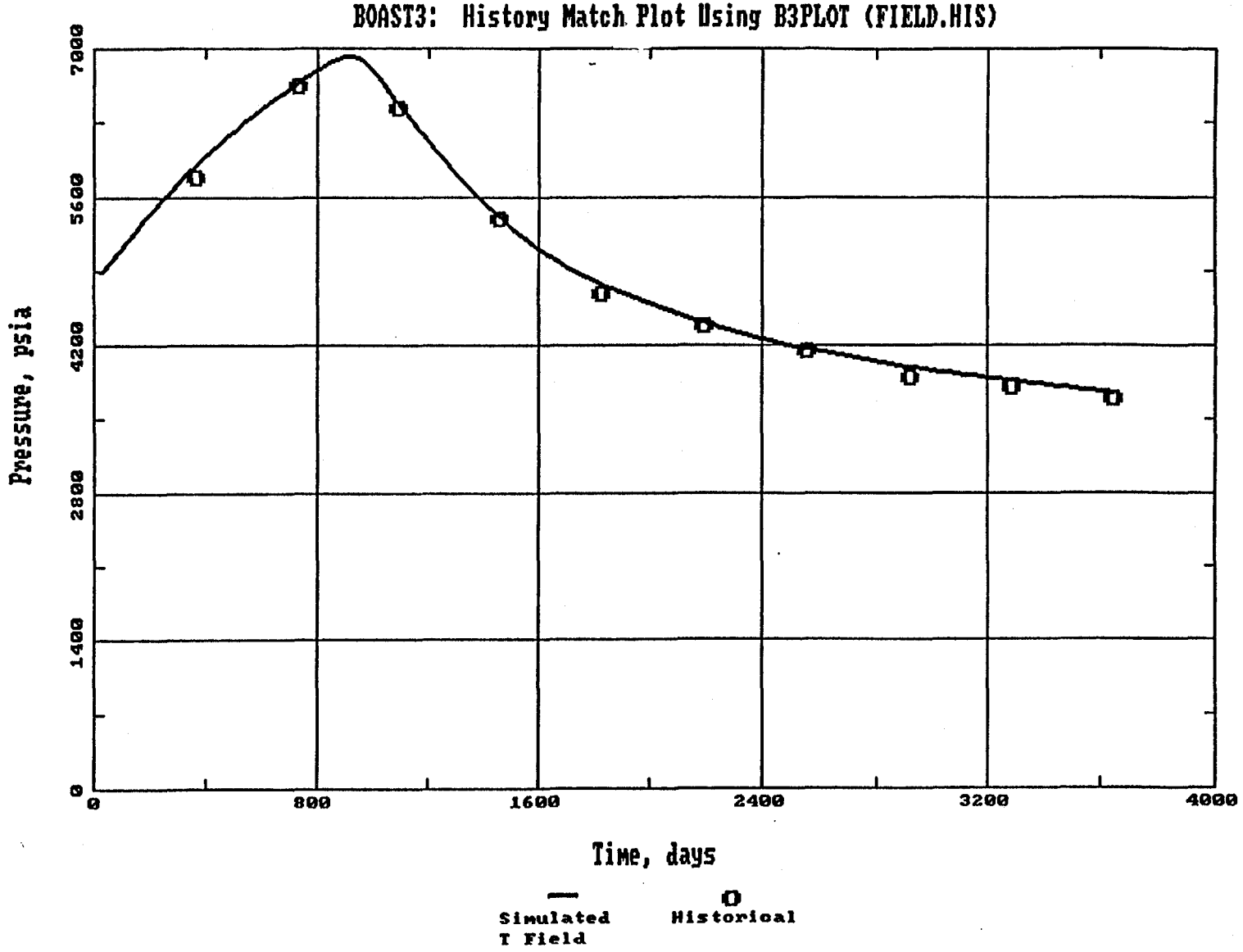


Figure A-4 - Average Pressure vs Time - Total Field

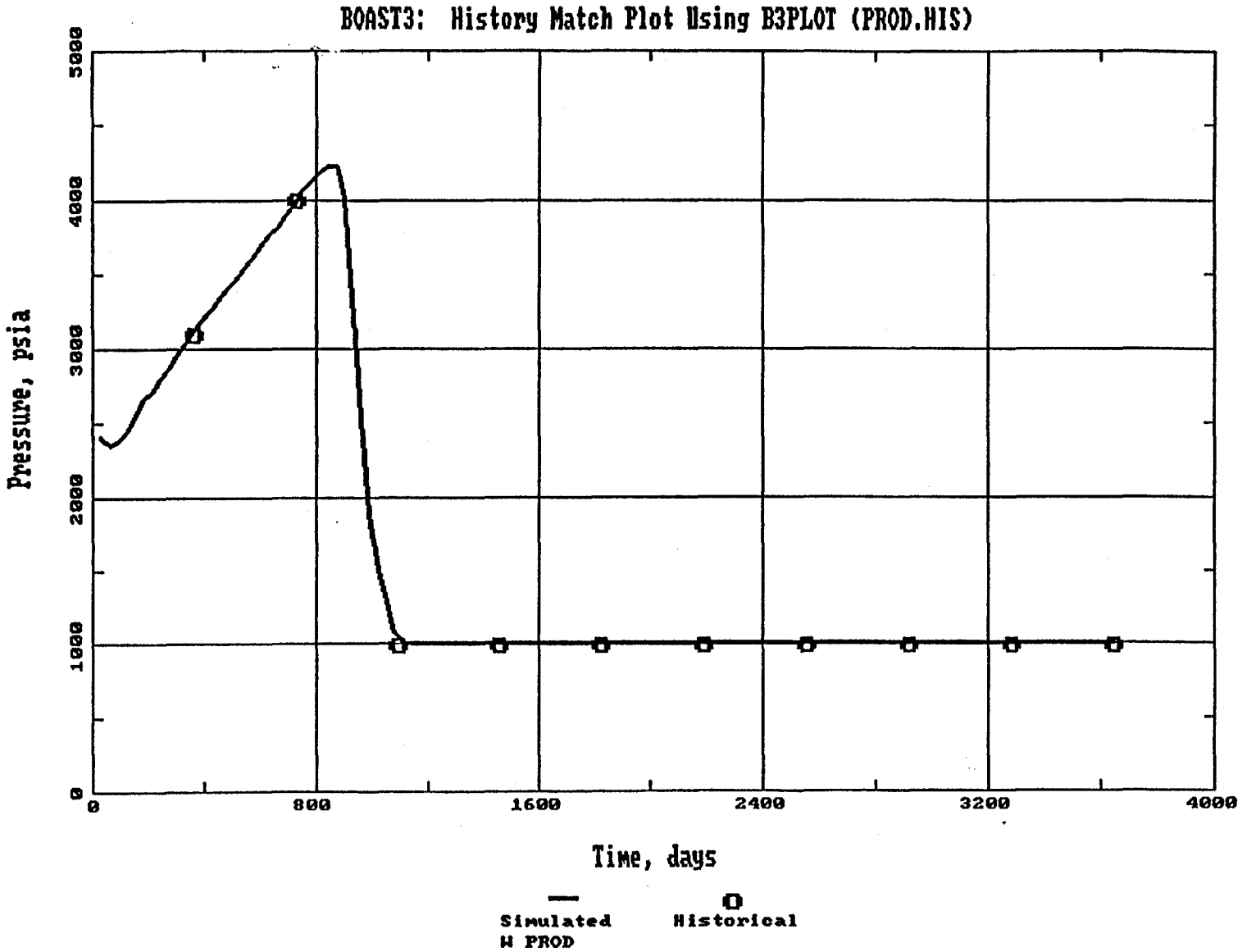


Figure A-5 - Well Pressure vs Time - Average BHP

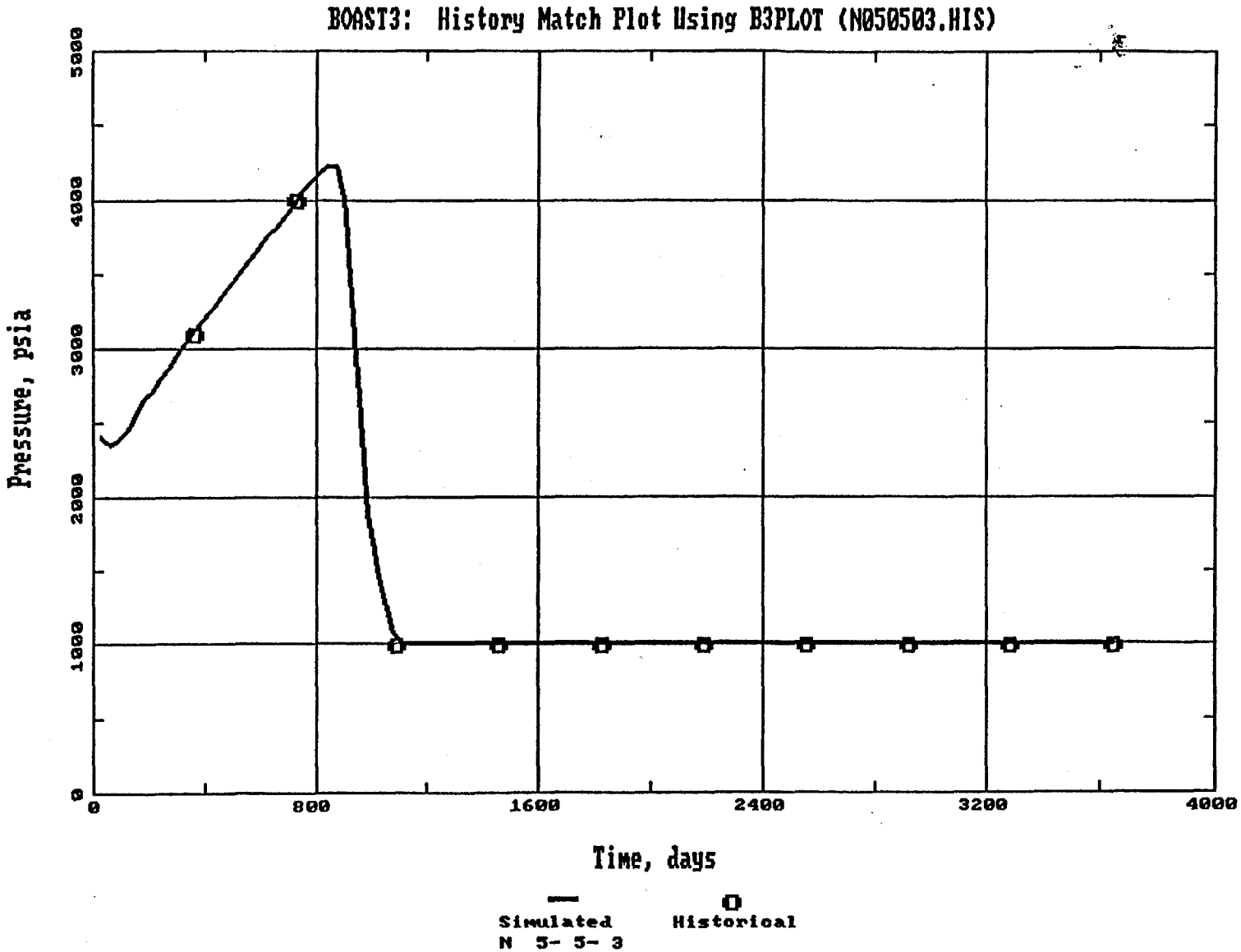


Figure A-6 - Bottomhole Pressure at Producing Well-Block (5,5,3) vs Time

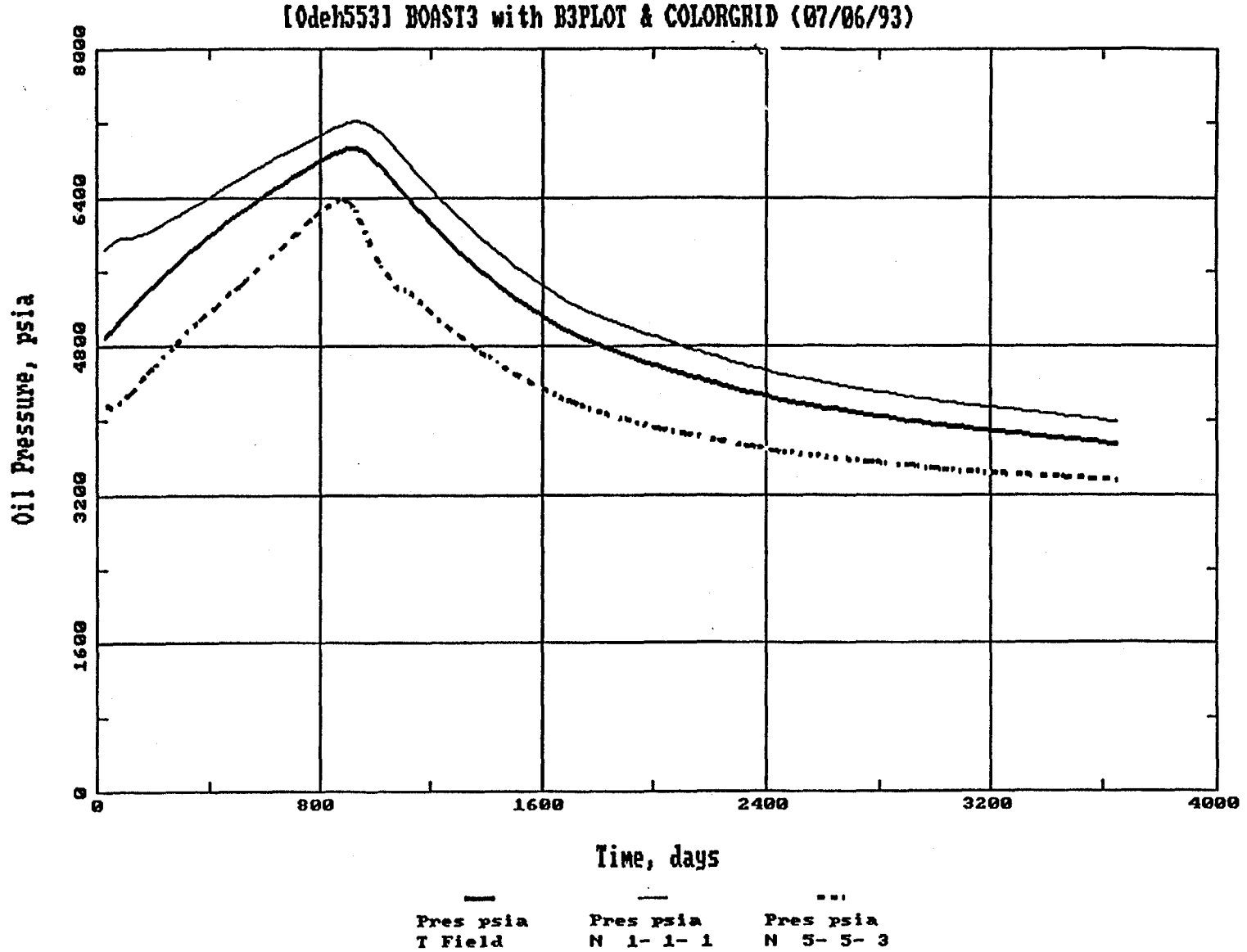


Figure A-7 - Simulated Pressure vs Time (Field Average, Injection Well-Block (1,1,1), and Producing Well-Block (5,5,3)

APPENDIX B

SAMPLE INPUT DATASET

```
[Odeh553] BOAST3 with B3PLOT & COLORGRID (07/06/93)
ID2:   Flowed producer at 20000 STB/d without constraint until 1095 days;
ID3:   then used KIP = -11 (instead of -1 in BOASTII) to get implicit
ID4:   BHP control.
ID5:
RESTART AND POST-RUN CODES
-1 0
GRID DATA
 5  5  3
GRID BLOCK LENGTHS
-1 -1 0 0
2000.
2000.
20. 30. 50.
20. 30. 50.
GRID BLOCK LENGTH MODIFICATIONS
5*0
CONSTANT DEPTH TO TOP OF LAYER ONE
0  0.0     <---- KEL, ALPHA
8325.
POROSITY AND PERMEABILITY DISTRIBUTIONS
-1 0 0 0
.30
500. 50. 200.
500. 50. 200.
100. 37.5 20.83
POROSITY & PERMEABILITY MODS:  (IPCODE replaced by KPHIMP,KXMP,KYMP,KZMP)
0 0 0 0   1  1  1  1
TRANSMISSIBILITY MODIFICATIONS
4*0
ROCK PVT
1 1
SAT   KRO       KRW     KRG      KROG PCOW PCGO
 .02  6*0.
 .05  0.        0.0     .005       3*0.
 .12  0.        0.0     .025       3*0.
 .18  0.        .0001   .06244     3*0.
 .2   .00002    .0005   .075       3*0.
 .25  .00007    .001    .125       3*0.
 .3   .00028    .0021   .190       3*0.
 .4   .0046     .0042   .41        3*0.
 .45  .0144     .0084   .6         3*0.
 .5   .0348     .0168   .72        3*0.
 .55  .0693     .0336   .795       3*0.
 .6   .134      .0672   .87        3*0.
 .7   .440      .1344   .94        3*0.
 .75  .66       .2016   .9533333   3*0.
 .8   .94       .2688   .9666667   3*0.
 .85  .985      .336    .98        3*0.
 .88  1.0       .3696   .984       3*0.
 .95  1.0       .4704   .9933333   3*0.
 .98  1.0       .5      .9973333   3*0.
 .999 1.0       .5      .9998667   3*0.
1.0   1.0       .5      1.0        3*0.
ITHREE SWR
  0    .12
 PBO    PBODAT PBGRAD
4014.7  8425.   0.
VSLOPE   BSLOPE  RSLOPE   PMAX  REPRS
.000046 -.0000232   0.    9014.7   1     <---- "OFF"
   P      MUO     BO    RSO
  14.7   1.04   1.062   1.0
 264.7   .975   1.15    90.5
 514.7   .91    1.207   180.
1014.7   .83    1.295   371.
2014.7   .695   1.435   636.
```

```
2514.7  .641  1.5    775.
3014.7  .594  1.565  930.
4014.7  .51   1.695  1270.
5014.7  .449  1.827  1618.
9014.7  .203  2.357  2984.
   P     MUW    BW
  14.7  .31   1.041
 264.7  .31   1.0403
 514.7  .31   1.0395
1014.7  .31   1.0380
2014.7  .31   1.0380
2514.7  .31   1.0335
3014.7  .31   1.0320
4014.7  .31   1.0290
5014.7  .31   1.0258
9014.7  .31   1.0130
GAS AND ROCK PROP
0
   P     MUG     BG      PSI     CR
  14.7  .008   .9358    0.0  .000003
 264.7  .0096  .067902  0.0  .000003
 514.7  .0112  .035228  0.0  .000003
1014.7  .014   .017951  0.0  .000003
2014.7  .0189  .009063  0.0  .000003
2514.7  .0208  .007266  0.0  .000003
3014.7  .0228  .006064  0.0  .000003
4014.7  .0268  .004554  0.0  .000003
5014.7  .0309  .003644  0.0  .000003
9014.7  .047   .002180  0.0  .000003
RHOSCO RHOSCW RHOSCG
46.244 62.238 .0647
Initialization Option Codes
 0  0  8425.  0.0      [KPI  KSI  PDATUM   GRAD]
 NR   Pwoc    WOC  Pgoc  GOC     Soi  Swi  Sgi  [Initialization by Rock Region]
  1  4806.6  8425.  0.0  8300.   .88  .12  0.0
Initialization by Layer (NZ Records)
 1  0.0  0.0  0.0  0.0   [Pi  Soi  Swi  Sgi]
 2  0.0  0.0  0.0  0.0   [Pi  Soi  Swi  Sgi]
 3  0.0  0.0  0.0  0.0   [Pi  Soi  Swi  Sgi]
KSN1 KSM1 KCO1 KCOF KSKIP  KOUT
  0    0    0    0   999    1          <--------- ADDED KOUT 07/03/93
NMAX FACT1 FACT2 TMAX WORMAX GORMAX PAMIN PAMAX
9999  1.50  .25  3650.   20.  500000. 150. 10000.
KSOL MITR OMEGA TOL TOL1 DSMAX DPMAX
4    350   1.7  .1   0.   .10   200.
NUMDIS IRK THRUIN
  0      0   .5
AQUIFER DATA
0
WELL and NODE DATA
 No. of Wells
   2
  Well Nodes WellName
   1    1     'INJ1'
   2    1     'PROD'
  Well   Node(I,J,K)   DIR
   1     1   1   1      1
   2     5   5   3      1
RECURRENT DATA
C======================= DATA SET 1 ========================================
 0  6  1          [ICHANG  IOMETH  IWLCNG -> NOTE: ICHANG not used if IOMETH>0]
 1.  15. 180. 365. 730. 1095.   [Times for output - IOMETH values]
 1  1  0  1  1  0       [IPmap ISOmap ISWmap ISGmap IPBmap IAQmap]
 1  0  1  0  0  0  1    [KROmap KRWmap KRGmap IRSOMP PCOWmap PCGOmap KPHImap]
 0.1  0.1  20.                [DT,DTMIN,DTMAX]
HEADER -----> Beginning of data read by NODES - if IWLCNG=1]
```

```
2  0    [NWELLN=No. of new wells, NWELLO=No. of old wells]
---NEW WELLS---
INJ    1  1  1  1  1  [FORMATTED: A5,5I3 - WELLID, IDWELL, I, J, PERF1, NLAYER]
 9.85    (PID)
 0.0     (PWF)
INJ    1  3       0.        0.  -100000.        0.  [FORMATTED: A5,2I3,4F10.0]
PROD   2  5  5  3  1
 9.85   (PID)
  0.0   (PWF)
PROD   2  1   20000.        0.        0.        0. (Rates used if KIP > 0)
C======================= DATA SET 2 ========================================
 0  7  1          [ICHANG  IOMETH  IWLCNG -> NOTE: ICHANG not used if IOMETH>0]
  1460. 1825. 2190. 2555. 2920. 3285. 3650.
1  1  0  1  1  0      [IPmap ISOmap ISWmap ISGmap IPBmap IAQmap]
1  0  1  0  0  0  1   [KROmap KRWmap KRGmap IRSOMP PCOWmap PCGOmap KPHImap]
0.1   0.1  30.0
HEADER ------> Beginning of data read by NODES - if IWLCNG=1]
2  0    [NWELLN=No. of new wells, NWELLO=No. of old wells]
---NEW WELLS---
INJ    1  1  1  1  1  [FORMATTED: A5,5I3 - WELLID, IDWELL, I, J, PERF1, NLAYER]
 9.85    (PID)
 0.0     (PWF)
INJ    1  3       0.        0.  -100000.        0.  [FORMATTED: A5,2I3,4F10.0]
PROD   2  5  5  3  1
 9.85   (PID)
1000.   (PWF)
PROD   2-11       0.        0.        0.        0. (Rates used if KIP > 0)
```