Appendix A

**USER’S MANUAL FOR MULTI-PURPOSE SIMULATOR FOR FIELD APPLICATIONS (MPSFFA, VERSION 1-16)**

**A.1 Introduction**

This manual provides a brief description of a multi-purpose reservoir simulator (MPSFFA) and its capabilities, detailed information on data file preparation, and a detailed description of the variables used in preparing a data file. It also gives instructions for running the reservoir simulator and the graphic post processor on a PC. The primary purpose of presenting this simulator as part of this book is to help MS and PhD graduate students who develop simulation models in their research to check their intermediate and final results and to provide simulation engineers and independent consultants with an advanced tool to run small size field cases and aid in the interpretation of simulation results using the graphic post processor. Educators may use the simulator in their teaching to train undergraduate students.

**A.2 The Simulator**

The present simulator (MPSFFA) models multi phase fluid, including polymer solution, flow in petroleum reservoirs. Model description (flow equations and boundary conditions), well operating conditions, and methods of solving the algebraic equations of the model are described in detail elsewhere (Luchmansingh, Ertekin, and Abou-Kassem, 1991; Abou-Kassem, Osman, and Zaid, 1996; Abou-Kassem, 1996; Ertekin, Abou-Kassem, and King, 2001, Abou-Kassem, Farouq Ali, and Islam, 2006) The simulator was written in FORTRAN 95 and the graphic post processor was developed for use with MATLAB version 5.1a and higher.

The simulator is fully implicit, multi-dimensional, and multi-purpose. The model equations are linearized using Newton’s iteration and the resulting linear equations are solved simultaneously (for natural ordering and D4 ordering) or iteratively employing advanced Block Iterative method (Behie and Vinsome, 1982) and Nested Factorization method (Appleyard and Cheshire, 1983) accelerated by ORTHOMIN (Vinsome, 1976). The simulator is based on 5-point scheme discertization and uses a block-centered grid. It can be run in one-, two-, or three-dimensional mode in rectangular coordinates (*x-y-z* space) for modeling field performance and in one- or two-dimensional mode in radial-cylindrical coordinates (*r-z* space) for modeling single-well performance. The simulator efficiently simulates several processes of practical interest to petroleum engineers including polymer injection, black-oil (oil-water-gas) reservoirs, oil-water reservoirs, oil-gas reservoirs, and gas reservoirs. It can be run as a single-phase, two-phase, or three-phase simulator and as a material balance equation (zero-dimensional simulator). The simulator implements advanced automatic time-step control based on the minimization of truncation error (Sammon and Rubin, 1984). ***It should be mentioned that the current version of the simulator handles single-block wells only and it needs further development to handle multi-block wells. The present version of the simulator may experience difficulties in severe single-well simulation problems (such as the test problem reported by Weinstein, Chappelear, and Nolen (1986).*** The simulator has the capacity to model irregular boundary reservoirs with the inactive grid blocks within or outside the reservoir being removed at the matrix level (Abou-Kassem and Ertekin, 1992). The simulator models heterogeneous reservoirs having rock regions with different relative permeability and capillary pressure data and different PVT and viscosity data. It permits performing manual history matching. It has sophisticated and yet simple data inputting procedure (Abou-Kassem et al., 1996). The formulation in the simulator removes, at the matrix level, the polymer equation when simulating a black-oil reservoir, the polymer and gas equations when simulating an oil-water reservoir, the polymer and water equations when simulating an oil-gas-irreducible water reservoir, and the polymer and oil equations when simulating gas reservoirs (Abou-Kassem et al., 1996). This capability considerably reduces the CPU time and memory storage requirements. Although the simulator does not permit multi-block wells, various well operating conditions are simulated.

**A.3 Data File Preparation**

The data required for the present simulator are classified into groups based on how the data within each group are related. A group of data could be as simple as defining a few related variables or as complicated as defining the variables for the well recursive data. These groups of data are classified, according to their format of input procedure, into five categories (A, B, C, D, and E). Categories A, B, and C include 27, 11, and 5 groups of data, respectively, whereas Categories D and E include one group of data each. The data of each category are entered using a specific format procedure; for example, category A uses format procedure A, category B uses format procedure B, etc. Each group of data carries an identification name consisting of the word “DATA” followed by a number and an alphabet character; the number identifies the group and the alphabet character identifies the category and the format procedure. For example, DATA 06B identifies a group of data that belongs to Category B and uses Format Procedure B, and whose variables are defined under DATA 06B in Sec. A.4. *Items of data that are not specific to the problem in question but are requested by the simulator can be set to zero, assigned dummy values, or left unchanged as supplied in the model data file*. *It is strongly recommended; however, to assign zero values to such items of data.*  Data file preparation, including format procedures and description of variables, follows the work of Abou-Kassem, Osman, and Zaid (1996) for black-oil simulation. The CD that accompanies this book contains examples of data files and output files for four problems reported in the literature: gas injection in a 3D reservoir (Odeh, 1981), water injection in a 2D reservoir (Yanosik and McCracken, 1979), polymer slug injection in a 1D reservoir (Lutchmansingh, 1987), and 2D, 3-phase black oil reservoir (Ertekin, Abou-Kassem, and King, 2001); and the data files and output files for three single-phase problems reported by Abou-Kassem, Faruoq Ali, and Islam (2006). In addition, three more data and output files are included for single-phase water reservoir, 3-phase single-well simulation, and the use of simulator as a material balance equation.

Each format procedure is introduced by a title line (line 1), which includes the identification name and the group of data to be entered, followed by a parameter sequence line (line 2), which lists the order of parameters to be entered by the user. Only format procedure D has an additional parameter sequence line (line 3). The user, in each subsequent data line, enters the values of the parameters ordered and preferably aligned with the parameters shown in the parameter sequence line for easy recognition. Each of format procedures B and E requires a single line data entry, whereas format procedures A, C, and D require multiple-line data entry and terminate with a line of zero entries for all parameters. The various groups of data and any specific instructions for each format procedure are presented in the following sections.

**A.3.1 Format Procedure A**

This format procedure is suitable for entering data that describe the distribution of a grid block property over the whole reservoir. Such data include block size and permeability in the *x*, *y*, and *z* directions; depth; porosity; fluid saturation; pressure; solution GOR at bubble-point pressure; polymer concentration; rock adsorption; maximum rock adsorption; modifiers for porosity, net thickness to gross thickness ratio, bulk volume, and transmissibilities in the *x*, *y*, and *z* directions; and block identifiers that label a grid block as being active, belonging to a rock region, belonging to a PVT region, and receiving influx from an aquifer.

Each line of data (for example, line 3) represents a property assignment for an arbitrary reservoir region having the shape of a prism with I1, I2; J1, J2; and K1, K2 being its lower and upper limits in the *x*, *y*, and *z* directions. The data entered by each subsequent line (for example, line 4) are superimposed on top of the data entered by all earlier lines; that is, the final distribution of a property is the result of the superposition of the entire arbitrary reservoir regions specified by all lines of data. This option is activated by setting the option identifier at the beginning of the parameter sequence line (line 2) to 1. This is a powerful method for entering data if a block property is distributed into well-defined (not necessarily regular) reservoir regions. For a homogeneous property distribution, only one line of data is needed (with I1 = J1 = K1 = 1, I2 =, J2 =, and K2 =). If, however, a block property is so heterogeneous that it varies from block to block and regional property distribution is minimal, this method loses its effectiveness. In such cases, the option identifier at the beginning of the parameter sequence line (line 2) is set to 0 and the data for all blocks are entered sequentially in a way similar to natural ordering of blocks along rows (i.e.,  is incremented first, *j* is incremented second, and *k* is incremented last). In this case, both active and inactive blocks are assigned property values and the terminating line of zero entries is omitted.

**A.3.2 Format Procedure B**

This format procedure is suitable for entering data involving a combination of integer and/or real variables. Groups of data of this type include the options for method of solution, block ordering scheme, restart-up, units of input and output, and interpolation; control integers for printing and debugging options, number of grid blocks in the *x*, *y*, and *z* directions; reservoir reference depth and reservoir orientation in space; oil API and gas and water specific gravities; oil and porosity compressibilities, rock density, and reference pressure for porosity; reservoir initialization data; time step control data, simulation time; number of rock regions; and number of PVT regions. Note that the values of the parameters are entered in line 3. They are ordered and aligned with the parameters shown in the parameter sequence line (line 2) for easy recognition.

**A.3.3 Format Procedure C**

This format procedure is suitable for entering property tables such as oil-water relative permeability and drainage and imbibition capillary pressure data, gas-oil relative permeability and drainage and imbibition capillary pressure data, PVT data, polymer viscosity data, and resistance factor and residual resistance factor data. The parameter sequence line (line 2) lists first the independent variable followed all other dependent variables. It is important to note that range of change of the independent variable in any table must cover the range that is expected to take place in the reservoir. Each line of data represents one entry in the table of data that corresponds to a specified value of the independent variable. The data of a table are entered in the order of increasing the value of the independent variable. A one-line table is; however, possible if the properties in the table are not function of the independent variable. Note that the data in each line of data (for example, line 3) are ordered and aligned with the parameters specified on the parameter sequence line (line 2) for easy recognition.

**A.3.4 Format Procedure D**

This format procedure is suitable for entering well recursive data. As mentioned earlier, this format procedure has two parameter sequence lines. The parameters in the first parameter sequence line (line 2) include a time specification which signals new user's request (SIMNEW), an over-ride time step to be used (DELT), the number of wells changing operation conditions (NOW), an over-ride printing option (IRITEI), a well economic limit (QOECON), and well production constraints on WOR (WORMAX) and GOR (GORMAX). This line of data can be repeated but each subsequent line must have a time specification larger than the last time specification. The parameters in the second parameter sequence line (line 3) include data for individual wells such as well type (IWT), well identification number (IDW), well coordinates (IW, JW, KW), well operating condition (IWOPC), well geometric factor (GW), the minimum (or maximum) flowing bottom-hole pressure (BHP), the specified maximum production (injection) rate (QSP), the polymer concentration of injected fluid (CONCPI), and the tracer concentration in injected aqua (CONCTI). There must exist NOW lines describing NOW individual wells immediately following the line where NOW specification appears if NOW >0. Using this format procedure, any number of wells can be introduced, shut in, re-opened, re-completed, etc. at any number of key times during both the history matching phase and future performance prediction phase of a study.

**A.3.5 Format Procedure E**

This format procedure is used to enter one line of information, such as the name of the user and the title of the computer run, consisting of up to eighty alphanumeric characters.

**A.4 Description of Variables Used in Preparing a Data File**

There are 45 data groups in the data file. The descriptions of variables within each data group are listed under the data group itself. Follows is a list of all 45 data groups starting with DATA 01E and ending with DATA 45D.

**Data 01E Title of Simulation Run**

TITLE Name of user and title of simulation run (one line having up to eighty alphanumeric characters)

**DATA 02B Restart-up Option and Simulation Time Data**

IPRTDAT Option for printing and debugging the input data file

= 0, do neither print nor debug the input data file.

= 1, print the input data file and activate messages to debug the file.

IRSTRT Restart-up option

= 0, simulation starts from initial conditions.

= 1, simulation continues from a restart-up file that was written previously.

TMTOTAL Maximum simulation time, D [d]

TMSTOP Time to stop this simulation run, D [d]

DELT Time step to be used if IRSTRT = 1, D [d]

*Notes: 1) Detailed output will be printed and restart-up file will be written at TMSTOP.*

*2) For IRSTRT = 1, the user has the option to modify any or all items of information contained in DATA 01E, DATA 02B, DATA 03B, DATA 04B, DATA 05B, and DATA 45D for the rest of the simulation run.*

**DATA 03B Units, Interpolation, Time-step Control, and Convergence Options**

MUNITIN Option for units of input data

= 1, customary units

= 2, SPE preferred metric units

= 3, laboratory units

MUNTOUT Option for units of output

= 1, customary units

= 2, SPE preferred metric units

= 3, laboratory units

IQUAD Degree of interpolating polynomial

= 0, linear interpolation using entries of supplied tables

= 1, linear interpolation using generated equi-spaced tables

= 2, quadratic interpolation using generated equi-spaced tables

NINTBLE Number of entries in generated equi-spaced tables

DTMAX Maximum allowed time step, D [d]

DTMIN Minimum allowed time step, D [d]

RERORP Relative error parameter, 0.0 ≤ RERORP ≤ ∞

DELPO Desired pressure change over a time step, psi [kPa]

DELRS Desired solution GOR change over a time step, scf/STB [std m3/std m3]

DELSAT Desired saturation change over a time step, fraction

MATBAK Convergence check and material balance accuracy

= 1, normal choice of convergence and material balance accuracy

= 2, normal choice of convergence and good material balance checks

= 3, strict convergence and better material balance checks

= 4, very strict convergence and best material balance checks.

*Notes: 1) Users are advised to refer to Ref. 11 (Sammon and Rubin, 1984) should they desire to change the time step control parameters.*

*2) Stricter convergence criterion results in better material balance checks. The CPU time, however, increases and smaller time steps are needed. Sometimes stricter convergence may not be achieved leading to difficulties in execution of program.*

*3) Use strict convergence for small problems and less strict convergence for large and practical problems.*

*4) If data are entered in lab units, the output will be in lab units only.*

*5) For* IQUAD , *it is recommended to use* NINTBLE = 500.

**DATA 04B Control Integers for Printing Frequency and Form of Output**

IPRINT Form of presenting arrays in output

= 0, variables are printed in arrays.

= 1, variables are printed for each grid block.

= 2, print coefficients of algebraic equations and variables of each grid block for debugging. This option is usually used during simulation development.

IFTSDBG The number of the first time step at which debugging starts.

ILTSDBG The number of the last time step to be included in debugging.

INOUTP Option for printing reservoir initialization

= 0, do not print initialization.

= 1, print initialization.

NFRRES Frequency of printing reservoir summary for whole reservoir

NFRWEL Frequency of printing detailed well performances

NFRARY Frequency of printing detailed variable arrays

NWRITE Frequency of writing restart-up file

*Note: Frequency means every N time steps.*

**DATA 05B Control Integers for Printing Desired Variable Arrays**

(1, an array is printed; 0, an array is not printed.)

SW Water phase saturation array

SO Oil phase saturation array

SG Gas phase saturation array

SP Polymer phase saturation array

ROIP Remaining oil-in-place

RS Solution GOR array

CONCT Tracer concentration

P Pressure array

CONCP Polymer concentration array

ADS Polymer adsorption on rock array

MAXADS Maximum polymer adsorption array

IWC Well operating condition array

**DATA 06B Components Present in Reservoir**

(1, component is present; 0, component is not present.)

IQW Water component

IQO Oil component

IQG Gas component

IQP Polymer component

**DATA 07B Reservoir Depth and Orientation in Space**

DEPTH1 Depth of the reservoir outside corner of grid block (1, 1, 1) below a chosen reference level, ft [m].

If DEPTH1 < -100,000, supply elevation array for top of grid blocks.

SINX Sine of angle between x-axis and its projection on horizontal plane

SINY Sine of angle between y-axis and its projection on horizontal plane

*Note: An elevation below the reference level is positive and increases downward.*

**DATA 08B Aquifer Parameters**

IDAQFR Type of aquifer

= 0, no aquifer. Enter zero for all other parameters.

= 1, pot aquifer

= 2, infinite steady-state radial aquifer

= 3, intermediate size unsteady-state radial aquifer

AQFH Aquifer porosity-thickness product, ft [m]

AQKH Aquifer permeability-thickness product, md-ft [µm2.m]

AQRW Aquifer internal radius, ft [m]

AQRE Aquifer external radius, ft [m]

ANGLE Aquifer Angle coverage of reservoir, degrees

AQCWE Effective compressibility of aquifer water, psi-1 [kPa-1]

AQMUW Aquifer water viscosity, cp [mPa.s]

**DATA 09B Reservoir Initialization Data**

INIOPT Option for reservoir initialization

= 0, initialization is not performed; therefore the user has to supply initialization. Enter zero for all other parameters.

= 1, simulator performs initialization.

ICASE Option for the type of initial fluids distribution in reservoir

= 1, single-phase oil (specify ZREF, PZREF, and RSO.)

= 2, single-phase water (specify ZREF and PZREF.)

= 3, single-phase gas (specify ZREF and PZREF.)

= 4, two-phase gas-water (specify ZREF for WGC and PZREF.)

= 5, two-phase gas-oil (specify ZREF for OGC and PZREF.)

= 6, two-phase oil-water (specify ZREF for WOC, PZREF, and RSO.)

= 7, three-phase gas-oil-aqua (specify ZREF for WOC and PZREF, and RSO at OGC.)

ZREF Depth below sea level of reference elevation in reservoir (OGC, WOC, or WGC), ft [m]

PZREF Pressure at ZREF, psia [kPa]

RSO Solution gas/oil ratio, scf/STB [std m3/std m3]

*Notes: 1) Initialization of single-phase reservoirs involves determination of grid block pressures only, whereas initialization of multi-phase reservoirs involves determination of phase pressures and saturations.*

*2) O/W capillary pressure data are needed for options 1, 3, and 5 in order to include irreducible water saturation in initialization.*

*3) For multi-phase reservoirs, capillary pressure data for initialization have to be supplied. These data may differ from those used for simulation. For example, water-wet reservoirs require drainage O/W and imbibition G/O capillary pressure data for initialization, whereas simulation requires imbibition O/W and drainage G/O capillary pressure data.*

**DATA 10B Reservoir Discretisation and Method of Solving Equations**

NX Number of grid blocks in the x-direction or in the r-direction if NY = 0.

NY Number of grid blocks in the y-direction. For single-well simulation, set NY = 0.

NZ Number of grid blocks in the z-direction

METHOD Method used to solve the linearized finite-difference equations

= 1, simultaneous solution using natural ordering

= 2, block iterative using natural ordering

= 3, nested factorization using natural ordering

= 4, simultaneous solution using D4 ordering

NXYXORD Order of axes followed in ordering grid blocks

= 1, automatic ordering to minimize CPU time and storage requirement for simultaneous solution methods (METHOD = 1, 4)

= 2, x-y-z (first x-axis followed by y-axis followed by z-axis)

= 3, x-z-y (first x-axis followed by z-axis followed by y-axis)

= 4, y-x-z (first y-axis followed by x-axis followed by z-axis)

= 5, y-z-x (first y-axis followed by z-axis followed by x-axis)

= 6, z-x-y (first z-axis followed by x-axis followed by y-axis)

= 7, z-y-x (first z-axis followed by y-axis followed by x-axis)

NUSLVR Option for direct solver

= 0, old version

= 1, new version

NKRRGN Number of relative permeability rock regions

NPVTRGN Number of PVT fluid regions

RADW Well radius for single-well simulation, ft [m]

RADE Reservoir external radius for single-well simulation, ft [m]

*Note: NXYXORD =2,3,4,5,6, or 7 may also aid in obtaining faster convergence, for the nested factorization iterative method, by ordering blocks along the highest transmissibility direction followed by the direction that has lower transmissibility and finally along the direction that has the least transmissibility (Appleyard and Cheshire, 1983).*

**DATA 11A Reservoir Description and Fluid Saturation and Pressure**

**DATA 37A** **Distributions**

I1, I2 The lower and upper limits in the x-direction of a parallelepiped region.

J1, J2 The lower and upper limits in the y-direction of a parallelepiped region.

K1, K2 The lower and upper limits in the z-direction of a parallelepiped region.

IACTIVE Block indicator for active and inactive blocks

= 0, inactive block

= 1, active block

NKRGN Block indicator for relative permeability rock region

= 1,2,3, ... if block belongs to rock region 1,2,3... respectively.

NPVTGN Block indicator for PVT fluid region

= 1,2,3... if block belongs to PVT region 1,2,3... respectively.

DX Block size in the x-direction, ft [m]

DY Block size in the y-direction, ft [m]

DZGROSS Block size in the z-direction (block gross thickness), ft [m]

DEPTH Elevation below sea level of top of grid block, ft [m]

KX Block permeability in the x-direction, or r-direction if NY = 0, md [µm2]

KY Block permeability in the y-direction, md [µm2]

KZ Block permeability in the z-direction, md [µm2]

PHI Block porosity at reference pressure, fraction

SO Block oil saturation, fraction

SW Block water saturation, fraction

SP Block polymer solution saturation, fraction

RSO Block solution GOR, scf/STB [std m3/std m3]

P Block pressure, psia [kPa]

CONCP Block polymer concentration in polymer solution, ppm

CRPMAX Block maximum allowed polymer adsorption on rock, lbm/lbm [kg/kg]

CRP Block polymer adsorption on rock, lbm/lbm [kg/kg]

INFBLK Block indicator for block sides receiving water influx parallel to a given direction.

= 0, no influx

= 1, one side, x-direction

= 2, one side, y-direction

= 3, two sides, x-and y-directions

= 4, three sides, two x-and one y-directions

= 5, three sides, one x-and two y-directions

= 6, four sides, two x-and two y-directions

= 7, one side, z-direction

BBLKWT Weighting factor given to a block receiving water influx, dimensionless

HNHGR Block net thickness to gross thickness ratio, fraction

VBMOD Modification for block bulk volume, fraction

VFMOD Modification for block porosity, fraction

TXMOD Modification for inter-block geometric factor in *x*- (or *r*-) direction, fraction

TYMOD Modification for inter-block geometric factor in *y*-direction, fraction

TZMOD Modification for inter-block geometric factor in *z*-direction, fraction

RATIO Property modifier, fraction

= 0.0, property is not modified.

> 0.0, property is increased by that ratio.

< 0.0, property is decreased by that ratio.

*Notes: 1) DX, DY, and DZGROSS have to be supplied for all active and inactive blocks.*

*2) Ratio; for VBMOD, VFMOD, TXMOD, TYMOD, and TZMOD; is the desired fractional change of the property value that was originally entered by the user or calculated by the simulator. In other words, new desired value = old value×*(1*+*RATIO). *Modifiers can be applied to block porosity, block volume, net to gross thickness, and transmissibility in the x, y, and z directions.*

**DATA 38C O/W Relative Permeability Data Table for Rock Region # 1**

SWT Water saturation, fraction

KRW Relative permeability to water, fraction

KROW Relative permeability to oil in oil-water system, fraction

PCOW Imbibition oil-water capillary pressure (water-wet rock) for reservoir simulation, psi [kPa]

PCOWI Drainage oil-water capillary pressure (water-wet rock) for reservoir initialization, psi [kPa]

**DATA 39C G/O Relative Permeability Data Table for Rock Region # 1**

SLT Liquid saturation, fraction

KRG Relative permeability to gas, fraction

KROG Relative permeability to oil in gas-oil system, in the presence of irreducible water, fraction

PCGO Drainage gas-oil capillary pressure for simulation, psi [kPa]

PCGOI Imbibition gas-oil capillary pressure for reservoir initialization, psi [kPa]

*Note: 1) DATA 38C and DATA 39C are repeated for regions no. 1, 2, 3, ... in that order until relative permeability and capillary pressure data for all NKRRGN regions are entered.*

*2) To simulate gas-water reservoirs, data for krw vs. Sw are entered in DATA 38C, whereas data for krg, Pcgw, and Pcgwi are entered in data DATA 39c. In this case SLT, PCGO, and PCGOI stand for Sw, Pcgw, and Pcgwi, respectively.*

**DATA 40C PVT Data Table of Saturated Fluids for PVT Fluid Region # 1**

PRES Pressure, psia [kPa]

RS Solution GOR, scf /STB [std m3/std m3]

BW Water formation volume factor, RB/B [m3/std m3]

BO Oil formation volume factor, RB/STB [m3/std m3]

BG Gas formation volume factor, RB/scf [m3/std m3]

MUW Water phase viscosity, cp [mPa.s]

MUO Oil phase viscosity, cp [mPa.s]

MUG Gas phase viscosity, cp [mPa.s]

**DATA 41B Oil, Water, and Gas Data at SC & Oil properties above PB.**

GAMAW Formation water specific gravity

GAMAG Gas gravity (air = 1)

OILAPI Oil API gravity

CO Oil compressibility, psi-1 [kPa-1]

CMUO Rate of relative change of oil viscosity w.r.t. pressure above bubble-point pressure, psi-1 [kPa-1]

*Note: DATA 40C and DATA 41B are repeated for PVT regions no. 1, 2, 3, ... in that order until PVT data for all NPVTRGN regions are entered.*

**DATA 42B Rock Properties**

DENR Rock density, lbm/ft3 [kg/m3]

CPHI Porosity compressibility, psi-1 [kPa-1]

PREF Reference pressure at which porosities are reported, psia [kPa]

**DATA 43C Polymer Viscosity Data Table**

CONCP Polymer concentration in polymer solution, ppm

MUP Polymer solution viscosity, cp [mPa.s]

**DATA 44C Resistance and Residual Resistance Factors Data Table**

CRP Polymer adsorption on rock, lbm/lbm [kg/kg]

RF Resistance factor, dimensionless

RRF Residual resistance factor, dimensionless

**DATA 45D Well Recursive Data**

NOW Number of wells that will change operational conditions

= 0, no change in well operations

> 0, number of wells that change operational conditions

IRITE1 Option for writing data to MATLAB files and printing detailed output at SIMNEW

= 0, output and/or data are not required.

= 1, output and/or data are required.

DELT1 Time step to be used, D [d]

SIMNEW Time specification signaling user's new request, D [d]. Well data entered here will be active starting from previous time specification until this time specification and beyond.

QOECON Economic limit of oil production, STB/D [std m3/d]

WORMAX Maximum allowable well producing WOR, B/STB [std m3/std m3]

GORMAX Maximum allowable well producing GOR, scf /STB [std m3/std m3]

IWT Index for well type

= 0, shut-in well

= -1, production well

= -2, injection well

IDW Well identification number. Each well must have a unique IDW.

= 1, 2, 3, 4...

IW, JW, KW (*i*, *j*, *k*) location of well block

IWOPC Well operating condition

IWOPC for Production Well

= 0, shut-in well

= 1, oil rate at standard conditions in MSTB/D [103 std m3/d]

= 2, aqua rate at standard conditions in MB/D [103 std m3/d]

= 3, gas rate at standard conditions in Mscf/D [103 std m3/d]

= 4, liquid rate at standard conditions in MSTB/D [103 std m3/d]

= 5, total rate at standard conditions in MSTB/D [103 std m3/d]

= 6, oil rate at reservoir conditions in MRB/D [103 m3/d]

= 7, aqua rate at reservoir conditions in MRB/D [103 m3/d]

= 8, gas rate at reservoir conditions in Mft3/D [103 m3/d]

= 9, liquid rate at reservoir conditions in MRB/D [103m3/d]

= 10, total rate at reservoir conditions in MRB/D [103m3/d]

= 11, specified bottom-hole pressure in psia [kPa]

IWOPC for Injection Well

= 0, shut-in well

= 1, oil rate at standard conditions in MSTB/D [103 std m3/d]

= 2, water rate at standard conditions in MB/D [103 std m3/d]

= 3, gas rate at standard conditions in Mscf/D [103 std m3/d]

= 4, polymer solution rate at standard conditions in MB/D [103 std m3/d]

GW Well geometric factor, B-cp/D-psi [m3.mPa.s/(d.kPa)]

BHP Minimum BHP of production well or maximum BHP allowed for injection well, psia [kPa]

QSP Specified well production (injection) rate in thousands of units or BHP in units of psia [kPa]

CONCPI Polymer concentration of injected polymer solution, ppm

= 0.0, water injection

> 0.0, polymer injection

CONCTI Tracer concentration in injected aqua, ppm

*Notes: 1) The NOW line can be repeated for different times but each subsequent line has to have time specification larger than the previous time specification. This line with NOW = 0 can be used to request printing of output and writing MATLAB data files, and to override control time step at specific times.*

*2) The IWT line enters specifications for one well. This line has to be repeated NOW times provided NOW > 0.*

*3) To activate maximum injection rate for an injection well, set QSP to a large but realistic value.*

*4) DELT1 is used only if it is smaller than that determined by the time step selection control. Therefore, to transfer control to automatic time-step selection, set DELT1 to a large value (say, DTMAX).*

*5) The specified value of BHP must be within the range of the pressure specified in PVT tables.*

**A.5 Instructions to Run Simulator and Graphic Post Processor on PC**

To use the graphic post processor to examine results generated by the simulator, the user has to run the simulator first. The user of the simulator is provided with copies of ten reference data files (e.g., ref.txt) similar to the one presented in Sec. A.7. The user first copies this file into his own data file (e.g., user-input.txt) and then follows instructions in Sec. A.3 and observe variable definitions given in Sec. A.4 to modify his/her own data file such that it describes the constructed model of the reservoir under study. *It is important to note that a data file must be saved as a* ***Notepad*** *file*. The simulator can be run any number of times during preparation of the data file to correct errors in data and format. The computer responds with the following statement requesting names (with file type) of input, output, and two restart-up files; and giving the format for reading such names:

**ENTER NAMES OF INPUT, OUTPUT, RESTART-UP FILES**

**input.txt, output.lis, restin.txt, restout.txt**

The user responds using the names of four files separated by blanks or commas as follows.

**user-input.txt user-output.lis r1.txt r2.txt**

The computer program continues execution until completion, which will be signaled by printing on the screen:

**END OF MPSFFA RUN**

Prior to using the post graphic processor, the user has to run MATLAB and set the path to the appropriate folders (within MALAB, highlight “File”, select “Set Path …”, then select “Add Folder”, “Browse For Folder”, and select the folder where the simulation results are stored and the folder for the MATLAB post processor program, push “OK”, then push “Save”, and finally push “Close”). Once the simulation run is completed successfully, the results (**user-output.lis**) and six other files needed for the post processor (**pvt.lis, krp.lis, well.lis, res.lis, resmat.lis, and rokmat.lis**) are generated by the simulator. The user may then proceed to examine the results using the graphic post processor (**mpsffa\_pp.m**) by issuing the following command at the MATLAB command level:

**mpsffa\_pp**

The user then follows instructions to run the post processor. It is important not to delete any window or interrupt the execution of the post processor program. The program gives the user an option to terminate program execution orderly at any time.

**A.6 Limitations Imposed on the Compiled Versions**

The compiled versions of MPSFFA contained in the accompanied CD is provided here for demonstration and student training purposes. The critical variables were therefore restricted to the dimensions given below. Dimensioning parameters are assigned values such that all methods of solving the linear algebraic equations can be run for the same problem. Advanced users may increase these dimensions by editing the dimensioning FORTRAN program (**sizempsffav1-16.for**) and then re-compiling the main program (**mpsffav1-16.for**).

1. Number of blocks in x-direction ≤ 40
2. Number of blocks in y-direction ≤ 40
3. Number of blocks in z-direction ≤ 40
4. Number of active blocks ≤ 4000
5. Number of Kr rock regions ≤ 30
6. Number of PVT fluid regions ≤ 30
7. Number of entries in any table ≤ 30
8. Number of wells ≤ 200
9. Number of times wells change operational conditions ≤ 100

The following is a list of the values of the parameters, in the dimensioning program (sizempsffav1-16.for), that are used in the compiled versions of MPSFFA. Advanced users may assign values for those parameters that appear in bold lines only.

1. **INTEGER, PARAMETER :: I9A=40**
2. **INTEGER, PARAMETER :: I9B=40**
3. **INTEGER, PARAMETER :: I9C=40**
4. INTEGER, PARAMETER :: I9D=I9A\*I9B\*I9C
5. **INTEGER, PARAMETER :: I9E=4000**
6. !Cmnt CCCCCCCC START CCCCCCC
7. INTEGER, PARAMETER :: I8E=I9E
8. **!Calt INTEGER, PARAMETER :: I8E=1**
9. !Cmnt CCCCCCCC END CCCCCCC
10. INTEGER, PARAMETER :: I7E=I9E
11. **INTEGER, PARAMETER :: I9F=30**
12. **INTEGER, PARAMETER :: I9G=30**
13. **INTEGER, PARAMETER :: I9H=30**
14. **INTEGER, PARAMETER :: I9I=30**
15. **INTEGER, PARAMETER :: I9J=30**
16. **INTEGER, PARAMETER :: I9K=30**
17. **INTEGER, PARAMETER :: I9L=30**
18. **INTEGER, PARAMETER :: I9M=200**
19. **INTEGER, PARAMETER :: I9N=500**
20. INTEGER, PARAMETER :: I1O=MIN(I9A,I9B,I9C)
21. INTEGER, PARAMETER :: I3O=MAX(I9A,I9B,I9C)
22. INTEGER, PARAMETER :: I2O=I9A+I9B+I9C-I1O-I3O
23. **INTEGER, PARAMETER :: I9Q=100**
24. **INTEGER, PARAMETER :: I9R=4**
25. !Cmnt CCCCCC START CCCCCC
26. INTEGER, PARAMETER :: I8R=I9R
27. **!Calt INTEGER, PARAMETER :: I8R=1**
28. !Cmnt CCCCCC END CCCCCC
29. INTEGER, PARAMETER :: I7R=I9R
30. INTEGER, PARAMETER :: I9S=1+I9R\*I9E
31. INTEGER, PARAMETER :: I9T=I9Q\*I9M
32. INTEGER, PARAMETER :: I9W=I9E
33. INTEGER, PARAMETER :: I9X=I9W
34. !Cmnt CCCCCC START CCCCCC
35. INTEGER, PARAMETER :: I8X=I9X
36. **INTEGER, PARAMETER :: I9Y=2000000**
37. **!Calt INTEGER, PARAMETER :: I8X=1**
38. **!Calt INTEGER, PARAMETER :: I9Y=1**
39. !Cmnt CCCCCCC END CCCCC
40. INTEGER, PARAMETER :: I9A1=1+I9A/10
41. INTEGER, PARAMETER :: I9A2=1+I9A/20
42. INTEGER, PARAMETER :: I9B1=1+I9B/10
43. INTEGER, PARAMETER :: I9C1=1+I9C/10
44. INTEGER, PARAMETER :: IEE1=1+9/10
45. INTEGER, PARAMETER :: I3E=40

**A.7 Example of a Prepared Data File**

The *oil-gas-swi-xyz(odeh-1981).txt* data file was prepared for the SPE bench-mark test problem of Odeh (1981).

'\*DATA 01E\* TITLE OF SIMULATION RUN'

'TITLE' NOTE: SUPPLY A TITLE UP TP 8O CHARACTERS IN LENGTH.

A DATA FILE TO MODEL 3D, 1/8TH OF 5-SPOT PATTERN. AZIZ ODEH'S DATA (JPT 1981).

'\*DATA 02B\* RESTART-UP OPTION AND SIMULATION TIME DATA'

'IPRTDAT IRSTRT TMTOTAL TMSTOP DELT'

1 0 36504.0 3650.4 30.42

'\*DATA 03B\* UNITS, INTERPOLATION, TIME-STEP CONTROL, AND CONVERGENCE OPTIONS'

'MUNITIN MUNTOUT IQUAD NINTBLE DTMAX DTMIN RERORP DELPO DELRS DELSAT MATBAK'

1 1 0 500 365.04 0.001 0.2 500.0 500.0 0.20 2

'\*DATA 04B\* CONTROL INTEGERS FOR PRINTING FREQUENCY AND FORM OF OUTPUT'

'IPRINT IFTSDBG ILTSDBG INOUTP NFRRES NFRWEL NFRARY NWRITE'

0 0 0 1 0 0 0 0

'\*DATA 05B\* CONTROL INTEGERS FOR PRINTING DESIRED VARIABLE ARRAYS'

' SW SO SG SP ROIP RS CONCT P CONCP ADS MAXADS IWC'

1 1 1 0 1 1 0 1 0 0 0 1

'\*DATA 06B\* COMPONENTS PRESENT IN RESERVOIR'

' IQW IQO IQG IQP'

1 1 1 0

'\*DATA 07B\* RESERVOIR DEPTH AND ORIENTATION IN SPACE'

'DEPTH1 SINX SINY'

-2E08 0.0 0.0

'\*DATA 08B\* AQUIFER PARAMETERS'

'IDAQFR AQFH AQKH AQRW AQRE ANGLE AQCWE AQMUW'

0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

'\*DATA 09B\* RESERVOIR INITIALIZATION DATA'

'INIOPT ICASE ZREF PREF RSO'

0 0 0.0 0.0 0.0

'\*DATA 10B\* RESERVOIR DISCRETIZATION AND METHOD OF SOLVING EQUATIONS'

' NX NY NZ METHOD NXYZORD NUSLVR NKRRGN NPVTRGN RADW RADE'

10 10 3 4 1 1 1 1 0.0 0.0

'\*DATA 11A\* RESERVOIR REGION WITH ACTIVE OR INACTIVE BLOCK IACTIVE'

1 ' I1 I2 J1 J2 K1 K2 IACTIVE'

1 10 1 10 1 3 1

1 1 2 10 1 3 0

2 2 3 10 1 3 0 NOTE:

3 3 4 10 1 3 0 FORMAT PROCEDURE A WITH OPTION = 1

4 4 5 10 1 3 0 MUST HAVE TERMINATING ZERO LINE.

5 5 6 10 1 3 0

6 6 7 10 1 3 0

7 7 8 10 1 3 0

8 8 9 10 1 3 0

9 9 10 10 1 3 0

0 0 0 0 0 0 0

'\*DATA 12A\* RESERVOIR REGION THAT BELONGS TO REL. PERM. REGION NKRGN'

0 ' I1 I2 J1 J2 K1 K2 NKRGN' NOTE: FORMAT PROCEDURE A WITH OPTION = 0

300\*1 DOES NOT TERMINATE WITH ZEROES.

'\*DATA 13A\* RESERVOIR REGION THAT BELONGS TO FLUID PVT REGION NPVTGN'

0 ' I1 I2 J1 J2 K1 K2 NPVTGN'

300\*1

'\*DATA 14A\* RESERVOIR REGION HAVING BLOCK SIZE DX IN THE X-DIRECTION'

0 ' I1 I2 J1 J2 K1 K2 DX'

300\*1000.0

'\*DATA 15A\* RESERVOIR REGION HAVING BLOCK SIZE DY IN THE Y-DIRECTION'

0 ' I1 I2 J1 J2 K1 K2 DY'

300\*1000.0

'\*DATA 16A\* RESERVOIR REGION HAVING BLOCK GROSS THICKNESS DZGROSS'

1 ' I1 I2 J1 J2 K1 K2 DZGROSS'

1 10 1 10 3 3 20.0

1 10 1 10 2 2 30.0

1 10 1 10 1 1 50.0

0 0 0 0 0 0 0.0

'\*DATA 17A\* RESERVOIR REGION HAVING TOP OF LAYER ELEVATION BELOW SEA LEVEL'

1 ' I1 I2 J1 J2 K1 K2 DEPTH'

1 10 1 10 3 3 8325.0

1 10 1 10 2 2 8345.0

1 10 1 10 1 1 8375.0

0 0 0 0 0 0 0.0

'\*DATA 18A\* RESERVOIR REGION HAVING PERMEABILITY KX IN THE X-DIRECTION'

1 ' I1 I2 J1 J2 K1 K2 KX'

1 10 1 10 3 3 500.0

1 10 1 10 2 2 50.0

1 10 1 10 1 1 200.0

0 0 0 0 0 0 0.0

'\*DATA 19A\* RESERVOIR REGION HAVING PERMEABILITY KY IN THE Y-DIRECTION'

1 ' I1 I2 J1 J2 K1 K2 KY'

1 10 1 10 3 3 500.0

1 10 1 10 2 2 50.0

1 10 1 10 1 1 200.0

0 0 0 0 0 0 0.0

'\*DATA 20A\* RESERVOIR REGION HAVING PERMEABILITY KZ IN THE Z-DIRECTION'

1 ' I1 I2 J1 J2 K1 K2 KZ'

1 10 1 10 3 3 50.0

1 10 1 10 2 2 50.0

1 10 1 10 1 1 19.23

0 0 0 0 0 0 0.0

'\*DATA 21A\* RESERVOIR REGION HAVING POROSITY PHI'

0 ' I1 I2 J1 J2 K1 K2 PHI'

300\*0.30

'\*DATA 22A\* RESERVOIR REGION HAVING OIL SATURATION SO'

0 ' I1 I2 J1 J2 K1 K2 SO'

300\*0.88

'\*DATA 23A\* RESERVOIR REGION HAVING WATER SATURATION SW'

0 ' I1 I2 J1 J2 K1 K2 SW'

300\*0.12

'\*DATA 24A\* RESERVOIR REGION HAVING POLYMER PHASE SATURATION SP'

0 ' I1 I2 J1 J2 K1 K2 SP'

300\*0.0

'\*DATA 25A\* RESERVOIR REGION HAVING SOLUTION GOR RSO'

0 ' I1 I2 J1 J2 K1 K2 RSO'

300\*1270.0

'\*DATA 26A\* RESERVOIR REGION HAVING INITIAL PRESSURE P'

0 ' I1 I2 J1 J2 K1 K2 P'

100\*4800.0 100\*4789.8 100\*4783.5

'\*DATA 27A\* RESERVOIR REGION HAVING POLYMER CONCENTRATION CONCP IN WATER'

0 ' I1 I2 J1 J2 K1 K2 CONCP'

300\*0.0

'\*DATA 28A\* RESERVOIR REGION HAVING HAVING MAX. POL. ADSORPTION CRPMAX'

0 ' I1 I2 J1 J2 K1 K2 CRPMAX'

300\*0.0

'\*DATA 29A\* RESERVOIR REGION HAVING POLYMER ADSORPTION CRP'

0 ' I1 I2 J1 J2 K1 K2 CRP'

300\*0.0

'\*DATA 30A\* RESERVOIR REGION FOR WATER INFLUX SIDES OF EDGE BLOCKS'

0 ' I1 I2 J1 J2 K1 K2 INFBLK'

300\*0

'\*DATA 31A\* RESERVOIR REGION FOR WEIGHT DISTRIBUTION OF INFLUX TO EDGE BLOCKS'

0 ' I1 I2 J1 J2 K1 K2 BBLKWT'

300\*0.0

'\*DATA 32A\* RESERVOIR REGION WITH BLOCK NET THICKNESS TO GROSS THICKNESS RATIO'

0 ' I1 I2 J1 J2 K1 K2 HNHGR'

300\*1.0

'\*DATA 33A\* RESERVOIR REGION WITH BLOCK VOLUME MODIFICATION RATIO'

1 ' I1 I2 J1 J2 K1 K2 RATIO'

1 1 1 1 1 3 -0.5

2 2 2 2 1 3 -0.5

3 3 3 3 1 3 -0.5

4 4 4 4 1 3 -0.5

5 5 5 5 1 3 -0.5

6 6 6 6 1 3 -0.5

7 7 7 7 1 3 -0.5

8 8 8 8 1 3 -0.5

9 9 9 9 1 3 -0.5

10 10 10 10 1 3 -0.5

0 0 0 0 0 0 0.0

'\*DATA 34A\* RESERVOIR REGION WITH BLOCK POROSITY MODIFICATION RATIO'

0 ' I1 I2 J1 J2 K1 K2 RATIO'

300\*0.0

'\*DATA 35A\* RESERVOIR REGION WITH X-TRANSMISSIBILITY MODIFICATION RATIO'

0 ' I1 I2 J1 J2 K1 K2 RATIO'

300\*0.0

'\*DATA 36A\* RESERVOIR REGION WITH Y-TRANSMISSIBILITY MODIFICATION RATIO'

0 ' I1 I2 J1 J2 K1 K2 RATIO'

300\*0.0

'\*DATA 37A\* RESERVOIR REGION WITH Z-TRANSMISSIBILITY MODIFICATION RATIO'

1 ' I1 I2 J1 J2 K1 K2 RATIO'

1 1 1 1 1 2 -0.5

2 2 2 2 1 2 -0.5

3 3 3 3 1 2 -0.5

4 4 4 4 1 2 -0.5

5 5 5 5 1 2 -0.5

6 6 6 6 1 2 -0.5

7 7 7 7 1 2 -0.5

8 8 8 8 1 2 -0.5

9 9 9 9 1 2 -0.5

10 10 10 10 1 2 -0.5

0 0 0 0 0 0 0.0

'ENTER O/W & G/O RELATIVE PERMEABILITY DATA FOR ALL ROCK REGIONS'

'\*DATA 38C\* O/W RELATIVE PERMEABILITY DATA TABLE FOR ROCK REGION # 1'

' SWT KRW KROW PCOW PCOWI'

0.120 0.00 1.00 0.00 0.0 FORMAT PROCEDURE C MUST

1.000 1.000 0.000 0.00 0.0 TERMINATE WITH A LINE OF ZEROES.

0.0 0.0 0.0 0.0 0.0

'\*DATA 39C\* G/O RELATIVE PERMEABILITY DATA TABLE FOR ROCK REGION # 1'

' SLT KRG KROG PCGO PCGOI'

0.0 1.0 0.0 0.0 0.0

0.150 0.980 0.0000 0.00 0.0

0.300 0.940 0.0000 0.00 0.0

0.400 0.870 0.0001 0.00 0.0

0.500 0.720 0.0010 0.00 0.0

0.550 0.600 0.0100 0.00 0.0

0.600 0.410 0.0210 0.00 0.0

0.700 0.190 0.0900 0.00 0.0

0.750 0.125 0.2000 0.00 0.0

0.800 0.075 0.3500 0.00 0.0

0.880 0.025 0.7000 0.00 0.0

0.950 0.005 0.9800 0.00 0.0

0.980 0.000 0.9970 0.00 0.0

0.999 0.000 1.0000 0.00 0.0

1.000 0.000 1.0000 0.00 0.0

0.0 0.0 0.0 0.0 0.0

'ENTER SATURATED FLUID PVT DATA FOR ALL FLUID PVT REGIONS'

'\*DATA 40C\* PVT DATA TABLE OF SATURATED FLUIDS FOR PVT FLUID REGION # 1'

' PRES RS BW BO BG MUW MUO MUG'

14.7 1.00 1.0410 1.0620 0.166666 0.3100 1.0400 0.0080

264.7 90.50 1.0403 1.1500 0.012093 0.3100 0.9750 0.0096

514.7 180.00 1.0395 1.2070 0.006274 0.3100 0.9100 0.0112

1014.7 371.00 1.0380 1.2950 0.003197 0.3100 0.8300 0.0140

2014.7 636.00 1.0350 1.4350 0.001614 0.3100 0.6950 0.0189

2514.7 775.00 1.0335 1.5000 0.001294 0.3100 0.6410 0.0208

3014.7 930.00 1.0320 1.5650 0.001080 0.3100 0.5940 0.0228

4014.7 1270.00 1.0290 1.6950 0.000811 0.3100 0.5100 0.0268

5014.7 1618.00 1.0258 1.8270 0.000649 0.3100 0.4490 0.0309

9014.7 2984.00 1.0130 2.3570 0.000386 0.3100 0.2030 0.0470

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

'\*DATA 41B\* OIL WATER AND GAS DATA AT SC AND OIL PROPERTIES ABOVE PB'

' GAMAW GAMAG OILAPI CO CMUO'

1.03784 0.792 48.41 0.147D-04 0.46D-04

'\*DATA 42B\* ROCK PROPERTIES'

' DENR CPHI PREF'

0.0 0.3E-05 14.7

'\*DATA 43C\* POLYMER VISCOSITY DATA TABLE'

' CONCP MUP' NOTE: SUPPLY TERMINATING ZERO LINE

0.0 0.0 IF DATA ARE NOT AVAILABLE.

'\*DATA 44C\* ADSORPTION VS. RESISTANCE & RESIDUAL RESIST. FACTORS TABLE'

' CRP RF RRF' NOTE: SUPPLY ZERO TERMINATING LINE

0.0 0.0 0.0 IF DATA ARE NOT AVAILABLE.

'\*DATA 45D\* WELL RECURSIVE DATA'

' NOW IRITE1 DELT1 SIMNEW QOECON WORMAX GORMAX'

' IWT IDW IW JW KW IWOPC GW BHP QSP CONCPI CONCTI'

2 1 0.001 365.04 0.0 99.0 20000.0

-2 1 1 1 3 3 5.3038 9000.0 50000.0 0.0 0.0

-1 2 10 10 1 1 5.3038 1000.0 10.0 0.0 0.0

0 1 365.04 730.08 0.0 99.0 20000.0

0 1 365.04 1095.12 0.0 99.0 20000.0

0 1 365.04 1460.16 0.0 99.0 20000.0

0 1 365.04 1825.20 0.0 99.0 20000.0

0 1 365.04 2190.24 0.0 99.0 20000.0

0 1 365.04 2555.28 0.0 99.0 20000.0

0 1 365.04 2920.32 0.0 99.0 20000.0

0 1 365.04 3285.36 0.0 99.0 20000.0

0 1 365.04 3650.40 0.0 99.0 20000.0

0 0 0.0 0.0 0.0 0.0 0.0

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