1 of 1

User's Guide and Documentation Manual
for Microbial Transport Simulator

Topical Report

By
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USER'S GUIDE AND DOCUMENTATION MANUAL FOR MICROBIAL TRANSPORT SIMULATOR

By Ming-Ming Chang

ABSTRACT

The microbial transport simulator (MTS) is a three-dimensional, three-phase, multiple-component numerical model that permits the study of the transport of microorganisms and nutrients in porous media. Microbial parameters incorporated into MTS include: microbial growth and decay, microbial deposition, chemotaxis, diffusion, convective dispersion, tumbling, and nutrient consumption. Governing equations for microbial and nutrient transport are coupled with continuity and flow equations under conditions appropriate for a black oil reservoir. The model's mathematical formulations and preparation procedures of data files for conducting simulations using MTS are described.

A general background of microbial transport simulation is given in Section I and the governing equations, mechanisms, and numerical solutions of MTS are given in Section II. Explanations for preparing an input data file with reservoir and microbial transport data are described in Section III, and recurrent data are given in Section IV. Example data inputs are enclosed after explanations of each input line to help the user prepare data files. Major items of the output files are reviewed in Section V. Finally, two sample problems for running MTS are described in Section VI, and input files and part of the output files of these problems are listed in the appendix.

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I. INTRODUCTION

Microbial methods for increasing oil recovery are potentially cost-effective, even at relatively low crude oil prices. Microbial formulations can be applied in a variety of methods,¹⁻³ including permeability-modification treatments, single well stimulation, and microbial-enhanced waterflooding. The flexibility and potential cost-effectiveness of the technology make it attractive, but further understanding of the transport mechanisms of microorganisms and the development of a sound engineering methodology for optimizing microbial formulations and injection strategies through modeling studies are needed to realize its potential.

The transport of microorganisms (bacteria, fungi, and viruses) in porous media governs many phenomena in bioremediation of environmental pollution problems and microbial enhanced oil recovery (MEOR). The transport of microorganisms in subsurface formations is associated with complicated physical, chemical, and biological phenomena⁴⁻⁸ such as adsorption, interaction between microorganisms and substrate, and growth and decay of cells. However, limited information exists concerning the transport, growth, and metabolism of viable cells in subsurface environments. Some of the phenomena are still not well understood.

Although several attempts⁹⁻¹¹ have been made to describe microbial processes, no model has yet fully incorporated all of the complex phenomena that are believed to be important. The complexity of oil recovery by microbial formulations requires close coordination between laboratory mechanistic studies and oil displacement experiments under carefully controlled conditions to develop and validate a computer model. The accuracy of a simulator designed for MEOR processes is strongly dependent upon the accuracy of the equations used to describe the transport phenomena. This report explains the mathematical formulations and preparation procedures of data files of a three-dimensional, three-phase, multiple-component numerical model, MTS, with sample simulation problems, to describe microbial transport phenomena in porous media.

The developed MTS is suitable for simulating microbial transport in porous media for laboratory or field scale. The simulator assumes that microbes and nutrient are injected with water into porous media which may contain oil, water, and gas phases. In model calculations the microbes and nutrient are assumed to stay only in the aqueous phase. This simulation can be used to simulate either microbial flow among multiple wells or single well treatments. The reservoir model of MTS accepts three-dimensional heterogeneous distributions in porosity, permeability, saturations, and depth to the formation top or formation dip. Since no microbial oil recovery

mechanisms have been incorporated into MTS, improved oil production due to microbial treatment is not provided in model calculations. Modeling the microbial transport by MTS is the first step for developing a complete MEOR simulator.

1.1 Background

Reservoir simulators are routinely used for predicting the future performance of a reservoir and to explore methods for increasing the ultimate recovery of hydrocarbons from a reservoir. A reservoir simulator is a sophisticated computer program which solves a system of differential equations describing multiphase (oil, water, and gas) fluid flow in porous reservoir rock.

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

1. number of phases and components in each phase in the model -
it can either be a one-, two-, or three-phase model (gas, oil, and/or water) and each phase contains up to N components;
2. type of process to be modeled -
it can be either a black oil, compositional, or EOR processes simulator;
3. model dimension -
it can be either a one-, two-, or three-dimensional model; and
4. formulation to be used to solve the flow equations -
it can be solved by an IMPES (implicit in pressure - explicit in saturation), a fully, or a adaptively implicit method.

The microbial transport simulator is a three-dimensional, three-phase, multiple-component numerical model which simulates the flow of microorganisms and nutrients in the environment of black-oil reservoirs. An IMPES formulation is used in MTS to solve the pressure distribution within the reservoir rock.

The MTS is based on:

- chemical transport equations, continuity equations, and Darcy law;
- a set of finite-difference forms of flow equations for each component in each grid in the reservoir model to describe the flow of fluids and components through porous media;
- numerical schemes to solve the linearized finite-difference equations for fluid flow; and

- computer programming to perform numerical calculations electronically.

During microbial transport simulations, the reservoir is first divided into segments, or blocks in Cartesian coordinates. Rock properties, fluid saturations, and pressures are assigned to each block to describe the reservoir system. Computations are then carried out for all phases in each block at discrete time steps according to the injection-production strategy specified by the user in the data file. The results, or output, consist of production volumes and rates, distributions of concentration for microorganism and nutrient, pressure, and saturation, and other process specific information provided at selected time steps.

II. MODEL DESCRIPTION

Mathematical models for microbial transport processes were developed in two steps. The first step was to develop a mathematical model to predict the propagation and distribution of microorganisms and nutrients in porous media. This transport model accounts for physical phenomena that affect the transport of microbial systems such as diffusion, adsorption, growth and decay of microorganisms, and consumption of nutrients. Porosity reduction and permeability change due to cell clogging have been considered in this model. This model can be used to predict the concentration distributions for injected nutrients and microorganisms with various injection modes at either field or laboratory scale.

The second step was to incorporate the transport equations for microorganisms and microbial nutrients into a three-dimensional, three-phase (oil, water, and gas) black oil simulator BOAST.³ Distributions of pressure and oil/water/gas saturation in porous media were solved from the continuity equation. The Darcy flow velocity due to the pressure gradient in porous media was then used in the transport calculation for microorganisms and microbial nutrients. Using this simulator, transport of microorganisms can be investigated, and effects of microbial systems on oil recovery can be determined. This section presents the mathematical formulations of transport equations, continuity equations, and numerical solution methods used in MTS.

2.1 Microbial Transport Formulation

Based on the macroscopic mass balance equation for microbes, microbial transport in porous media is described by Eq. 1:

$$\begin{aligned} \vec{\nabla} \cdot \vec{D} \cdot \vec{\nabla} (\phi SC) - \vec{\nabla} \cdot (\vec{u}C) - k_m \vec{\nabla} \cdot (C \vec{\nabla} \ln C_f) + \phi S(\mu - k_d)C \\ + QC/V = \frac{\partial(\phi SC)}{\partial t} + \phi S k_c C - k_y \rho \sigma \left(\frac{\sigma}{\phi}\right)^h \end{aligned} \quad (1)$$

The five terms on the left-hand side of Eq. 1 correspond to the diffusion and dispersion, convection, chemotaxis, growth and decay, and injection/production of microbes, respectively. The right-hand side of Eq. 1 shows the accumulation, clogging, and declogging of microbes in the aqueous phase.

Like colloidal particles, microbes are subject to Brownian motion by which the path of the individual particle appears quite erratic. The chaotic, random movement of microbes is referred to as tumbling. This random movement is assumed to be superimposed upon mechanical

dispersion by introducing an effective diffusivity. The diffusion, tumbling, and dispersion of microbes are accounted for in the first term on the right-hand side of Eq. 1.

Microbes move systematically toward a richer food supply, and this motion, induced by the presence of nutrients, is called chemotaxis. The microbes detect and respond to a difference in nutrient concentration on a gradient of the nutrient. The motion of microbial cells is influenced by nutrient molecules through a chemical interaction rather than by the characteristic of Brownian motion. The chemotactic flow of microbes was assumed to follow an exponential gradient of nutrient concentration.⁴⁻⁵ The chemotactic coefficient, k_m , is a weakly function of nutrient concentration C_f . For the problems considered, it may be safely assumed as a constant.

Microbial growth occurs with the utilization of the nutrient. The growth of microbes, μ , was assumed to follow the Monod equation:¹²

$$\mu = \frac{\mu_m C_f}{K_s + C_f} \quad (2)$$

where μ_m is the maximum growth rate achievable and K_s is that value of the concentration of the substrate where the specific growth rate has half its maximum value. Values of μ_m and K_s can be obtained from experimental results. The decay rate was assumed to be a first-order reaction.

The accumulation of microbes on grain surfaces forms clusters. The straining effects increase with cluster growth until the clusters become unstably large and break off. The deposition (clogging) of microbes is by various mechanisms: adsorption, straining, and sedimentation. The clogging and declogging of microbes are expressed in the last two terms in Eq. 1. The clogging rate is assumed to be proportional to the microbial concentration. The power term in the declogging term dictates the desorption rate of microbes as a function of adsorption saturation on rock surface.⁴ The change in porosity of the porous medium was accounted for by the deposition of microbes:

$$\phi = \phi_o - \sigma \quad (3)$$

where ϕ_o is the original porosity of the porous medium. Permeability reduction due to the deposition of microorganisms in the rock pore space was assumed to follow:¹³

$$\log(k) = a_0 + a_1 \phi \quad (4)$$

where a_0 and a_1 are experimentally determined values.

The amount of deposited microbes, σ , in Eq. 1 is solved from Eq. 5:

$$\frac{\partial \sigma}{\partial t} = (\mu - k_d)\sigma + k_c \frac{\phi SC}{\rho} - k_y \sigma (\sigma)^\eta \quad (5)$$

Equation 5 describes the growth, decay, clogging, and declogging of microbes on the rock surface.

The nutrient, which is consumed by microbes, is assumed to be transported by convection and dispersion. It was shown that adsorption of nutrient, such as sucrose and molasses, in Berea rock can be ignored. Thus the transport of nutrient is described by Eq. 6:

$$\begin{aligned} \vec{\nabla} \cdot \vec{D}_f \cdot \vec{\nabla}(\phi SC_f) - \vec{\nabla} \cdot (\vec{u} C_f) - \mu (\phi SC + \rho \sigma) / Y + Q C_f / V \\ = \frac{\partial(\phi SC_f)}{\partial t} \end{aligned} \quad (6)$$

Shown on the left-hand side of Eq. 6, the dispersion, convection, consumption, and injection-production terms of nutrient make up the nutrient transport equation in the aqueous phase. As indicated in the third term on the left-hand side of Eq. 6, the rate of nutrient consumption is assumed to be proportional to the microbial growth rate and the microbial concentration in both aqueous phase and rock surface. The yield coefficient Y is defined as the mass of cells produced per unit of nutrient consumed. Equation 1 is coupled with Eq. 6 in solving concentration distributions of microbes and nutrients.

2.2 Black Oil Model

The flux terms in transport Eqs. 1 and 6 are solved from three-dimensional, three-phase continuity equations applicable in an environment of black oil reservoirs.¹⁴ The continuity equations are given by:

$$-\vec{\nabla} \cdot \left(\frac{\rho}{B} \vec{u} \right)_m - Q_m = \frac{\partial}{\partial t} \left(\frac{\phi \rho S}{B} \right)_m \quad (7)$$

where m = oil, water, or gas phase.

Sources (injectors) and sinks (producers) at various strengths are assigned through well rates (Q) in the model.

Black oil simulators describe multiphase flow in porous media without considering the change of composition of the hydrocarbon fluid with production time. They assume that the

liquid hydrocarbon phase consists of only two components: oil and dissolved-gas. The gas phase consists of only free hydrocarbon gas. It is assumed that the fluid phase behavior at the reservoir temperature can be represented by a pressure-volume-temperature (PVT) table which is a function of pressure only. An isothermal reservoir is assumed in the model.

The reservoir fluid approximations are found to be acceptable for a large percentage of the world's oil reservoirs. Thus, black oil simulators have a wide range of applicability and are routinely used for solving field production problems. Although black oil simulators are well suited for studies of numerous problems, they do have some limitations in their scope of application. They cannot be used to study cases where mass transfer between phases is important. For example, black oil simulators cannot be used to study problems associated with gas condensate and volatile oil reservoirs. In these reservoirs, the composition and physical properties of the phases change with pressure. Since reservoirs are usually pressurized during microbial injection, oil composition does not change much with production time so that the black oil model treatment is acceptable to the microbial transport simulations.

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

2.3 Numerical Solution

The solution of microbial transport is done in two steps in MST. The fluid flow Eq. 7 is first solved for Darcy velocity using the implicit pressure - explicit saturation (IMPES) procedure. A no-flow boundary of the reservoir is implemented by setting pressure gradient at boundary interfaces to zero. This is followed by the solution of transport equations of microbes (Eq. 1) and nutrients (Eq. 6). The Crank-Nicolson method¹⁵ was used in formulating the finite difference form of transport equations. Both microbial and nutrient concentrations were solved implicitly in space using a direct solution method for the sparse matrix. The amount of deposition of microorganism was then calculated, and the permeability was adjusted for pressure calculations in the next time step. The above solution procedures are repeated for each time step until the total simulation time is reached.

The microbial transport simulator employs IMPES formulation for solving its system of finite-difference equations. The IMPES method solves the pressure distribution for a given time step first, then the saturation distribution for the same time step. The IMPES formulation is

straightforward, requires less arithmetic per time step, and hence usually is faster than other formulations. The central processing unit (CPU) time for the iterative methods depends on the type of problem to be solved and the selection of the iterative parameter. Further, the IMPES formulation requires less storage than a fully implicit formulation. This permits the simulation of larger problems on a small computer such as a personal computer.

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

Time-step material balances are printed on each recurrent production report and should always be checked carefully before accepting any run as a 'final' result. In general, time-step material balance errors should normally be less than 0.1%. An excessive material-balance error is an indication of a large saturation and/or pressure change that causes the results of MTS to be invalid. The problem can usually be overcome by reducing the time-step size. This can be performed by specifying a smaller minimum time step-size and reducing saturation and pressure tolerances.

2.4 Data Input Requirements

The microbial transport simulator is a program that needs an input data file to run. This section describes briefly the input requirements for MTS. A complete description of the input data required to run MTS is given in Sections III and IV.

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

The recurrent data (Section IV) include the location and initial specifications of wells in the model, time step control information for advancing the simulation through time, a schedule

of individual well rates and/or pressure performance, changes in well completions and operations over time, and controls on the type and frequency of printout information provided by the simulator.

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

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

Only one value is required for the homogeneously distributed reservoir parameter. If a full grid of input values of rows (x-direction), columns (y-direction), and layers (z-direction) must be read for a particular parameter, the following input order must be followed:

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

The microbial transport simulator uses a right-hand coordinate reference. The z-direction values will increase going down. For $K = 1$, $II \times JJ$ values must be read in the following order.

$J = 1, I = 1, 2 \dots II$

$J = 2, I = 1, 2 \dots II$

$J = \dots$

$J = JJ, I = 1, 2 \dots II$

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

III. DATA INITIALIZATION

3.1 Introduction

This section describes in detail the microbial transport and reservoir model data required to initialize the simulation program. Listed in sub-section 3.10, microbial transport data include clogging-declogging, diffusion, chemotaxis, growth and decay, and nutrient consumption parameters. The reservoir model data include the model grid dimensions and geometry, porosity and permeability distributions, relative permeability and capillary pressure data, fluid PVT data, initial pressure and saturation distributions within the reservoir, run control and diagnostic parameters, time step control parameters, and parameters for numerical solution procedures. These data are read only once at the beginning of the simulation. They must be read in the order in which they appear in the following input data sections. Please refer the example data files of test problem 1 in appendix A and test problem 2 in appendix B.

The next several sub-sections describe in detail the input data for the simulator. In each sub-section of the data file a particular set of reservoir, fluid, or reaction data of the model is grouped together. Each input entry is illustrated by an example.

3.2 Grid Dimensions and Geometry

Line 1: Title or name of the run

READ: Header

FORMAT: 40A2

Note: This line is used to enter the title of the simulation program. Enter any desired alphanumeric run title information up to 80 characters.

Example: *MICROBIAL TRANSPORT TEST RUN*

Line 2: This line is used to enter the number of grid blocks in each direction.

READ: **II, JJ, KK**

II = number of grid blocks in the X-direction

JJ = number of grid blocks in the Y-direction

KK = number of grid blocks in the Z-direction

Example: 9 9 1

This specifies that there are 9 grid blocks each in the X- and Y-direction, respectively, and 1 in the Z direction.

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

READ: Header (40A2)

Example: *SO SHALE RESTART NGEL*

Line 4: Enter switch codes or flags.

READ: **NSO, NSHALE, NRESTART, NGEL**

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

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

NRESTART = 1, "RESTART" data file will be created at the end of simulation run.
0, "RESTART" data file will not be created at the end of simulation.

NGEL = 1, "Microbial Transport" option will be invoked.
0, "Microbial Transport" option will not be invoked and MTS will work as a regular black oil reservoir simulator.

Example: 0 0 0 1
This specifies that "Microbial Transport" option will be invoked.

Line 4A: Use this line to identify the following two lines for separate oil saturation files.
(Skip this line and go to line 5 if NSO = 0.)

READ: Header (40A2)

Example: *SEPARATE OIL SATURATION FILES*

Note: Enter lines 4A to 4C only if NSO = 1 entered from line 3.

Line 4B: Read the two-character tag for oil saturation files. (Go to line 5 if NSO = 0.)

READ: **TAG** (A2)

Example: A/
Oil saturation files A1SO01.DAT, A1SO02.DAT, A1SO03.DAT, will be created with production time up to a maximum of 40 files.

Line 4C: Read time increment in days for oil saturation files. (Go to line 5 if NSO = 0.)

READ: **SONTVL**

Example: 90.
The oil saturation files will be generated every 90 days.

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

READ: Header (40A2)

Example: *GRID BLOCK LENGTHS*

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

READ: **KDX, KDY, KDZ**

KDX = Code for specifying X-direction grid dimensions (see Table 3-1)
KDY = Code for specifying Y-direction grid dimensions (see Table 3-1)
KDZ = Code for specifying Z-direction grid dimensions (see Table 3-1)

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

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

READ: **DX**

Example: 147

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

Note: See table 3-1 for the number of values. When KDX = 0 or 1, the order of input must be as follows:

J = 1, I = 1, 2, II

J = 2, I = 1, 2, II

.....

J = JJ, I = 1, 2, II

TABLE 3-1. - Options for grid-block geometry

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

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

READ: **DY**

Example: *147.*

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

Note: See table 3-1 for the number of values. When KDY = 0 or 1, the order of input must be the same as that indicated in line 7.

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

READ: **DZ**

Example: *20.*

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

Note: See table 3-1 for the number of values. When KDZ = 1 the order of input must be as indicated in line 7 above with the layer order K = 1, 2, ..., KK.

3.3 Modifications to Grid Dimensions:

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

READ: Header (40A2)

Example: *GRID BLOCK DIMENSION MODIFICATIONS*

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

READ: **NUMDX, NUMDY, NUMDZ, IDCODE**

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

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

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

IDCODE = Print code for grid dimension alterations.

If IDCODE = 0, do not print the modified grid dimensions.

If IDCODE = 1, print the modified grid dimensions.

Example: *0 0 0 0*

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

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

READ: **I, J, K, DX**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

DX = New X-direction grid dimension (DX) for block (I, J, K)

Note: NUMDX lines must be read.

Line 4: Use NUMDY set of lines to enter the coordinates of the blocks in the Y-direction whose dimensions are to be modified; omit this line if NUMDY = 0.

READ: **I, J, K, DY**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

DY = New Y-direction grid dimension (DY) for block (I, J, K)

Note: NUMDY lines must be read

Line 5: Use NUMDZ set of lines to enter the coordinates of the blocks in the Z-direction whose dimensions are to be modified; omit this line if NUMDZ = 0.

READ: **I, J, K, DZ**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

DZ = New Z-direction grid dimension (DZ) for block (I, J, K)

Note: NUMDZ lines must be read.

3.4 Elevations to Top of Grid-Blocks in Layer I

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

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

READ: Header (40A2)

Example: *CAP ROCK AT BASE DEPTHS*

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

READ: **KEL**

KEL = Input code

REMARKS: (1) If KEL = 0, a single constant value is read for the elevation at the top of all grid blocks in Layer 1. (i.e., horizontal plane).

(2) If KEL = 1, a separate elevation value must be read for each grid block in Layer 1. II x JJ values must be read.

Example: 0

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

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

READ: **ELEV**

ELEV = Elevation to top of grid blocks in feet

Example: 8325.0

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

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

(2) When KEL = 1, read II x JJ values. These values must be read in the same order as indicated in line 7.

(3) Elevations to the top of the grid-blocks in layers below Layer 1 will be calculated by adding the layer thickness to the preceding layer elevation; i.e.,
 $TOP(I, J, K + 1) = TOP(I, J, K) + DZ(I, J, K)$

3.5 Porosity and Permeability Distributions

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

READ: Header (40A2)

Example: *POROSITY AND PERMEABILITY INPUTS*

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

READ: **KPH, KXX, KKY, KKZ**

KPH = Code for controlling porosity input data (See table 3-2)

KXX = Code for controlling X-direction permeability (See table 3-2)

KKY = Code for controlling Y-direction permeability (See table 3-2)

KKZ = Code for controlling Z-direction permeability (See table 3-2)

Example: -1 -1 -1 -1

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

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

READ: **PHI**

Example: 0.25 Specifies 25% porosity.

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

(b) See table 3-2 for the number of values. When KPH = + 1, the order of input must be as indicated below with layer order

for K = 1,2, . . . KK:

J = 1, I = 1,2, II

J = 2, I = 1,2, II

.....

J = JJ, I = 1,2, II

TABLE 3-2. - Options for grid-block properties

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

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

READ: **KX**

KX = X-direction permeability values

Example: 200.0

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

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

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

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

READ: **KY**

KY = Y-direction permeability values (in millidarcies)

KY is a real variable

Example: 200.0

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

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

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

READ: **KZ**

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

KZ is a real variable

Example: 20.0

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

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

3.6 Modifications to Porosity and Permeability Distributions

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

READ: Header (40A2)

Example: *POROSITY AND PERMEABILITY MODIFICATION*

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

READ: **NUMP, NUMKX, NUMKY, NUMKZ, IPCODE**

NUMP = Number of grid-blocks where porosity (PHI) values are to be changed
 NUMKX = Number of grid-blocks where X-direction permeability values (KX) are to be changed
 NUMKY = Number of grid-blocks where Y-direction permeability values (KY) are to be changed
 NUMKZ = Number of grid-blocks where Z-direction permeability values (KZ) are to be changed
 IPCODE = Print code for porosity and permeability alterations
 If IPCODE $\neq$ 0, do not print modified porosity and permeability alterations
 If IPCODE = 1, print modified porosity and permeability distribution

Example: 2 0 0 0 1

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

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

READ: **I, J, K, PHI**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Example: 1 1 1 0.125

9 1 1 0.125

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

Note: (1) Porosity must be entered as a fraction
(2) NUMP lines must be read

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

READ: **I, J, K, KX**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Note: (1) NUMKX lines must be read
(2) KX is a real variable

Example: No line in our example problem.

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

READ: **I, J, K, KY**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Example: No line in our example problem.

Note: (1) NUMKY lines must be read
(2) KY is a real variable

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

READ: **I, J, K, KZ**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Example: No line in our example problem.

Note: (1) NUMKZ lines must be read
(2) KZ is a real variable

3.7 Transmissibility Modifications

The shale zero option is invoked only if SHALE = 1 is entered in section 3.2. If SHALE = 0, go to line 7 in section 3.7.2.

3.7.1 Shale Zeroing Options

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

READ: Header (40A2)

Example: *SHALE BREAKS*

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

READ: NSHOPS

NSHOPS = Code for selecting shale options

Example: 0; this specifies no shale (option)

REMARKS: (1) If NSHOPS = 0, no shale option is selected. Go to Line 7

(2) If NSHOPS = 1, zero out the entire layer(s) i.e., continuous shale layer.

(3) If NSHOPS = 2, simulate broken layers, i.e., discontinuous shale layer

(4) Skip lines 3 through 6 if NSHOPS = 0

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

READ: NTLAYR

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

Example: No line in our example problem.

Line 4: Omit this line if NSHOPS = 2.

Line 4 is used to enter the location of an interface where transmissibilities are to be zeroed. Read NTLAYR values; one value per line.

READ: KT

KT = Location of the interface

Example: No line in our example problem.

Note: (1) NTLAYR lines must be read

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

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

Line 5: Omit this line if NSHOPS = 1

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

READ: KT, NUTM

KT = location of the interface

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

Example: No line in our example problem.

Note: (1) NTLAYR lines must be read.

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

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

(4) Read this line only if $NSHOPS = 2$

Line 6: Omit this line if $NSHOPS = 1$

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

READ: **IGBL**

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

Example: No line in our example problem.

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

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

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

$NSHOPS = 1$

$NTLAYR = 3$

$KT = 2$

$KT = 4$

$KT = 6$

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

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

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

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

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

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

NSHOPS = 2

NTLAYR = 3

KT,NUTM = 2,2

IGBL = 2

IGBL = 5

for NUTM = 2

for NTLAYR = 1

KT, NUTM = 3,3

IGBL = 1

IGBL = 3

IGBL = 4

for NUTM = 3

for NTLAYR = 2

KT NUTM = 5, 1

IGBL = 2

for NTLAYR = 3

Explanation: In the above example, broken shale (discontinuous) streak occurs along three interfaces; between layers 1 and 2 (KT = 2) two (NUTM = 2) values of Z-direction

transmissibility will be zeroed resulting in no flow between blocks (2,1,1) and (2,1,2) and no flow between blocks (5,1,1) and (5,1,2) (IGBL = 2 and 5). The remainder of the sequence zeros flow between blocks: (1,1,2) and (1,1,3); (3,1,2) and (3,1,3); (4,1,2) and (4,1,3); (2,1,4) and (2,1,5).

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

3.7.2 Grid-Transmissibility Modification

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

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

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

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

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

READ: Header (40A2)

Example: *TRANSMISSIBILITY MODIFICATIONS*

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

READ: **NUMTX, NUMTY, NUMTZ, ITCODE**

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

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

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

ITCODE = Print code for transmissibility modification

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

If ITCODE = 1, print the modified transmissibility distributions

Example: 0 0 0 0

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

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

READ: **I, J, K, TX**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Note: NUMTX lines must be read

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

READ: **I, J, K, TY**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Note: NUMTY lines must be read

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

READ: **I, J, K, TZ**

I = X-coordinate of block to be modified

J = Y-coordinate of block to be modified

K = Z-coordinate of block to be modified

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

Note: NUMTZ lines must be read

3.8 Relative Permeability and Capillary Pressure Tables

Line 1: Use this line to input table headings.

READ: Header (40A2)

Example: *SAT KRO KRW KRG PCOW PCGO*

Line 2: Read relative permeability and capillary pressure tables.

READ: **SAT1 KRO1 KRW1 KRG1 PCOW1 PCGO1**

SAT2 KRO2 KRW2 KRG2 PCOW2 PCGO2

.....

SATn KROn KRWn KRGn PCOWn PCGO n

Note: (1) SATn must be 1.1 or greater

(2) Read each saturation as a fraction in ascending order

(3) Read as many lines as there are table entries (Maximum number of table entries allowed is assigned in the 'DIMENSION' block in MTS)

(4) KRO, KRW etc. are real variables

Example:

0.0	0.0	0.0	0.0	0.	0.	Begin the relative permeability/capillary pressure data with lowest saturation.
0.10	0.0	0.0	0.0	0.	0.	
0.20	0.0015	0.0	0.075	0.	0.	
0.30	0.0023	0.0122	0.190	0.	0.	
0.40	0.0370	0.0244	0.410	0.	0.	
0.50	0.0571	0.0336	0.72	0.	0.	
0.60	0.134	0.0672	0.87	0.	0.	
0.70	0.207	0.1344	0.94	0.	0.	
0.80	0.604	0.2688	0.966	0.	0.	
0.90	1.00	0.4704	0.993	0.	0.	

1.10 1.0 0.5 1.0 0 0. Saturation greater than or equal to 1.10 specifies the end of the relative permeability/capillary pressure data.

SAT = Phase saturation

KRO = Oil phase relative permeability, fraction

KRW = Water phase relative permeability, fraction

KRG = Gas phase relative permeability, fraction

PCOW = Oil-water capillary pressure, psi

PCGO = Gas-oil capillary pressure, psi

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

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

3.9 Oil-Water-Gas PVT Tables

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

READ: Header (40A2)

Example: *PBO VSLOPE BSLOPE RSLOPE PMAX IREPRS*

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

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

PBO = Initial reservoir oil bubble-point pressure, psia

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

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

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

PMAX = Maximum pressure entry for all PVT tables, psia

IREPRS = Code for repressurization algorithm;

IREPRES = 0 means no repressurization will be performed,

IREPRES = 1 means repressurization will be performed.

Example: 4014.7 0.0 -0.000001 0. 9014.7 1

- Notes: (1) VSLOPE, BSLOPE and RSLOPE are used only for under-saturated oil
(2) BSLOPE should be a negative number and is related to under-saturated oil compressibility, C_o by $C_o = BSLOPE/BO$
(3) Normally, RSLOPE will be zero
(4) If IREPRS = 0, a new bubble-point pressure will be calculated for each grid block containing free gas at the end of each time step.
(5) PMAX (9014.7 in this example data file) is used as a termination flag for other PVT input variables.

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

READ: Header (40A2)

Example: PRES VISCO BO RSO

Line 4: Read oil PVT data.

READ: P1 MUO1 BO1 RSO1
P2 MUO2 BO2 RSO2

.....

PMAX MUOn BOn RSO_n

P = Pressure, psia

MUO = Oil viscosity, cp

BO = Oil formation volume factor, RB/STB

RSO = Solution gas-oil ratio, SCF/STB

Example: 14.7 2.0 1.5 1.0

4014.7 2.0 1.5 1.0

9014.7 2.0 1.5 1.0

PMAX (9014.7) specifies end of oil PVT data

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

- (2) Oil properties must be entered as saturated data over the entire pressure range. Laboratory saturated oil data will generally have to be extrapolated above the measured bubble-point pressure to cover the maximum pressure range anticipated during the simulation run. The saturated oil data are required because of the bubble-point tracking scheme used by MTS.
- (3) The saturated oil data above the initial bubble point pressure will only be used if the local reservoir pressure rises above the initial bubble point pressure and free gas is introduced. An example of this would be pressure maintenance by gas injection into the oil zone.

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

READ: Header (40A2)

Example: *PRES VISW BW RSW*

Line 6: Read water PVT data.

READ: **P1 MUW1 BW1 RSW1**

P2 MUW2 BW2 RSW2

.....

PMAX MUWn BWn RSWn

P = Pressure, psia

MUW = Water viscosity, cp

BW = Water formation volume factor, RB/STB

RSW = Solution gas-water ratio, SCF/STB

Example: *14.7 1.0 1.0 0.0*

4014.7 1.0 1.0 0.0

9014.7 1.0 1.0 0.0

PMAX (9014.7) specifies end of water PVT data

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

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

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

READ: Header (40A2)

Example: *PRES VISG BG CR*

Line 8: Read gas PVT data and rock compressibility.

READ: **P1 MUG1 BG1 CR1**

P2 MUG2 BG2 CR2

.....

PMAX MUGn BGn CRn

P = Pressure, psia

MUG = Gas viscosity, cp

BG = Gas formation volume factor, RCF/SCF

CR = Rock compressibility, psi⁻¹

Example: 14.7 0.0080 0.935800 0.000003
 514.7 0.0112 0.035228 0.000003
 1014.7 0.0140 0.017951 0.000003
 2014.7 0.0189 0.009063 0.000003
 3014.7 0.0228 0.006064 0.000003
 5014.7 0.0309 0.003644 0.000003
 9014.7 0.0470 0.002167 0.000003 PMAX (9014.7) specifies end of gas PVT data.

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

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

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

READ: Header (40A2)

Example: *RHOSCO RHOSCW RHOSCG*

Line 10: Read stock tank fluid densities.

READ: **RHOSCO, RHOSCW, RHOSCG**

RHOSCO = Stock tank oil density, lb/cu ft

RHOSCW = Stock tank water density, lb/cu ft

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

Example: 46.24 62.24 0.0647

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

3.10 Microbial Transport Data

Only if NGEL = 1 is entered in section 3.2, transport data of the microbial system are entered in this section. If NGEL = 0, no microbial transport calculation will be conducted, and no microbial transport data are required; therefore; go to section 3.11. The physical meaning of parameters required in the transport equation is explained in Section II.

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

READ: Header (40A2)

Example: *MICROBIAL TRANSPORT DATA.*

Line 2: Use this line to enter microbial density, cell yield coefficient, and amount of gas produced from consumption of each lb of nutrient.

READ: **RHOMIC, YIELD, GASMEOR**

RHOMIC = Microorganism density, lb/cu ft

YIELD = Cell yield coefficient

GASMEOR = Amount of gas generation by nutrient, cu ft/lb

Example: 62.37 0.53 0.15

Line 3: Use this line to enter parameters of microbial clogging-declogging reactions.

READ: **AKC, AKY, AKDN, SIGMAX, REDK**

AKC = Clogging rate constant, day^{-1}

AKY = Declogging rate constant, day^{-1}

AKDN = Declogging coefficient

SIGMAX = Declogging parameter

REDK = Permeability-porosity reduction factor

Example: 5.62 37.58 0. 0.3 25.2

Line 4: Use this line to enter parameters of microbial growth and decay.

READ: **AKD, AKS, AMUM**

AKD = Specific decay constant, day^{-1}

AKS = Monod half growth constant, mg/mL

AMUM = Maximum growth rate, day^{-1}

Example: 0.086 6.237 9.12

Line 5: Use this line to enter chemotaxis coefficient of microorganisms.

READ: **AKM**

AKM = Chemotaxis coefficient

Example: 0.

Line 6: Use this line to enter dispersion coefficients in the aqueous phase.

READ: **ALPHAL, ALPHAT**

ALPHAL = Longitudinal dispersion coefficient, ft

ALPHAT = Transverse dispersion coefficient, ft

Example: 0. 0.

Line 7: Use this line to enter microbial tumbling coefficient.

READ: **DTUMB**

DTUMB = Tumbling coefficient, ft^2/day

Example: 0.

Line 8: Use this line to enter diffusion coefficients of nutrient.

READ: **DDX(1), DDY(1), DDZ(1)**

DDX(1) = Nutrient's diffusion coefficient in X-direction, ft²/day

DDY(1) = Nutrient's diffusion coefficient in Y-direction, ft²/day

DDZ(1) = Nutrient's diffusion coefficient in Z-direction, ft²/day

Example: 0.0002 0.0002 0.0002

Line 9: Use this line to enter diffusion coefficients of microorganisms.

READ: **DDX(2), DDY(2), DDZ(2)**

DDX(2) = Microbial diffusion coefficient in X-direction, ft²/day

DDY(2) = Microbial diffusion coefficient in Y-direction, ft²/day

DDZ(2) = Microbial diffusion coefficient in Z-direction, ft²/day

Example: 0.0002 0.0002 0.0002

3.11 Pressure and Saturation Initialization

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

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

READ: Header (40A2)

Example: *INITIAL PRESSURE & SATURATION BASED ON EQUILIBRIUM CONDITION*

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

READ: **KPI, KSI**

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

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

Example: 0 0

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

Skip this line if KPI = 1 or 2.

If KIP = 0 then

READ: **PWOC, PGOC, WOC, GOC**

PWOC' = Pressure at the water-oil contact, psia

PGOC' = Pressure at the gas-oil contact, psia

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

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

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

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

Example: 4806.6 0.0 8425.0 8300.0

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

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

Line 4: Use this line to enter the non-equilibrium pressure initialization data.

Skip this line if KPI = 0.

(a) If KPI = 1, then

READ: **P**

P = Pressure for the entire grid, psia

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

$J = 1 \quad I = 1, 2, \dots, II$

$J = 2 \quad I = 1, 2, \dots, II$

.....

$J = JJ \quad I = 1, 2, \dots, II$

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

(b) If $KPI = 2$, then

READ: **P**

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

Example: 4800. 4810. 4820.

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

(2) Input this record only if $KPI = 2$

Line 5: Use this line to initialize the saturation data for a constant saturation case.

If $KSI=0$, then see (a) below. If $KSI = 1$, then see (b) below. If $KSI = 2$, then see (c) below.

(a) If $KSI = 0$, then

READ: **SOI, SWI, SGI**

SOI = Initial oil saturation to be assigned to all grid blocks in the model

SWI = Initial water saturation to be assigned to all grid blocks in the model

SGI = Initial gas saturation to be assigned to all grid blocks in the model

Example: 0.8 0.2 0.0

Note: Input all saturation values as a fraction.

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

READ: **SO, SW**

SO = Initial oil saturation array

SW = Initial water saturation array

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

$J = 1 \quad I = 1, 2, \dots, II$

$J = 2 \quad I = 1, 2, \dots, II$

.....

$J = JJ \quad I = 1, 2, \dots, II$

- (2) A value of S_w must be read for each grid block in the model grid. Read a total of $II \times JJ \times KK$ values. The order of input must be as indicated above (see note 1) with layer order $K = 1, 2, \dots, KK$
- (3) Input this record only if $KSI = 1$

(c) If $KSI = 2$, then

READ: **SO**

READ: **SW**

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

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

Example: 0.8 0.5 0.9

0.2 0.5 0.1

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

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

3.12 Debug and Diagnostics Codes

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

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

READ: Header (40A2)

Example: *KSN1 KSM1 KCO1 KTR KCOF*

Line 2: Use this line to input diagnostics codes.

READ: **KSN1, KSM1, KCO1, KTR, KCOF**

KSN1 = LSOR parameter debug output control (see table 3-4)

KSM1 = Solution matrix debug output control (see table 3-4)

KCO1 = Compressibility and formation volume factors debug output control (see table 3-4)

KTR = Transmissibility debug output control (see table 3-4)

KCOF = Density and saturation debug output control (see table 3-4)

Example: 0 0 0 0 0

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

TABLE 3-4. - Options for controlling diagnostics output

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

3.13 Run Control Parameters

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

READ: Header (40A2)

Example: *NMAX FACT1 FACT2 TMAX WORMAX GORMAX PAMIN PAMAX*

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

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

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

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

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

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

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

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

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

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

Example: 500 1.2 0.5 365.0 20.0 500000.0 14.7 10000

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

- (a) simulation time steps exceed 500 or
- (b) simulation run time exceeds 1 year (365 days) or
- (c) total producing water-oil ratio exceeds 20 STB/STB or
- (d) total producing gas-oil ratio exceeds 500,000 SCF/STB or
- (e) average reservoir pressure falls below 14.7 psia or
- (f) average reservoir pressure exceeds 10,000 psia.

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

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

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

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

- (a) If at the beginning of a time-step, the maximum grid-block pressure and saturation changes from the previous step are less than DPMAX and DSMAX, respectively (DPMAX and DSMAX are defined in Section 3.14), the size of the current time-step will be increased by FACT1
- (b) If at the beginning of a time-step, the maximum grid-block pressure or saturation change from the previous step is greater than DPMAX or DSMAX, respectively, the size of the current time-step will be decreased by FACT2
- (c) If at the end of one iteration (after new pressures and saturations are calculated), the maximum pressure change exceeds DPMAX or the maximum saturation

change exceeds DSMAX, and FACT2 < 1.0, the size of the current time-step will be decreased by FACT2 and the iteration will be repeated.

3.14 Solution Method Control Parameters

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

READ: Header (40A2)

Example: *MITR OMEGA TOL TOL1 DSMAX DPMAX*

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

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

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

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

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

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

DSMAX = Maximum saturation change (fraction) permitted over a time-step. The time-step size will be reduced by FACT2 if FACT2 < 1.0 and the saturation change of any phase in any grid-block exceeds DSMAX and the current step-size is greater than DTMIN. If the resulting step-size is less than DTMIN, the time-step will be repeated with the step-size DTMIN. A typical value of DSMAX is 0.05

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

Example: *100 1.70 0.1 0.0 0.05 50.0*

IV. RECURRENT DATA

4.1 Introduction

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

Recurrent data record pairs are input which control printed output and time-step size for a specified time period. The first parameter (IWLCNG) on the first recurrent data record specifies whether or not to read well information. If IWLCNG = 0, well information is not read. If IWLCNG = 1, well information is read immediately following the recurrent data record pair. In any case, the simulator advances through time-steps until the specified elapsed time (ICHANG times DT) has occurred. During this period, all print codes and the latest well information applies. At the end of this period, a new set of recurrent data records are read again. This reading process of recurrent data records is repeated until the cumulative simulation time TMAX specified in section 3.13 is reached or exceeded. A general flow diagram outlining the data input structure for recurrent data is shown in Fig. 3.

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

READ: Header (40A2)

Example: *RECURRENT DATA RECORDS*

Note: This line is read only once.

Line 2: Use this line to signify the time increment (in day) for printing simulation results in the rate summary report.

READ: **DTPRINT**

Example: 5.

This example specifies that key simulation results will be printed every 5 days in the rate summary report.

Note: This line is read only once.

FIGURE 3. - Flow chart of data input structure for recurrent data.

4.2 Time-Step and Output Control Codes

- Note: (a) Recurrent data record pairs are read at preselected times
- (b) A recurrent data record 'pair' consists of one integer control record and one time-step size specification record
- (c) Lines 1 and 2 below constitute a recurrent data record pair. These records may be read any number of times during a simulation run until the cumulative simulation time TMAX specified in section 3.13 is reached or exceeded
- (d) Well information records (section 4.3) must be read immediately following each pair of recurrent data records if and only if IWLCNG = 1
- (e) If well information is read, all specified rates and pressures will be used this time-step and all subsequent time-steps until new well information is read

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

READ: **IWLCNG, ICHANG, IWLREP, ISUMRY, IPMAP, ISOMAP, ISWMAP, ISGMAP, IPBMAP, ICHMAP, NGEL**

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

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

IWLREP = Output code for printing well report, (1 = print, 0 = no print)

ISUMRY = Output code for printing summary report, (1 = print, 0 = no print)

IPMAP = Output code for printing pressure distribution, (1 = print, 0 = no print)

ISOMAP = Output code for printing oil saturation distribution, (1=print, 0=no print)

ISWMAP = Output code for printing water saturation distribution, (1 = print, 0 = no print)

ISGMAP = Output code for printing gas saturation distribution (1=print, 0=no print)

IPBMAP = Output code for printing bubble-point pressures (1 = print, 0 = no print)

ICHMAP = Output code for printing microbial and nutrient distribution, (1 = print, 0 = no print)

NGEL = Flag code for invoking microbial transport calculation

If NGEL = 0, no transport calculation, e.g. during waterflood

If NGEL = 1, invoke transport calculation

Example: 1 1 1 1 0 0 0 0 0 0 0

The above example specifies that:

- (a) Well information is read at this step;
- (b) 1 is to be used as the number for calculating the time period for which this recurrent data will apply;
- (c) well report and summary reports are to be printed at this step;
- (d) no pressure, saturation, or microbial/nutrient concentration maps are to be printed at this step; and
- (e) no microbial and nutrient transport calculations.

Note: (1) If IWLCNG = 1, well information lines must be read.

- (2) If 'ETI' is the time at the beginning of the current step, then this recurrent data record pair will apply from ETI until FTMAX = ETI + ITIME where ITIME = ICHANG times DT. DT is the initial time-step size for this period as read in line 2 below.
- (3) The actual number of time-steps for which ICHANG is used will likely be different from ICHANG if automatic time-step control is 'on.' Whenever the calculated simulation time exceeds 'FTMAX,' the current step-size is reduced to give an elapsed time of exactly FTMAX. Whenever FTMAX is reached, another recurrent data record pair is read.
- (4) If the output code value = 0, the information will not be printed.
If the output code value = 1, the information will be printed for each time-step during this period from ETI days to ETI + ITIME days.
- (5) NGEL should be set to 0 before injection of microorganisms to save model computation time. Once the microbial injection is initiated, NGEL should be always set to 1 in subsequent time steps.

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

READ: **DT, DTMIN, DTMAX**

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

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

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

Example: 3.0 3.0 3.0

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

- Note: (a) The time period referred to is the time for which this recurrent data pair will be used. This period is from the current simulation time (ETI) to an elapsed time of ETI + ITIME, where ITIME = ICHANG times DT.
- (b) Common (suggested) values for DTMIN and DTMAX are 0.1 and 10.0 days, respectively.

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

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

4.3 Well Information Records

Line 1: Use this line to describe well activities. (Omit this line if $IWLCNG = 0$)

READ: Header (40A2)

Example: *NUMBER OF WELLS*

Line 2: Total number of vertical wells for which well information is to be read (Omit this line if $IWLCNG = 0$)

READ: **NVQN**

NVQN = Number of vertical wells

Example: 2; specifies 2 vertical wells

Note: (1) Must repeat lines 3, 4, 5, 6 a total of NVQN times

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

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

READ: **WELLID**

WELLID = five character well name

Example: *PROD1*; this indicates the vertical well name is PROD1

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

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

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

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

PERFI = Layer number of the uppermost layer completed.

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

KIP = Code for specifying both well type and whether the well's production (injection) performance is determined by specifying rates or specifying flowing bottomhole pressure and also whether an explicit or implicit pressure calculation is to be made. For most cases, the implicit pressure calculation is recommended. See Table 4-1 for the code details. For more information on KIP see the notes of this section.

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

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

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

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

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

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

Note: (1) Table 4-1 summarizes all well control options

- (2) Negative rates indicate fluid injection; positive values indicate fluid production.
- (3) NLAYER must include all layers from PERFI to the lower most layer completed. For example, in a 5-layer model, if a well is completed in layers 2, 3, & 5, set PERFI = 2 and NLAYER = 4. Note that in this, layer 4 must be included in NLAYER even though layer 4 is not perforated. Layer 4 may be shut in by specifying a large SKIN value (e.g. 9999) for layer 4 in line 4 below.
- (4) The total fluid rate given by QT is the oil plus water plus gas production for the well or the total reservoir voidage at stock tank conditions.
- (5) Only one of the four values (QO, QW, QG, or QT) may be nonzero. If KIP < 0, all four values should be zero.
- (6) For most applications, implicit pressure calculations are recommended.
- (7) If KIP = 2, -2 or -12, only water will be produced or injected; if KIP = 3, -3, or -13, only gas will be produced or injected; solution gas is not considered; therefore, these options are only recommended for water or gas injection wells. If KIP = 1, -1, or -11, oil, water, and gas will be produced in proportion to fluid mobilities and pressure constraints.
- (8) If KIP > 0, the specified rate will be allocated to layers based on total layer mobilities; e.g. if QW is specified and there are two layers $QW1 = QW * TM1 / (TM1 + TM2)$ and $QW2 = QW * TM2 / (TM1 + TM2)$, where TM1 = total mobility for layer 1 and TM2 = total mobility for layer 2.

TABLE 4-1. - Options for controlling well performance

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

Line 5: Use this line to enter wellbore radius, skin, and flowing bottomhole pressure in each layer for vertical well. Wellbore radius and skin values are used to calculate layer productivity index PID. (Omit this line if IWLCNG = 0)

READ: **RW, SKIN, PWF**

RW = Wellbore radius, ft

SKIN = Wellbore skin (no unit)

PWF = Layer flowing bottomhole pressure, psia

Example: 0.25 0.0 2500.0

Note: (1) Exactly NLAYER lines must be read (even if the well is rate controlled). Each of these lines specify a wellbore radius (RW), skin (SKIN), and flowing bottomhole pressure (FBHP) for one completion layer; thus, NLAYER of these lines must be read. The first line read applies to the uppermost completion layer (PERFI);

additional lines apply to succeeding layers. If rates are specified for this well (KIP = +1, +2, or +3), PWF will not be used and should be read as zero; however, RW and SKIN will be used to calculate a FBHP for the well. This FBHP will be printed out on the well report, but it will not be used in any way to control the well performance.

- (2) The layer productivity index PID is calculated from Peaceman's formula in the model.
- (3) Formation damage or stimulation at any point in time can be handled on a layer-by-layer basis by changing the layer SKIN.

Example This illustrates the well information for well 2, INJ1

```
1 1 1 1 2 0 -900.0 0.0 0.0
0.25 0.0 7500.0
```

The above example specifies that well number 2 is an injection well (INJ1), is located in the grid block (1,1,1), completed in one layer; the well is a water injection well (KIP=2) and the injection rate is 900 STB/D. The layer wellbore radius for this well is 0.25 ft, skin factor is 0.0, and the flowing bottomhole pressure 7500 psia will not be used in calculations.

Line 6: Use this line to enter injection concentration of microorganism and nutrient. (Omit this line if IWLCNG = 0, or NGEL=0, or for production well)

READ: CQI(1), CQI(2)

CQI(1) = injection concentration of microorganism, mg/mL

CQI(2) = injection concentration of nutrient, mg/mL

Example: 2.5 1.8

The above example specifies that the well injects 2.5 mg/mL of microorganism and 1.8 mg/mL of nutrient into the reservoir.

V. MODEL OUTPUT

The microbial transport simulator generates two output files: rate summary report and regular output report. This section provides a brief description of these two output reports. Example output files of test problems 1 and 2 are listed in the appendix.

5.1 Rate Summary Report

The rate summary report provides a quick overview of simulation results of the production history in a table format. The information listed includes average reservoir pressure, production and injection data of oil, water, and gas, respectively, and produced concentrations with simulation times. The variation of oil rates, water-oil ratio, and gas-oil ratio reveal useful information about the performance and production status of the reservoir. If an automatic time step control is employed, the number of time steps used is a good indicator of computation time required and how fast the change of saturations or pressures in the reservoir model.

5.2 Regular Output Report

The regular output file of MTS provides a complete report of simulation results. This regular output report consists of two parts: (1) reservoir, fluid, and well data initialized by the user, and (2) recurrent production report at times specified by the user.

5.2.1 Model Start Up

At model start up the program always writes the initialization data to the output file. The program also writes the initial well locations and well control information to this file. In addition to providing a complete report, this gives the user an excellent opportunity to quickly check for input data errors. The information printed prior to the first summary report consists of the following items, in the order given:

- (1) Grid-block sizes;
- (2) Node midpoint elevations;
- (3) Porosity distribution;
- (4) Permeability distribution;
- (5) Relative permeability and capillary pressure table;
- (6) Oil-water-gas PVT table;
- (7) Slopes calculated from PVT data for use in determining fluid compressibilities;
- (8) Microbial system parameters;
- (9) Solution method parameters and time-step control data;

- (10) Initial well locations and well control information;
- (11) Initial fluids in place by layer; and
- (12) Initial pressure and saturation distributions.

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

5.2.2 Recurrent Production Report:

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

1. Well report;
2. Summary report;
3. Pressure and saturation distribution arrays;
4. Microbial and nutrient distributions; and
5. Porosity reduction distribution.

Well Report:

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

Summary Report:

The summary report provides useful information which can also be obtained at any desired time. The summary report contains a concise summary of field injection and production performance information including (a) average reservoir pressure, (b) total reservoir oil, water, and gas production rates and cumulative production, (c) total reservoir water, and gas injection rates and cumulative injection, (d) total reservoir current and cumulative water-oil, and gas-oil ratios, (e) time-step and material balances for oil, water, and gas, and (f) maximum pressure, and saturation changes for the current time-step, and where these changes are occurring in the reservoir model.

The summary report serves two major purposes by permitting the user to (1) quickly review total reservoir performance and (2) determine if the model is functioning properly. As a

general rule, maximum saturation changes nearly always should be less than 5%, and time-step material balance errors should normally be less than 0.1%.

Material balances or saturation changes that are excessive do not necessarily mean that the model cannot handle the problem at hand. However, it does mean that adjustments are needed to some of the input parameters. Normally, the first adjustment is reduction of time-step size. If this modification does not completely solve the problem, reduce injection and/or production rates to determine if well controls are excessive based on existing flow capacity and reservoir pressure. By making full use of automatic time-step control and being careful not to over-pressure or overproduce the reservoir, most reservoir production-injection problems with or without microbial treatment can be properly simulated using MTS.

Pressure and Saturation Distributions:

The user may output pressure, saturation, and bubble-point pressure arrays at any time-step desired. Distributions of pressure and saturations provide useful information about fluid flow in the reservoir and strategies for optimizing production and injection. For large two-dimensional or three-dimensional problems, an enormous output file can result if all these arrays are frequently printed. Therefore, these distributions should only be printed when needed. Normally, the bubble-point pressure array need not ever be printed out. This array provides mainly diagnostic information.

The pressure and saturation arrays should always be checked carefully at discrete times during the simulation to assure that overall pressure and saturation trends are as they should be. Reducing the time step size of simulation usually will eliminate or reduce the numerical dispersion which results in distorted distributions of pressure and saturations. Also, if a material balance problem exists, these maps may help to isolate the problem.

Microbial, Nutrient, and Porosity Reduction Distributions:

Distributions of microbial, nutrient, and porosity reduction are printed for user's information about the microbial transport in porous media. The nutrient concentration is closely associated with the microbial concentration for the growth and decay of microorganisms in porous media. The porosity reduction (in fraction) reflects the amount of deposition of microorganisms on the rock grain surface. The decrease of permeability is calculated according to the logarithm relation (Eq. 5 in section II) and parameters defined by the user in the input file.

VI. EXAMPLE PROBLEMS

6.1 Introduction

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

6.2 Problem Description

Among the two example problems, one problem demonstrates the simulation of coreflood experiments and the other problem illustrates the application of MTS in field-scale simulation. Parameters of microbial transport system used in the example problems were determined from laboratory experiments or from simulation matches of laboratory tests using the developed MTS model. The laboratory experiments performed include microbial coreflood tests and flask tests.

A maximum growth rate of 8.4 day^{-1} was determined for microorganism NIPER1 in the laboratory. The decay rate constant measured from the population change during the period of 600 hours is 0.22 day^{-1} . The cell yield coefficient, Y , of 0.5 is computed from the nutrient consumption rate. The relative permeability values used were determined from a microbial coreflood in the laboratory.¹⁶ Table 6-1 lists the microbial system parameters used in the example problems.

TABLE 6-1. Microbial system parameters used in simulations

Diffusion coefficient	
microbes, ft^2/day	0.0055
nutrient, ft^2/day	0.0083
Declogging rate constant, day^{-1}	37.
Declogging parameter	0
Cell yield coefficient (Y)	0.5
Monod half growth constant, $\text{lb}/\text{cu ft}$	0.5 or 6.23
Maximum growth rate, day^{-1}	8.4
Decay rate, day^{-1}	0.22
Chemotaxis coefficient	0.

A brief description of each example problem is given below. The input file and partial output file for each example are in the appendices.

6.2.1 Coreflood Simulation

Mathematical simulations¹⁷ can be performed to match microbial transport systems in coreflood tests (one-dimensional system) for determining parameters such as diffusion, adsorption, concentration profiles, and pressure profiles. The core model was dimensioned at 50 by 1 by 1 in the simulation run of example problem 1.

Test Problem 1:

One microbial/nutrient coreflood experiment was simulated. In the simulation, an 11-inch core was injected with 0.1 pore volume of microbes and nutrient (4% molasses) followed by injections of 0.2 pore volumes of nutrient. The core was then shut-in for three days before the initiation of waterflood. Simulation results show that the microbial concentration decreased with the core length and waterflood due to the loss of microbes to rock adsorption. The nutrient concentration decreased with waterflood because of the microbial consumption. This example problem demonstrated the capability of MTS in simulating microbial coreflooding procedures.

6.2.2 Field-Scale Simulation

The field-scale simulation (two-dimensional system) run was conducted using MTS to study the microbial transport in a reservoir. Table 6-2 shows the reservoir model and the microbial parameters used in the simulation.

Test Problem 2:

The feasibility of applying the microbial system for modifying injection profile from the wellbore was investigated in a two-dimensional cross section reservoir model. The top layer has permeability of 100 mD and pay thickness of 20 feet, whereas the bottom layer has permeability of 1,000 mD and pay thickness of 10 feet. Five feet in the x-direction was used as the size for wellbore grids and grids next to the injection wellbore. The microbes and nutrients were introduced into the injection well in the model after water breakthrough from the high permeability layer. The plugging by microorganisms in the wellbore next to the high permeability layer diverts the injection water to the low permeability layer. The well report in appendix B shows that the water injection rate to the high permeability layer decreases from 278 B/D before the microbial treatment to 73 B/D after 25 days of microbial treatment. In contrast, the water injection rate to the low permeability layer increases from 22 B/D to 227 B/D during

the same period. Comparing to the case without the microbial treatment, this results in a decrease of water-oil-ratio, therefore, an increase of oil recovery during the waterflood. The clogging rate constant was assumed to be 25 day^{-1} in the model. These simulation runs examine the feasibility of applying the microbial treatment to improve the injection profile in waterfloods.

TABLE 6-2. Reservoir model and microbial system parameters used in field-scale simulation runs

Parameter	Value
Reservoir:	
length, ft	200
width, ft.....	200
thickness (top/bottom layers), ft.....	20 and 10
Porosity, %	20
Permeability:	
kx, ky, kz (top layer), mD	100, 100, 10
kx, ky, kz (bottom layer), mD	1,000, 1,000, 100
Initial oil saturation, %	75
Initial water saturation, %	25
Injected microbial conc., mg/mL.....	30
Injected nutrient conc., mg/mL.....	40

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VIII. NOMENCLATURE

C = microbial concentration, mg/mL or cells/mL

C_f = nutrient concentration, mg/mL

$\vec{D}$ = effective dispersion coefficient tensor for microbes

$\vec{D}_f$ = dispersion coefficient tensor for nutrient

Q = well rate, STB/day or mL/sec

S = aqueous saturation

V = bulk volume of well block, ft³ or mL

h = declogging parameter

k = permeability, mD

k_o = initial permeability, mD

k_m = chemotaxis coefficient

k_d = decay rate, day⁻¹

k_c = clogging rate, day⁻¹

k_r = declogging rate, day⁻¹

u = Darcy velocity, cm/sec or ft/day

ρ = microbial density, g/mL or lb/ft³

μ = growth rate, day⁻¹

ϕ = porosity

σ = volume of deposited microbes / volume of porous medium

Y = yield coefficient

APPENDIX A. TEST PROBLEM 1

Input File for Test Problem 1 (TSTPBM1.DAT)

```

11 INCH COREFLOOD SIMULATION --- BUG + MOLASSES + WF
50      1      1
SO SHALE RESTART NGEL(MEOR) (SWITCHES)
0      0      0      1
GRID BLOCK LENGTHS
-1      -1      -1
0.01824 0.111 0.111
GRID BLOCK LENGTH MODIFICATIONS
0      0      0      0
CAPROCK BASE DEPTHS TO TOP OF SAND
0
800.
POROSITY AND PERMEABILITY DISTRIBUTIONS
-1      -1      -1      -1
0.2136
65.2
65.2
32.6
POROSITY AND PERMEABILITY MODIFICATIONS
0      0      0      0
TRANSMISSIBILITY MODIFICATIONS
0      0      0      0
SAT      KRO      KRW      KRG      PCOW      PCGO
0.0      0      0      0      0      0.
0.02      0      0      0      0      0.
0.15      0      0      0.00      0      0.
0.3      0.01      0.0      0.0      1.877      0.
0.3409      0.05      0.005      0.00      1.8      0.
0.4179      0.17      0.012      0.001      1.632      0.
0.5158      0.32      0.029      0.1      1.387      0.
0.5974      0.60      0.057      0.2      1.142      0.
0.6431      0.80      0.082      0.5      0.896      0.
0.6702      0.91      0.098      0.70      0.774      0.
0.7532      1.0      0.128      0.90      0.7      0.
1.0      1.0      0.20      0.90      0.7      0.
1.1      1.0      0.6      0.      0.7      0.
PBO      VSLOPE      BSLOPE      RSLOPE      PMAX      IREPRS
10.      .000000      -.0000030      0.0      8000.      0
P      MUO      BO      RSO
14.7      5.0      1.00      0.0
8000.0      5.0      1.00      1000.0
P      MUW      BW      RSW
14.7      1.9      1.0000      0.0
8000.0      1.9      1.00      0.0
P      MUG      BG      CR
14.7      .0107      0.0634      .0000040
8000.0      .0121      .0202      .0000040
RHOSCO      RHOSCW      RHOSCG      RHOROCK
53.0      64.5      .0574      143.585
-----MEOR DATA-----
62.37 0.5 0.15 (MICROB DENSITY, YIELD COEFFICIENT, GAS/NUTRIENT)
25. 37.58 0. 0.3 25.2 (CLOG, DECLOG, AKDN, SIGMAX, K REDUCTION)
0.1 0.5 8.4 (DECAY, HALF GROWTH, MAX GROWTH)
0. (CHEMOTAXIS COEFFICIENT)
0. 0. (DISPERSITIVITY - LONGI./TRANSV.)
0. (TUMBLING COEFFICIENT)
.0083 .0083 .0083 (DIFF. COEFFICIENTS (X, Y, Z) FOR NUTRIENT)
.0055 .0055 .0055 (DIFF. COEFFICIENTS (X, Y, Z) FOR MICROBE)

```

EQUILIBRIUM PRESSURE INITIALIZATION/CONSTANT SATURATIONS

0	0										
351.	340.	800.	700.								
.414	.586	.00									
KSN1	KSM1	KCO1	KTR	KCOF							
0	0	0	0	0							
NMAX	FACT1	FACT2	TMAX	WORMAX	GORMAX	PAMIN	PAMAX				
3000	1.2	.5	6	9999999.	500000.	0.	10000.				
KSOL	MITR	OMEGA	TOL	TOL1	DSMAX	DPMAX					
2	300	1.2	.1	0.	.25	50.					

RECURRENT DATA

0.1											
1	49	0	0	0	0	0	0	0	0	2.	1
.002	0.001	.02									

RATES -- INJ.(BUG + MOLASSES) (0.1 PV)

2	0	0									
---	---	---	--	--	--	--	--	--	--	--	--

INJ

1	1	1	1	2	0	-0.000427	0	0			
0.004	0.	0.									
2.5	1.25										

PROD

50	1	1	1	-11	0	0.	0.	0.			
0.004	0.	300.									
0	1	1	1	1	1	1	1	0	1	1.	1
.002	0.001	.02									
1	20	0	0	0	0	0	0	0	0	2.	1
.01	0.001	.02									

RATES -- INJ. (MOLASSES) (0.2 PV)

2	0	0									
---	---	---	--	--	--	--	--	--	--	--	--

INJ

1	1	1	1	2	0	-0.000427	0	0			
0.004	0.	0.									
2.5	0.										

PROD

50	1	1	1	-11	0	0.	0.	0.			
0.004	0.	300.									
0	1	1	1	1	1	1	1	0	1	1.	1
.01	0.001	0.2									
1	30	0	0	0	0	0	0	0	1	1.	1
.1	0.001	0.2									

RATES -- (3 DAYS SHUT-IN)

1	0	0									
---	---	---	--	--	--	--	--	--	--	--	--

PROD

50	1	1	1	2	0	0.	0.	0.			
0.004	0.	300.									
0	1	1	1	1	1	1	1	0	1	20.	1
.01	0.001	0.2									
1	20	0	0	0	0	0	0	0	0	2.	1
.01	0.001	.02									

RATES -- INJ. (MOLASSES) (0.2 PV)

2	0	0									
---	---	---	--	--	--	--	--	--	--	--	--

INJ

1	1	1	1	2	0	-0.000427	0	0			
0.004	0.	0.									
2.5	0.										

PROD

50	1	1	1	-11	0	0.	0.	0.			
0.004	0.	300.									
1	1	1	1	1	1	1	1	0	1	1.1	
.01	0.001	0.2									

RATES -- WATERFLOOD

2	0	0									
---	---	---	--	--	--	--	--	--	--	--	--

INJ

1	1	1	1	2	0	-0.000427	0	0			
---	---	---	---	---	---	-----------	---	---	--	--	--

0.004	0.	0.									
0.	0.0										
PROD											
50	1	1	1	-11	0	0.	0.	0.			
0.004	0.	300.									
0	19	0	0	0	0	0	0	0	1	15.	1
0.02	0.001	0.2									
0	1	1	1	1	1	1	1	0	1	20.	1
02	0.001	0.2									
0	19	0	0	0	0	0	0	0	1	15.	1
0.02	0.001	0.2									
0	1	1	1	1	1	1	1	0	1	20.	1
.02	0.001	0.2									
0	200	0	0	0	0	0	0	0	1	15.	1
0.02	0.001	0.2									

Part of the Output File for Test Problem 1 (TSTPBM1.OUT)

```
*****
*                                     *
*                                     *
*                                     *
*          NIPER                     *
*   BLACK OIL PRIMARY AND SECONDARY RECOVERY MODEL.      *
*         (VERSION 1)                               *
*                                     *
*                                     *
*****
```

```
*****
*
*      11 INCH CORE FLOOD SIMULATION -- BUG+MOLASSES + WF
*
*****
```

GRID BLOCK LENGTH (DX) IS INITIALLY SET AT 0.0182 FOR ALL NODES

GRID BLOCK WIDTH (DY) IS INITIALLY SET AT 0.1110 FOR ALL NODES

GRID BLOCK DEPTH (DZ) IS INITIALLY SET AT 0.1110 FOR ALL NODES

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

$$K = 1$$
[illegible]

POROSITY (PHI) IS INITIALLY SET AT 0.2136 FOR ALL NODES

PERMEABILITY (KX) IN LAYER 1 IS INITIALLY SET AT 65.20 FOR ALL NODES

PERMEABILITY (KY) IN LAYER 1 IS INITIALLY SET AT 65.20 FOR ALL NODES

PERMEABILITY (KZ) IN LAYER 1 IS INITIALLY SET AT 32.60 FOR ALL NODES

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

SAT	KRO	KRW	KRG	PCOW	PCGO
0.0000	0.0000	0.0000	0.0000	0.00	0.00
0.0200	0.0000	0.0000	0.0000	0.00	0.00
0.1500	0.0000	0.0000	0.0000	0.00	0.00
0.3000	0.0100	0.0000	0.0000	1.88	0.00
0.3409	0.0500	0.0050	0.0000	1.80	0.00
0.4179	0.1700	0.0120	0.0010	1.63	0.00
0.5158	0.3200	0.0290	0.1000	1.39	0.00
0.5974	0.6000	0.0570	0.2000	1.14	0.00
0.6431	0.8000	0.0820	0.5000	0.90	0.00
0.6702	0.9100	0.0980	0.7000	0.77	0.00
0.7532	1.0000	0.1280	0.9000	0.70	0.00
1.0000	1.0000	0.2000	0.9000	0.70	0.00
1.1000	1.0000	0.6000	0.0000	0.70	0.00

PBO	VSLOPE	BSLOPE	RSLOPE	PMAX	IREPRS
10.00	0.000E+00	-0.300E-05	0.00	8000.00	0

P	MUO	BO	RSO
14.7	5.0000	1.0000	0.00
8000.0	5.0000	1.0000	1000.00

P	MUW	BW	RSW
14.7	1.9000	1.0000	0.00
8000.0	1.9000	1.0000	0.00

P	MUG	BG	CR
14.7	0.0107	0.6340E-01	0.400E-05
8000.0	0.0121	0.2020E-01	0.400E-05

RHOSCO	RHOSCW	RHOSCG	RHOROCK
53.0000	64.5000	0.0574	

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

P	B	ODBO/DP	RSO	DRSO/DP
8000.0	1.0000	0.0000E+00	178.1	0.2230E-01

P	BW	DBW/DP	RSW	DRSW/DP
8000.0	1.0000	0.0000E+00	0.0	0.0000E+00

P	BG	DBGDP
8000.0	0.2020E-01	-0.5410E-05

*****MICROBIAL SYSTEM PARAMETERS*****

MICROBE DENSITY (LB/FT³/FT/FT) 62.370
 CELL YIELD COEFFICIENT 0.500
 GAS PRODUCED BY NUTRIENT (CU FT/LB) 0.1500000

CLOGGING RATE CONSTANT (1/DAY) 25.000
 DECLOGGING RATE CONSTANT (1/DAY) 37.580
 DECLOGGING COEFFICIENT 0.000
 PERMEABILITY-POROSITY REDUCTION FACTOR 25.200

SPECIFIC DECAY CONSTANT (1/DAY) 0.100
 MONOD HALF GROWTH CONSTANT (MG/ML) 0.5
 MAXIMUM GROWTH RATE (1/DAY) 8.400

CHEMOTATIC COEFFICIENT 0.000

LONGITUDINAL DISPERSIVITY (FT) 0.000
 TRANSVERSE DISPERSIVITY (FT) 0.000

TUMBLING COEFFICIENT (FT*FT/DAY) 0.000

DISPERSION COEFFICIENT (FT*FT/DAY) FOR NUTRIENT IN X Y Z DIRECTIONS:
 0.83000E-02 0.83000E-02 0.83000E-02

DISPERSION COEFFICIENT (FT*FT/DAY) FOR MICROBE IN X Y Z DIRECTIONS:
 0.55000E-02 0.55000E-02 0.55000E-02

MAXIMUM NUMBER OF TIME STEPS = 3000
 FACTOR FOR INCREASING DELT = 1.200000 WHEN DSMAX AND DPMAX NOT EXCEEDED
 FACTOR FOR DECREASING DELT = 0.500000 WHEN DSMAX OR DPMAX IS EXCEEDED
 MAXIMUM SIMULATION TIME = 6.000000
 MAXIMUM RESERVOIR WOR/TIME STEP = 9999999 STB/STB
 MAXIMUM RESERVOIR GOR/TIME STEP = 500000 SCF/STB
 MINIMUM AVERAGE RESERVOIR PRESSURE/TIME STEP = 0
 MAXIMUM AVERAGE RESERVOIR PRESSURE/TIME STEP = 10000

SOLUTION METHOD IS LSOR

MAXIMUM NUMBER OF ITERATIONS (MITR) = 300
 INITIAL ACCELERATION PARAMETER (OMEGA) = 1.2000
 MAXIMUM PRESSURE RESIDUAL (TOL) = 0.1000
 PARAMETER FOR CHANGING OMEGA (TOL1) = 0.0000

AUTOMATIC TIME STEP CRITERIA

MAXIMUM ALLOWED SATURATION CHANGE (DSMAX) = 0.2500

RESERVOIR CONTAINS THE FOLLOWING RATE NODES (FOR VERTICAL WELLS)

NODE	OIL(STBD)	WATER(STBD)	GAS(MCFD)	TOTAL(RBD)	BHP(Psia)	PII
1 1 1	0.00	0.00	0.00	0.00	0.00	0.037389
50 1 1	0.00	0.00	0.00	0.00	300.00	0.037389

BLOCK 1 1 1 CONTAINS A RATE SPECIFIED WATER INJECTION WELL
 BLOCK 50 1 1 CONTAINS AN IMPLICIT PRESSURE SPECIFIED PRODUCING WELL

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

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

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

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

K = 1
 351. 351. 351. 351. 351. 351. 351. 351. 351. 351.
 351. 351. 351. 351. 351. 351. 351. 351. 351. 351.
 351. 351. 351. 351. 351. 351. 351. 351. 351. 351.
 351. 351. 351. 351. 351. 351. 351. 351. 351. 351.
 351. 351. 351. 351. 351. 351. 351. 351. 351. 351.

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

K = 1
 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414
 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414
 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414
 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414
 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414 0.414

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

K = 1
 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586
 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586
 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586
 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586
 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586 0.586

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

K = 1

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

***** WELL REPORT FOR ALL ACTIVE WELLS *****

*****ELAPSED TIME = 0.100000 DAYS FROM BEGINNING OF SIMULATION *****

WELL LOCATION ID I J K	CALC BHFP	SPEC BHFP	SPEC PI	----- RATE -----			GOR	WOR	--- CUMULATIVE ---		
				OIL STB/D	GAS MCF/D	WATER STB/D			OIL MSTB	GAS MMCF	WATER MSTB
INJ 1 1 1	308	0	0.037	0	0	0	0	0.000	0	0	0
PROD 50 1 1	300		0.037	0	0	0	0	0.547	0	0	0
TOTALS				0	0	0			0	0	0

*
*
* SUMMARY REPORT NIPIR MODEL *
*
*

ELAPSED TIME (DAYS) = 0.10 TIME STEP NUMBER = 61 TIME STEP SIZE (DAYS) = 0.00

CURRENT AVG RES PRESSURE = 303.9 PREVIOUS AVG RES PRESSURE = 303.8 PRESSURE DPMAX(21, 1, 1) = 0.1
OIL DSMAX(29, 1, 1) = 0.5076E-01 GAS DSMAX(0, 0, 0) = 0.0000E+00 WATER DSMAX(29, 1, 1) = -.5592E-01
OIL MATERIAL BALANCE (%) = -.1788E-04 GAS MATERIAL BALANCE (%) = 0.0000E+00
WATER MATERIAL BALANCE (%) = 0.6428E+00

OIL PRODUCTION RATE (STB/D) = 0.0 CUM. OIL PRODUCTION (STB) = 0.2268E-04
GAS PRODUCTION RATE (MSCF/D) = 0.0 CUM. GAS PRODUCTION (MSCF) = 0.0000E+00
WATER PRODUCTION RATE (STB/D) = 0.0 CUM. WATER PRODUCTION (STB) = 0.1311E-04

GAS INJECTION RATE (MSCF/D) = 0.0 CUM. GAS INJECTION (MSCF) = -0.3633E-07
WATER INJECTION RATE (STB/D) = 0.0 CUM. WATER INJECTION (STB) = 0.4271E-04

PRODUCING WOR (STB/STB) = 0.547 CUM. WOR (STB/STB) = 0.578
PRODUCING GOR (SCF/STB) = 0. CUM. GOR (SCF/STB) = 0

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

K = 1

308.	307.	307.	307.	307.	307.	307.	306.	306.	306.
306.	306.	306.	306.	305.	305.	305.	305.	305.	305.
305.	304.	304.	304.	304.	304.	304.	303.	303.	303.
303.	303.	303.	303.	302.	302.	302.	302.	302.	302.
301.	301.	301.	301.	301.	301.	301.	300.	300.	300.

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

K = 1

0.237	0.255	0.300	0.255	0.301	0.299	0.301	0.301	0.309	0.300
0.309	0.313	0.315	0.320	0.315	0.331	0.326	0.333	0.332	0.346
0.346	0.372	0.327	0.387	0.352	0.402	0.387	0.374	0.436	0.364
0.407	0.409	0.382	0.419	0.418	0.395	0.430	0.371	0.439	0.364
0.416	0.403	0.388	0.417	0.410	0.429	0.418	0.433	0.420	0.438

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

K = 1

0.742	0.700	0.693	0.667	0.691	0.674	0.681	0.680	0.685	0.663
0.686	0.675	0.668	0.666	0.661	0.666	0.657	0.657	0.642	0.652
0.615	0.628	0.594	0.612	0.587	0.598	0.572	0.620	0.558	0.623
0.581	0.591	0.575	0.580	0.576	0.570	0.570	0.577	0.559	0.598
0.579	0.581	0.612	0.577	0.573	0.570	0.565	0.567	0.559	0.562

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

K = 1

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

***** CHEMICAL CONCENTRATION DISTRIBUTION *****

=== NUTRIENT CONCENTRATION (MG/ML) ===

4.535	3.181	2.162	1.408	0.849	0.478	0.248	0.119	0.052	0.021	0.008
0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000					

=== MICROBE CONCENTRATION (MG/ML) ===

1.007	0.799	0.629	0.493	0.365	0.252	0.158	0.090	0.047	0.022	0.010
0.004	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

=== POROSITY REDUCTION (FRACTION) ===

0.0078	0.0049	0.0030	0.0017	0.0010	0.0005	0.0003	0.0001	0.0001	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

APPENDIX B. TEST PROBLEM 2

Input File for Test Problem 2 (TSTPBM2.DAT)

PERMEABILITY PROFILE MODIFICATION --- MICROB(5D) + NUTR(20D) + WATERFLOOD

20 1 2
SO SHALE RESTART NGEL(MEOR) (SWITCHES)
0 0 0 1

GRID BLOCK LENGTHS

0 -1 0
5 5 10 10 10 10 10 10 10
15 15 10 10 10 10 10 10 10
200.
20. 10.

GRID BLOCK LENGTH MODIFICATIONS

0 0 0 0
CAPROCK BASE DEPTHS TO TOP OF SAND

0
8000.
POROSITY AND PERMEABILITY DISTRIBUTIONS

-1 0 0 0
.20

100. 1000.

100. 1000.

10. 100.

POROSITY AND PERMEABILITY MODIFICATIONS

0 0 0 0 0
TRANSMISSIBILITY MODIFICATIONS

SAT	KRO	KRW	KRG	PCOW	PCGO
0.0	0.	0.	0.	0.	0.
0.25	0.01	0.0	0.	2.	0.
0.3	0.03	0.004	0.	1.877	0.
0.35	0.054	0.02	0.	1.755	0.
0.4	0.085	0.04	0.	1.632	0.
0.45	0.13	0.08	0.	1.509	0.
0.5	0.18	0.12	0.	1.387	0.
0.55	0.24	0.17	0.	1.264	0.
0.6	0.33	0.24	0.	1.142	0.
0.65	0.44	0.32	0.	1.019	0.
0.7	0.63	0.41	0.	0.896	0.
0.75	0.9	0.52	0.	0.774	0.
0.78	0.9	0.6	0.	0.7	0.
1.0	0.9	0.6	0.	0.7	0.
1.1	0.9	0.6	0.	0.7	0.
PBO	VSLOPE	BSLOPE	RSLOPE	PMAX	IREPRS
10.	.000000	-.0000030	0.0	8000.	0
P	MUO	BO	RSO		
14.7	3.0	1.00	0.0		
8000.0	3.0	1.00	0.0		
P	MUW	BW	RSW		
14.7.	80	1.0000	0.0		
8000.0	80	1.00	0.0		
P	MUG	BG	CR		
14.7	0107	0.0634	.0000040		
8000.0	0121	.0202	.0000040		
RHOSCO	RHOSCW	RHOSCG	RHOROCK		
53.0	64.5	.0574	143.585		

CHEMICAL DATA FOR MEOR
62.37 0.5 0.15 (MICROB DENSITY, YIELD COEFFICIENT, GAS/NUTRIENT)
25. 37. 2 0.2 25.2 (CLOG, DECLOG, AKDN, SIGMAX, K REDUCTION)
0.1 6.23 8.4 (DECAY, HALF GROWTH, MAX GROWTH)
0. (CHEMOTAXIS COEFFICIENT)

0.	0.	(DISPERSIVITY - LONGI/TRANSV.)									
0.		(TUMBLING COEFFICIENT)									
.0083	.0083	.0083	(DIFF. COEFFICIENTS (X, Y, Z) FOR NUTRIENT)								
.0055	.0055	.0055	(DIFF. COEFFICIENTS (X, Y, Z) FOR MICROBE)								
EQUILIBRIUM PRESSURE INITIALIZATION/CONSTANT SATURATIONS											
0	0										
2511.	2400.	8000.	7000.								
.75	.25	.00									
KSN1	KSM1	KCO1	KTR	KCOF							
0	0	0	0	0							
NMAX	FACT1	FACT2	TMAX	WORMAX	GORMAX	PAMIN	PAMAX				
3000	1.2	.5	120.	1000.	500000.	0.	10000.				
KSOL	MITR	OMEGA	TOL	TOL1	DSMAX	DPMAX					
2	3000	1.2	.1	0.	.05	50.					
RECURRENT DATA											
2.											
1	1	0	0	0	0	0	0	0	0	364.	0
1	0.001	1.									
RATES -- 1 WATER INJ. WELL, 1 PROD. WELL (30 DAY)											
2	0	0									
INJ											
1	1	1	2	2	0	-300.	0	0			
0.25	0.	0.									
0.25	0.	0.									
PROD											
20	1	1	2	1	0	0.	0	300.			
0.25	0.	0.									
0.25	0.	0.									
0	29	0	0	0	0	0	0	0	0	60.	0
1.	0.01	10.									
0	1	1	1	1	1	0	1	0	0	120.	0
1.	0.01	5.									
1	50	0	0	0	0	0	0	0	0	2.	1
1	0.01	1									
RATES -- 1 INJ.(MICROB +NUTRIENT) WELL, 1 PROD. WELL (5 DAYS)											
2	0	0									
INJ											
1	1	2	1	2	0	-300.0	0	0			
0.25	0.	0.									
2.495	1.875										
PROD											
20	1	1	2	1	0	0.	0	300.			
0.25	0	0.									
0.25	0.	0.									
1	1	1	1	1	0	0	0	1	1	1	
1	0.001	2.									
RATES -- 1 NUTRIENT INJ. WELL, 1 PROD. WELL (20 DAYS)											
2	0	0									
INJ											
1	1	1	2	2	0	-300.0	0	0			
0.25	0.	0.									
0.25	0.	0.									
2.495	0.0										
PROD											
20	1	1	2	1	0	0.	0	300.0			
0.25	0.	0.									
0.25	0.	0.									
0	100	0	0	0	0	0	0	0	1	15.	1
0.1	0.01	0.1									
0	1	1	1	1	1	0	1	0	1	20.	1
1	0.01	2.									
0	100	0	0	0	0	0	0	1	15.	1	
0.1	0.01	0.1									
0	1	1	1	1	0	1	0	1	20.	1	

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Summary Report for Test Problem 2 (TSTPBM2.RATE)

MICROB(5D) + NUTR(20D) -- 20*1*2, SINGLE-LAYER MODIFICATION, GAS/NUT=.5
NIPER : BLACK OIL VERTIC/SLANT/HORIZ. WELL MODEL

SUMMARY REPORT

N	ETI DAY	PAVG PSI	OPR CUF/D	COP BBL	GPR MCF/D	CGP MCF	FOR	WPR CUF/D	CWP BBL	WOR B/B	PVWI	CPOI LB	WIR B/D	CWI BBL
16	2.15	2530.5	1684.5	646.0	0.0	0.0	0.02000	0.0	0.0	0.00	0.0151	0.0	300.0	0.000
25	4.27	2542.0	1684.5	1280.3	0.0	0.0	0.03964	0.0	0.0	0.00	0.0300	0.0	300.0	0.000
33	6.47	2553.6	1684.5	1942.4	0.0	0.0	0.06014	0.0	0.0	0.00	0.0454	0.0	300.0	0.000
40	8.55	2565.1	1684.5	2564.4	0.0	0.0	0.07939	0.0	0.0	0.00	0.0600	0.0	300.0	0.000
46	10.58	2575.9	1684.5	3173.1	0.0	0.0	0.09824	0.0	0.0	0.00	0.0742	0.0	300.0	0.000
53	12.62	2587.3	1684.5	3785.3	0.0	0.0	0.11719	0.0	0.0	0.00	0.0886	0.0	300.0	0.000
61	14.80	2599.2	1684.5	4441.2	0.0	0.0	0.13750	0.0	0.0	0.00	0.1039	0.0	300.0	0.000
69	16.96	2610.7	1683.9	5088.4	0.0	0.0	0.15754	0.6	0.0	0.00	0.1190	0.0	300.0	0.000
77	19.29	2620.0	1124.4	5697.6	0.0	0.0	0.17640	560.1	88.8	0.50	0.1354	0.0	300.0	0.000
81	21.95	2622.7	796.6	6114.5	0.0	0.0	0.18930	887.9	472.0	1.11	0.1541	0.0	300.0	0.000
83	24.22	2624.0	695.2	6404.5	0.0	0.0	0.19828	989.3	861.8	1.42	0.1700	0.0	300.0	0.000
85	27.48	2625.1	610.3	6770.1	0.0	0.0	0.20960	1074.2	1475.1	1.76	0.1929	0.0	300.0	0.000
87	30.10	2626.0	537.8	7029.7	0.0	0.0	0.21764	1146.7	2000.3	2.13	0.2113	0.0	300.0	0.000
107	32.10	2661.4	490.7	7209.6	0.0	0.0	0.22321	1193.8	2420.4	2.43	0.2253	0.0	300.0	0.000
128	34.20	2704.7	463.1	7387.6	0.0	0.0	0.22872	1221.4	2872.4	2.64	0.2400	0.0	300.0	0.000
149	36.20	2767.4	440.1	7548.4	0.0	0.0	0.23370	1244.4	3311.7	2.83	0.2541	0.0	300.0	0.000
170	38.30	2835.7	423.0	7709.5	0.0	0.0	0.23869	1261.5	3780.5	2.98	0.2688	0.0	300.0	0.000
191	40.40	2893.7	403.1	7863.8	0.0	0.0	0.24346	1281.4	4256.3	3.18	0.2836	0.0	300.0	0.000
212	42.50	2950.6	390.9	8012.1	0.0	0.0	0.24805	1293.6	4737.9	3.31	0.2983	0.0	300.0	0.000
233	44.60	2997.4	376.3	8155.4	0.0	0.0	0.25249	1308.2	5224.7	3.48	0.3130	0.0	300.0	0.000
254	46.60	3039.3	366.6	8287.9	0.0	0.0	0.25659	1317.9	5692.2	3.59	0.3271	0.0	300.0	0.001
275	48.70	3081.7	360.2	8423.6	0.0	0.0	0.26079	1324.3	6186.4	3.68	0.3418	0.0	300.0	0.008
296	50.80	3117.3	351.1	8556.5	0.0	0.0	0.26491	1333.4	6683.6	3.80	0.3566	0.0	300.0	0.044
317	52.90	3152.7	347.1	8686.9	0.0	0.0	0.26894	1337.4	7183.2	3.85	0.3713	0.0	300.0	0.154
338	55.00	3183.0	341.1	8815.3	0.0	0.0	0.27292	1343.4	7684.7	3.94	0.3860	0.0	300.0	0.368
360	57.01	3191.1	342.1	8937.7	0.0	0.0	0.27671	1342.4	8165.4	3.92	0.4001	0.0	300.0	0.634
381	59.11	3191.9	344.0	9066.0	0.0	0.0	0.28068	1340.6	8667.1	3.90	0.4149	0.0	300.0	0.886
402	61.21	3192.3	348.5	9195.4	0.0	0.0	0.28469	1336.0	9167.7	3.83	0.4296	0.0	300.0	1.043
423	63.31	3192.8	356.2	9327.1	0.0	0.0	0.28877	1328.3	9666.0	3.73	0.4444	0.0	300.0	1.099
444	65.41	3193.7	367.8	9462.6	0.0	0.0	0.29296	1316.7	10160.5	3.58	0.4591	0.0	300.0	1.099
465	67.51	3194.9	381.3	9602.8	0.0	0.0	0.29730	1303.2	10650.3	3.42	0.4738	0.0	300.0	1.098
486	69.61	3195.5	394.1	9748.0	0.0	0.0	0.30180	1290.4	11135.1	3.27	0.4886	0.0	300.0	1.098
507	71.71	3195.9	403.7	9897.4	0.0	0.0	0.30642	1280.8	11615.7	3.17	0.5033	0.0	300.0	1.112
528	73.81	3196.4	408.6	10049.5	0.0	0.0	0.31113	1275.9	12093.6	3.12	0.5181	0.0	300.0	1.171
547	76.51	3196.8	409.4	10246.3	0.0	0.0	0.31722	1275.1	12706.9	3.11	0.5370	0.0	300.0	1.141
549	78.51	3196.9	407.4	10391.7	0.0	0.0	0.32173	1277.1	13161.5	3.13	0.5510	0.0	300.0	1.146
551	80.51	3197.0	402.3	10535.5	0.0	0.0	0.32618	1282.2	13617.7	3.19	0.5651	0.0	300.0	1.146
553	82.51	3197.1	395.3	10677.0	0.0	0.0	0.33056	1289.2	14076.2	3.26	0.5791	0.0	300.0	1.145
555	84.51	3197.3	387.0	10815.6	0.0	0.0	0.33485	1297.5	14537.6	3.35	0.5932	0.0	300.0	1.144
557	86.51	3197.4	378.3	10951.1	0.0	0.0	0.33904	1306.2	15002.1	3.45	0.6072	0.0	300.0	1.143
559	88.51	3197.6	369.5	11083.5	0.0	0.0	0.34314	1315.0	15469.7	3.56	0.6212	0.0	300.0	1.141
561	90.51	3197.8	361.2	11212.9	0.0	0.0	0.34715	1323.3	15940.3	3.66	0.6353	0.0	300.0	1.140
563	92.51	3198.0	353.6	11339.6	0.0	0.0	0.35107	1330.9	16413.6	3.76	0.6493	0.0	300.0	1.138
565	94.51	3198.2	347.0	11463.7	0.0	0.0	0.35491	1337.5	16889.5	3.85	0.6633	0.0	300.0	1.136
567	96.51	3198.5	340.0	11585.4	0.0	0.0	0.35868	1344.5	17367.8	3.95	0.6774	0.0	300.0	1.134
569	98.51	3198.6	332.9	11704.7	0.0	0.0	0.36237	1351.6	17848.5	4.06	0.6914	0.0	300.0	1.133
571	100.51	3198.8	325.8	11821.3	0.0	0.0	0.36599	1358.7	18331.9	4.17	0.7055	0.0	300.0	1.131
573	102.51	3199.0	318.6	11935.4	0.0	0.0	0.36952	1365.9	18817.8	4.29	0.7195	0.0	300.0	1.129
575	104.51	3199.1	311.6	12047.0	0.0	0.0	0.37297	1372.9	19306.2	4.41	0.7335	0.0	300.0	1.126
577	106.51	3199.3	304.7	12156.1	0.0	0.0	0.37635	1379.8	19797.0	4.53	0.7476	0.0	300.0	1.124
579	108.51	3199.4	298.0	12262.9	0.0	0.0	0.37966	1386.5	20290.3	4.65	0.7616	0.0	300.0	1.122
581	110.51	3199.6	291.5	12367.3	0.0	0.0	0.38289	1393.0	20785.9	4.78	0.7756	0.0	300.0	1.119
583	112.51	3199.7	285.4	12469.5	0.0	0.0	0.38605	1399.1	21283.7	4.90	0.7897	0.0	300.0	1.117

**Part of the Well Report in the Output File for Test Problem 2
(TSTPBM2.OUT)**

*** WELL REPORT FOR ALL ACTIVE WELLS ELAPSED TIME = 30.100000 DAYS FROM BEGINNING OF

***** SIMULATION *****

				----- RATE -----			--- CUMULATIVE ---						
WELL LOCATION				CALC	SPEC	SPEC	OIL	GAS	WATER	GOR	WOR	OIL	GAS
WATER													
ID	I	J	K	BHFP	BHFP	PI	STB/D	MCF/D	STB/D			MSTB	MMCF
MSTB													
INJ	1	1	1	2676.	0.	3.001	0.	0.	-22.	0.000		0.	0.
INJ	1	1	2	2682.	0.	15.004	0.	0.	-278.	0.	0.000	0.	0.
PROD	20	1	1	2527.	0.	3.000	53.	0.	0.	0.002	2.	0.	0.
PROD	20	1	2	2533.	0.	15.001	42.	0.	204.	0.	4.809	5.	0.
TOTALS							96.	0.	-96.			7.	0.

***** WELL REPORT FOR ALL ACTIVE WELLS ELAPSED TIME = 35.200001 DAYS*****
***** OF SIMULATION FROM BEGINNING *****

				----- RATE -----			--- CUMULATIVE ---						
WELL LOCATION				CALC	SPEC	SPEC	OIL	GAS	WATER	GOR	WOR	OIL	GAS
I J K				BHFP	BHFP	PI	STB/D	MCF/D	STB/D			MSTB	MMCF
MSTB													
INJ	1	1	1	2884.	0.	3.001	0.	0.	-122.	0.	0.000	0.	0.
INJ	1	1	2	2891.	0	15.004	0.	-2.	-178.	0.	0.000	0.	0.
PROD	20	1	1	2646.	0.	3.000	47.	0.	0.	0.004	2.	0.	0.
PROD	20	1	2	2651.	0	15.001	33.	0.	220.	0	6.687	6.	0.
TOTALS							80.	-2.	80.			7.	0.

***** WELL REPORT FOR ALL ACTIVE WELLS ELAPSED TIME = 45.299999 DAYS *****
***** FROM BEGINNING OF SIMULATION *****

				----- RATE -----			--- CUMULATIVE ---						
WELL LOCATION				CALC	SPEC	SPEC	OIL	GAS	WATER	GOR	WOR	OIL	GAS
ID I J K				BHFP	BHFP	PI	STB/D	MCF/D	STB/D			MSTB	MMCF
MSTB													
INJ	1	1	1	3218.	0.	3.001	0.	0.	-207.	0.	0.000	0.	0.
INJ	1	1	2	3225.	0.	15.004	0.	0.	-93.	0.	0.000	0.	0.
PROD	20	1	1	2917.	0.	3.000	43.	0.	0.	0.006	2.	0.	0.
PROD	20	1	2	2923.	0	15.001	24.	0.	233.	0.	9.881	6.	0.
TOTALS							67.	0.	-67.			8.	0.

***** WELL REPORT FOR ALL ACTIVE WELLS ELAPSED TIME = 55.399998 DAYS *****
***** FROM BEGINNING OF SIMULATION *****

				----- RATE -----			--- CUMULATIVE ---						
WELL LOCATION				CALC	SPEC	SPEC	OIL	GAS	WATER	GOR	WOR	OIL	GAS
ID I J K				BHFP	BHFP	PI	STB/D	MCF/D	STB/D			MSTB	MMCF
MSTB													
INJ	1	1	1	3378.	0.	3.001	0.	0.	-227.	0.	0.000	0.	0.
INJ	1	1	2	3385.	0	15.004	0.	-1.	-73.	0.	0.000	0.	0.
PROD	20	1	1	3097.	0.	3.000	41.	0.	0.	0.006	3.	0.	0.
PROD	20	1	2	3102.	0	15.001	20.	0.	239.	0.	12.146	6.	0.
TOTALS							61.	-1.	-61.			9.	0.

**DATE
FILMED**

12/22/93

END