A User's Guide to the Rice Steam Displacement Model

by

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1. Purpose

To provide an accurate model of heavy oil steam displacement processes. The primary advantage of this model over other state-of-the-art models is that it does not exhibit grid orientation effects. Serious grid effects have been reported in other steam displacement models [1] [2].

2. Features

2.1. Numerical Discretization

Three numerical discretization techniques are implemented in this model. Included are a five point finite difference scheme [1], a nine point finite difference procedure due to McCracken and Yanosik [2], and an upstream weighted finite element method due to Potempa [3] [4] [5]. All three of these discretization schemes are node centered in the areal plane and block centered in the vertical direction.

2.2. Mobility Weighting

Three different mobility weighting techniques are implemented in this model. During the course of this investigation it has been shown that the mobility weighting is the most important factor affecting the magnitude of grid effects that are present in steam displacement models [6]. Mobility weighting schemes implemented in the model include upstream mobility weighting [1], a mobility weighting scheme similar to that introduced by Au and Vinson [7], and a new mobility weighting scheme [6]. Harmonic averaging of the scaling parameter [7] is used in finite difference procedures. A combination of harmonic and arithmetic averaging is used in the upwind finite element method.

2.3. Domain

The model is three dimensional. Reservoir dip is treated. Reduced elements of symmetry, such as an eighth of a repeated five spot pattern or a sixth of a seven spot pattern, are treated. Radial, linear, and zero dimensional flow options exist.

2.4. PVT Behavior

The model is valid for flow regimes exhibiting three phase two component flow. The assumptions used in the model are in general valid for the heavy oil systems. The hydrocarbon component is allowed to partition into only the oleic phase, while the aqueous component is allowed to partition into both the liquid and the gaseous phase. Data relating to the steam table is tabulated as a cubic spline functions internally. The spline functions have been slightly modified to maintain curvature of the correct sign at all tabular entries. Oil thermodynamic properties are specified by the user. The oil viscosity as a function of temperature is evaluated from a user supplied table with the help of linear exponential interpolation. Superheated steam is treated superficially, and the model of thermodynamic properties for superheated steam is only guaranteed to be qualitatively correct.
2.5. Primary Unknowns

To avoid saturation constraints on the discretized system of nonlinear equations, the pressure and the total component densities are used as primary unknowns [5].

2.6. Relative Permeability

Two phase relative permeability data is input as either tabular data or a power law function. Three phase oil relative permeability is calculated using Stone's method [8]. Normalization of the input data is performed automatically.

2.7. High Temperature Effects

High temperature relative permeability effects are very important to the steamflooding mechanism [9]. Three phase relative permeability endpoint data is allowed to vary as a function of temperature in this model. The method described earlier by Coats [10] is used to generate the two phase relative permeability functions from the endpoint data and the normalized relative permeability curves.

2.8. Other Formation Properties

Anisotropic values of the absolute permeability are allowed to vary as a function of the location \((x,y,z)\). The permeability is also allowed to vary as a function of the location \((x,y,z)\). Rock compressibility is treated. The product of the rock fractional volume, the rock density, and the rock heat capacity is assumed to be constant. The formation thermal conductivity is assumed to be constant. Initial conditions can be specified as a function of the location \((x,y,z)\).

2.9. Overburden Calculations

Energy losses to the cap and base rock are treated. The superposition method described by Coats [10] is used to implicitly determine the temperature distribution within the cap or base rock. The energy flux from the cap or base rock is computed using a procedure due to J.A. Wheeler [11].

2.10. Time Stepping

Time step size is controlled automatically by the procedure described by Coats [10]. Time stepping is highly implicit, as all upstream weighted terms are computed implicitly, and the scaling parameter representing the total mobility parameter is evaluated explicitly.

2.11. Wells

Both production and injection wells can be placed on either pressure or flow constraints. The flow rate and the bottom hole pressure are related to the local reservoir properties using the procedure due to Peaceman [12]. The gravity head within the wellbore is calculated explicitly. The pump layer is designated by the user at the production wells, while the pressure constraints are enforced at the lowest simulated layer at the injection wells.
2.12. Nonlinear Equations

Either Newton's method or stationary Newton's method is used. The initial guess is taken to be the solution at the old time level. The Jacobian is evaluated only if the ratio of the norm of the new function to that of the old function is larger than a user supplied threshold value. Level two descent is necessary to insure convergence, as the norm of the function necessarily increases if a phase transition has taken place over an implicit timestep. If descent relative to the level two function value is not achieved by two Newton iterations, the time step size is reduced to half the initial size, and the iteration is started anew using the old solution as the initial guess.

2.13. Linear Equations

The resulting linear equations are solved exactly by an efficient band solver. A symbolic factorization is performed to determine the maximum fill of each band. This procedure results in a twofold savings over a naive banded matrix approach in many applications.

2.14. Output

Detailed output is provided at intervals specified by the user. Contour plots of functions dependent upon the computed solution are available. Time dependent functions such as recovery curves can be saved in a file for later graphical processing.

2.15. Restarting

The model has restart capabilities.

2.16. Error Recovery

The model checks for errors in the input data stream. If an error is detected, a message indicating the type of error is printed, and the program is halted. This check is incomplete, and it is possible to specify an inconsistent set of input parameters. The model checks for nonconvergence of all iterative algorithms which can result in an infinite loop. If a loop is detected, a message is printed, a restart file is written, and the program is halted. Debugging procedures are usually required to find the cause of the loop in this instance of abnormal termination, although the loop is commonly a result of bad input data. For example, during a particular set of computational experiments, the program automatically halted due to a negative value of the oil total density. In this example, the problem was eventually traced to a nonzero oil relative permeability for a zero oil saturation, as calculated by Stone's method for determining three phase oil relative permeability from two phase data. Thus either Stone's model or the relative permeability curves were determined to be the source of the problem.

2.17. Testing

The model has been extensively tested. Many of the test calculations have involved isothermal systems to insure that such systems remain constant temperature.
3. Description

3.1. Fortran Units Used

Fortran units one through eight are used by the code. Unformatted output is directed to the file assigned to Fortran unit one if and only if the run is not a restart run. This file contains fluid property parameters and reservoir geometry information for a potential restart run. Unformatted output is directed to Fortran unit two at a frequency of \texttt{FREST} simulated days, where \texttt{FREST} is an input parameter. This file contains time dependent reservoir parameters for a potential restart run. The information stored in these files is sufficient to determine the state of the reservoir system for use in a later restart run. Fortran units three and four are unformatted files used as input data during restart runs. These files are created as files assigned to units one and two during earlier runs. The data read from units three and four during restart runs replace the reservoir initialization data that is specified for other runs. The file assigned to Fortran unit five contains the input data stream, and the file assigned to Fortran unit six is the output data stream. Fortran unit seven is used for contour plots. An areal map of the discretized domain is generated and written to unit seven if and only if the run is not a restart run. Fortran unit eight is used to store time dependent functions. The first three places in each record, signified as \texttt{ITYPE}, indicate the type of information stored. The next ten places contain the simulated time in days using an F10.5 format. The final ten places contain the simulated value of the time dependent function associated with \texttt{ITYPE} using an F10.5 format. The meanings of various values of \texttt{ITYPE} is given by below.

\begin{itemize}
  \item \texttt{ITYPE} = -3 Timestep reductions
  \item \texttt{ITYPE} = -2 Newton iterations
  \item \texttt{ITYPE} = -1 Timestep length
  \item \texttt{ITYPE} =  0 Percentage OOIP recovered
  \item \texttt{ITYPE} =  1 Rate information for well 1
  \item \texttt{ITYPE} =  2 Rate information for well 2
  \item \texttt{ITYPE} =  3 Rate information for well 3
  \item \texttt{ITYPE} =  4 Rate information for well 4
  \item \texttt{ITYPE} =  5 Rate information for well 5
  \item \texttt{ITYPE} =  6 Rate information for well 6
  \item \texttt{ITYPE} =  7 Rate information for well 7
  \item \texttt{ITYPE} =  8 Rate information for well 8
  \item \texttt{ITYPE} =  9 Rate information for well 9
  \item \texttt{ITYPE} = 10 Rate information for well 10
\end{itemize}

3.2. Internal Ordering

Specification of certain input parameters requires a limited amount of knowledge of the internal ordering used by the program. There are three levels of organization within the code that the user need be aware of. The ordering of the \texttt{NZ} layers in the vertical direction is taken from bottom to top. The deepest layer of the reservoir is designated internally as layer 1, and the topmost layer is designated as layer \texttt{NZ}. 

- 4 -
Within each individual layer a point centered discretization is employed. Figure 1 illustrates both layers of a modified $7 \times 7 \times 2$ grid. The numbering scheme used for both the nodes and elements of the triangulation varies fastest from bottom to top, then south to north, and finally from west to east. Representative ordering used for both the nodes and the elements of a typical triangulation is illustrated by Figure 1.

3.3. Input Data Records

The input data stream is read from the file assigned to Fortran unit five. The first four characters of each record must be the string "CARD". The next three positions are reserved for the card number BCARD. The card number must always be specified, as the card number parameter is used to facilitate error detection. The eighth position of a record should be left blank. Positions 9-68 of each record are used for the values of the input parameters. All numeric fields contain ten positions, i.e., the numeric fields either use format F10.0 or format 110. Only six numeric fields are found on each record. All integer data parameters, which are indicated using the standard Fortran variable name convention that any and all parameters beginning with an I, J, K, L, M, or N, should be right justified in the associated data field. Decimal points should always be used for noninteger parameters. Character fields are read using the format 9A8.

Title and Restart Data

CARD 1 TITLE
CARD 1 TITLE
CARD 1...
CARD 1 TITLE
CARD 1 END

The user may specify a label to appear at the top of the output directed to Fortran unit six that is generated by the code.

TITLE A label which is any alphanumeric string. This string is echoed at the top of the output until the string "END" is encountered. The title may be used to include the date and the source of the input data. Records of this form are read until the variable TITLE is equal to the character string "END".

CARD 2 IREST

The value of IREST indicates whether or not the run is a restart run.

IREST If IREST is one, the run is a restart run. Cards 3-28 are not included in the input data stream for restart runs, and proceed to the section marked Time Page Data. If IREST is zero, the run is a new run. The program is halted if IREST is not zero or one.
Reservoir, Rock, and Fluid Data

CARD 3  SIZEX  SIZEY  HEIGHT  DIPX  DIPY  RWELL

The parameters appearing on this record are used to initialize variables associated with reservoir geometry.

SIZEX  Length in feet of the pattern in the x direction. Must be positive.

SIZEY  Length in feet of the pattern in the x direction. Must be positive unless radial geometry is used.

HEIGHT  Height in feet of the reservoir. Must be positive.

DIPX  Dip angle in degrees of the reservoir with respect to the x direction. Must lie between -90 and 90 degrees. A positive dip angle indicates that the depth is an increasing function of the location x.

DIPY  Dip angle in degrees of the reservoir with respect to the y direction. Must lie between -90 and 90 degrees. A positive dip angle indicates that the depth is an increasing function of the location y.

RWELL  Well radius in feet for studies using radial geometry. Ignored for other geometries. Must be positive and less than SIZEX if a radial geometry is to be used.

CARD 4  NOMECA  NMOBIL  NPROC

The data appearing on this record supplies parameters controlling the numerical discretization procedure.

NOMECA  The value of this parameter controls the element of symmetry used in the calculations. NOMECA must lie between one and seven. NOMECA can be set to two or to three only if DIPX and DIPY are both set to zero. The possible options for NOMECA are listed below.

NOMECA = 1  Rectangular element
NOMECA = 2  One half rectangular element
NOMECA = 3  One quarter rectangular element
NOMECA = 4  Linear geometry (x-z)
NOMECA = 5  2 variations only (z)
NOMECA = 6  Radial geometry (r-z)
NOMECA = 7  Equilateral triangular element
**NHOBIL**  This parameter is used to specify the mobility weighting scheme used by the model. **NHOBIL** must lie between one and three. The suggested value of **NHOBIL** is one. The possible options are listed below.

- **NHOBIL** = 1  Kinematic mobility weighting
- **NHOBIL** = 2  Upstream fractional flow mobility weighting
- **NHOBIL** = 3  Upstream mobility weighting

**NPROC**  This value of this parameter controls the discretization procedure used by the model. **NPROC** must lie between one and four. **NPROC** must be set to four if and only if **NOHEGA** is set to seven. The possible options are listed below.

- **NPROC** = 1  Rectangular upwinded finite elements
- **NPROC** = 2  Five point finite differences
- **NPROC** = 3  Nine point finite differences
- **NPROC** = 4  Triangular upwinded finite elements

**CARD 5**  

**NX**  Number of elements in the x direction partition. Must be greater than or equal to one, and must be equal to one if **NOHEGA** is set to five.

**NY**  Number of elements in the y direction partition. Must be greater than or equal to one, and must be equal to one if **NOHEGA** is set to four, five, or six. Must be equal to **NX** if **NOHEGA** is set to two, three, or seven.

**NZ**  Number of layers in the simulation. Must be greater than or equal to one.

**CARD 6**  

**IDUNIFX**  **IDUNIFY**  **IDUNIFZ**  The data appearing on this record indicates whether a uniform or nonuniform partition is to be utilized along each coordinate axis.

**IDUNIFX**  Indicates whether a uniform partition is to be used along the x coordinate axis. Must be zero or one. A value of unity indicates a uniform partition, and a zero value indicates that a non uniform mesh is specified by data appearing on card 7.
**IUNIFY**
Indicates whether a uniform partition is to be used along the y coordinate axis. Must be zero or one. A value of unity indicates a uniform partition, and a zero value indicates that a non uniform mesh is specified by data appearing on card 8.

**IUNIFZ**
Indicates whether a uniform partition is to be used along the z coordinate axis. Must be zero or one. A value of unity indicates a uniform partition, and a zero value indicates that a non uniform mesh is specified by data appearing on card 9.

<table>
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<tr>
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<td>x(nx)</td>
<td>x(nx+1)</td>
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</table>

The data appearing on these records specify the location of the x direction nodes for a nonuniform grid. Read only if IUNIFY is zero. There must be no more than six values per data card.

**X(I)**
Location of the i'th x direction node in feet. The nodes must be monotonically increasing. X(1) must be set to zero, and X(nx+1) must be equal to SIZEX.

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<td>y(...)</td>
<td>y(...)</td>
<td>y(ny)</td>
<td>y(ny+1)</td>
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</table>

The data appearing on these records specify the location of the y direction nodes for a nonuniform grid. Read only if IUNIFY is zero. There must be no more than six values per data card.

**Y(J)**
Location of the j'th x direction node in feet. The nodes must be monotonically increasing. Y(1) must be set to zero, and Y(ny+1) must be equal to SIZEY.

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<td>z(1)</td>
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<td>z(nz)</td>
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</table>

The data appearing on these records specify the width of each layer in the z direction for a nonuniform grid. Read only if IUNIFZ is zero.

**Z(K)**
Width of the k'th z direction layer in feet. The width of each layer must be positive. The ordering is from bottom to top. The sum of the widths Z(K) must be equal to HEIGHT.

**CARD 10**
**ALPHAO** **BETAO** **DENSO** **CAPACO**

Oil thermodynamic data used to compute density and internal energy are supplied on this data record.

**ALPHAO**
Oil compressibility in inverse pounds per square inch. Must be nonnegative.
**BETA0** Oil coefficient of thermal expansion in inverse degrees Fahrenheit. Must be greater than zero.

**DEBSO** Stock tank density of the oleic phase in pounds per cubic feet. Must be nonnegative.

**CAPACO** Heat capacity of the oleic phase in btu's per pound per degrees Fahrenheit. Must be positive.

**CARD 11**

The data appearing on this record controls the number of entries in oil viscosity table.

**NV** Number of entries in the table of oil viscosity versus temperature used by the program. Must lie between one and eleven inclusive. The number of entries **NV** in practice should be close to the maximum allowed number to insure adequate functional interpolation.

**CARD 12**

**TVISC(1) VISCO(1)**

**CARD 12**

**TVISC(2) VISCO(2)**

**CARD 12**

**TVISC(NV) VISCO(NV)**

The data found on these records is used to initialize the oil viscosity table. Water and steam viscosities are tabulated at the knots of this table from a rational exponential correlation for internal use.

**TVISC(I)** Temperature in degrees Fahrenheit. The values of **TVISC(I)** must be monotonically increasing. It is recommended that knots should appear in this table at 100 °F intervals between 100 °F and 500 °F. **TVISC(I)** must lie between 32 °F and 705 °F.

**VISCO(I)** Oil phase viscosity in centipoise. **VISCO(I)** must be a nonincreasing function of temperature, and must have positive values.

**CARD 13**

**NG**

**NW**

**NT**

The data found on this record supplies the number of entries which are to appear in the relative permeability tables.

**NG** Number of entries appearing in the gas-oil relative permeability table. Must be between one and eleven, inclusive. If **NG** is one, a power law relationship is used to calculate normalized relative permeability curves, and card 14a applies. If **NG** is greater than one, the relative permeability functions are tabulated as a function of gas saturation, and card 14b applies. Tabular gas-oil curves are automatically normalized for internal use by the program.
**NW**

Number of entries appearing in the water-oil relative permeability table. Must be between one and eleven, inclusive. If NW is one, a power law relationship is used to calculate the normalized relative permeability curves, and card 15a applies. If NW is greater than one, the relative permeability functions are tabulated as a function of water saturation, and card 15b applies. Tabular water-oil curves are automatically normalized for internal use by the program.

**NT**

Number of entries in the table containing the temperature dependent endpoint values. Must be between one and six, inclusive.

**CARD 14a**

**PKRG**

Power for the gas relative permeability curve.

**PKROG**

Power for the oil relative permeability curve with respect to gas.

**CARD 14b**

SATG(1)  XRG(1)  XROG(1)
CARD 14b  SATG(2)  XRG(2)  XROG(2)
CARD 14b  ...  ...  ...  ...  ...
CARD 14b  SATG(NG)  XRG(NG)  XROG(NG)

The data appearing on these records initialize the gas-oil relative permeability table if NG is greater than one.

**SATG(I)**

Gas saturation. SATG(I) must be monotonically increasing, nonnegative, and less than or equal to unity.

**XRG(I)**

Gas relative permeability. XRG(I) must be monotonically increasing, nonnegative, and less than or equal to unity.

**XROG(I)**

Oil relative permeability to gas flow. XROG(I) must be monotonically decreasing, nonnegative, and less than or equal to unity.

**CARD 15a**

**PKRW**

Power for the water relative permeability curve.

**PKROW**

Power for the oil relative permeability curve with respect to water.

**CARD 15b**

SATW(1)  XRW(1)  XROW(1)
CARD 15b  SATW(2)  XRW(2)  XROW(2)
CARD 15b  ...  ...  ...  ...
CARD 15b  SATW(NW)  XRW(NW)  XROW(NW)

The data appearing on these records are used to initialize the water-oil relative permeability table if NW is greater than one.
SATW(I) Water saturation. SATW(I) must be monotonically increasing, nonnegative, and less than or equal to unity.

XRW(I) Water relative permeability. XRW(I) must be monotonically increasing, nonnegative, and less than or equal to unity.

XROW(I) Oil relative permeability to water flow. XROW(I) must be monotonically decreasing, nonnegative, and less than or equal to unity.

CARD 16 ETEMP(1) SGRC(1) SGRO(1) SWRW(1) SWRO(1)
CARD 17 EKRG(1) EKRG(1) EKROW(1) EKRW(1)
CARD 16 ETEMP(2) SGRC(2) SGRO(2) SWRW(2) SWRO(2)
CARD 17 EKRG(2) EKRG(2) EKROW(2) EKRW(2)
CARD 16 . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
CARD 17 . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
CARD 16 ETEMP(HT) SGRC(HT) SGRO(HT) SWRW(HT) SWRO(HT)
CARD 17 EKRG(HT) EKRG(HT) EKROW(HT) EKRW(HT)

The data appearing on these records initialize the temperature dependent endpoint functions associated with the relative permeability curves.

ETEMP(I) Temperature in degrees Fahrenheit. ETEMP(I) must be monotonically increasing, be greater than 32 °F, and be less than 705 °F.

SGRC(I) Maximum gas saturation at which the gas phase does not flow. Must be between zero and one.

SGRO(I) Minimum gas saturation at which the oil phase does not flow. SGRO(I) must be greater than SGRC(I). Must be between zero and one.

SWRW(I) Maximum water saturation at which the water phase does not flow. Must be between zero and one.

SWRO(I) Minimum water saturation at which the oil phase does not flow. SWRO(I) must be greater than SWRW(I). Must be between zero and one.

EKROG(I) Oil relative permeability with respect to gas at gas saturation SGRC(I). Must be greater than zero.

EKRG(I) Gas relative permeability at gas saturation SGRO(I). Must be greater than zero.

EKROW(I) Oil relative permeability with respect to water at water saturation SWRW(I). Must be greater than zero.

EKRW(I) Water relative permeability at water saturation SWRO(I). Must be greater than zero.

CARD 18 XPERMU YPERMU ZPERMU PRIDU ALPHAR

The data found on this record controls reservoir rock properties.

XPERMU Uniform value of the x directional permeability in milledarcies. XPERMU must be nonnegative. Spatial variations of the x permeability are supplied by data associated with card 21.
Uniform value of the y directional permeability in milleardarcies. **YPERMU** must be nonnegative. Spatial variations of the y permeability are supplied by data associated with card 21.

Uniform value of the z directional permeability in milleardarcies. **ZPERMU** must be nonnegative. Spatial variations of the z permeability are supplied by data associated with card 23.

Uniform value for the porosity. **PHIU** must be greater than zero. Spatial variations of the porosity are supplied by data associated with card 23.

Rock compressibility in inverse pounds per square inch. **ALPHAR** must be nonnegative.

**CARD 19**

**RROCF**

The data found on this record initializes reservoir, cap rock, and base rock thermal properties.

**RROCF**

The product of the rock density and the rock heat capacity at standard conditions in btu's per cubic feet per degrees Fahrenheit. Must be positive.

**XXF**

Formation thermal conductivity in btu's per feet per day per degrees Fahrenheit. Must be nonnegative.

**XXOB**

Overburden thermal conductivity in btu's per feet per day per degrees Fahrenheit. Must be nonnegative.

**RHOCOB**

The product of the overburden density and the cap rock heat capacity at standard conditions in btu's per cubic feet per degrees Fahrenheit. Must be positive.

**XXUB**

Underburden thermal conductivity in btu's per feet per day per degrees Fahrenheit. Must be nonnegative.

**RHOCUD**

The product of the underburden density and the base rock heat capacity at standard conditions in btu's per cubic feet per degrees Fahrenheit. Must be positive.

**CARD 20**

**ME1**

**ME2**

**ME3**

**CARD 21**

**XPERMN**

**YPERMN**

**CARD 20**

**CARD 21**

**ME1**

**ME2**

**ME3**

**CARD 21**

**XPERMN**

**YPERMN**

**CARD 20**

0

The data appearing in these records is used to modify the x and y directional permeability over each individual element of the triangulation. The indexing follows the order indicated for the elements of the partition in Figure 1. The records found in the input data stream alternate between cards 20 and 21 until **ME1** is set to zero.
**N**

Lowest index of the elements to be modified. Must be greater than or equal to zero and less than or equal to the total number of elements.

**H**

Highest index of the elements to be modified. Must be less than or equal to the total number of elements, and be greater than or equal to **N**.

**I**

Increment for the index of the elements to be modified by this procedure. Must be greater than zero.

**X**

Fraction by which the current value of the x permeability within the element is multiplied by to obtain the updated value of the x permeability. The original value of the x permeability is set to **XPERMU**. Must be greater than or equal to zero. The x permeability associated with an element of the triangulation can be modified by this procedure many different times.

**Y**

Fraction by which the current value of the y permeability within the element is multiplied by to obtain the updated value of the y permeability. The original value of the y permeability is set to **YPERMU**. Must be greater than or equal to zero. The y permeability associated with an element of the triangulation can be modified by this procedure many different times.

```
CARD 22 MN1 MN2 MN3
CARD 23 ZPERMH PR1M
CARD 22 MN1 MN2 MN3
CARD 23 ZPERMH PR1M
CARD 22 0
```

The data appearing in these records is used to modify the z directional permeability and the porosity associated with each individual node of the triangulation. The indexing follows the order indicated in Figure 1. The records alternate between cards 22 and 23 until **MN1** is set to zero.

**MN1**

Lowest index of the nodes to be modified. Must be greater than or equal to zero and less than or equal to the total number of nodes.

**MN2**

Highest index of the nodes to be modified. Must be less than or equal to the total number of nodes, and be greater than or equal to **MN1**.

**MN3**

Increment for the index of the nodes to be modified by this procedure. Must be greater than zero.

**ZPERMH**

Fraction by which the current value of the z permeability is multiplied by for the nodes modified by this procedure. The original value of the z permeability is set to **ZPERMU**. Must be greater than zero. It is possible to modify any particular node by this procedure many different times.
PHIM  Fraction by which the current value of the porosity is multiplied for the nodes modified by this procedure. The original value of the porosity is set to PH10. Must be greater than zero. It is possible that to modify any particular node by this procedure many different times.

CARD 24  SIZEPL  ISMALL

The data appearing in this record specifies the size and shape of the contour plots generated by the model.

SIZEPL  Size of contour plots in inches. Must be between 0 and 6 inches.

ISMALL  Indicates whether the plot is reduced to a triangular subset of the original plot. If ISMALL is set to zero, the contour plots are generated for the entire region. If ISMALL is set to one, all contour plots are reduced to a triangle bounded by the vertices specified in card 25. ISMALL must be either zero or one. Setting ISMALL to one is useful, for example, in plotting the computed results of displacement only over one sixth of an inverted seven spot pattern for the rectangular basic element of symmetry.

CARD 25  XTRIAN(1)  YTRIAN(1)
CARD 25  XTRIAN(2)  YTRIAN(2)
CARD 25  XTRIAN(3)  YTRIAN(3)

The data appearing on these records determines the boundaries used to reduce contour plots to a triangular region. These records are read only if ISMALL is set equal to unity on card 24.

XTRIAN(I) Location in feet of the x coordinate of the i'th vertex.

YTRIAN(I) Location in feet of the y coordinate of the i'th vertex.

CARD 26  PINITU  TINITU  WINITU  GINITU

The data found on this record is used to perform a uniform initialization the of the reservoir conditions. Spatial variations in the initial conditions can be specified using cards 27 and 28.

PINITU  Initial pressure in pounds per square inch. Must be greater than zero or less than 3200.

TINITU  Initial temperature in degrees Fahrenheit. Ignored if WINITU and GINITU are both nonzero, as the initial temperature is determined by the initial pressure if water exists in both liquid and vapor phases. PINITU and TINITU must be consistent with either WINITU or GINITU if water is present in only a single phase. For example, if the initial temperature is set to that of superheated steam and if GINITU is set to zero, the initial temperature is clearly inconsistent with the initial gas saturation. Must lie between 32 °F and 705 °F.

WINITU  Initial water saturation. Must lie between zero and one.
GIRITU Initial gas saturation. Must lie between zero and one. The sum of WINITU and GIRITU must be less than or equal to unity.

CARD 27  MIL  MI2  MI3
CARD 28  PINITH  TINITH  WINITH  GINITH
CARD 27  .  .  .  .  .
CARD 28  .  .  .  .  .  .  .
CARD 27  MIL  MI2  MI3
CARD 28  PINITH  TINITH  WINITH  GINITH
CARD 27  0

The data appearing on these records controls the modification of the initial conditions until MIL is set to zero. The input record alternates between cards 27 and 28. The ordering used to initialize the individual nodes follows that which is indicated in Figure 1.

MIL Lowest index of the nodes to be modified. Must be greater than or equal to zero and less than or equal to the total number of nodes.

MI2 Highest index of the nodes to be modified. Must be less than or equal to the total number of nodes, and be greater than or equal to MIL.

MI3 Increment for the index of the nodes to be modified by this procedure. Must be greater than zero.

PINITH Modified initial pressure in pounds per square inch. Must be greater than zero or less than 3200.

TINITH Modified initial temperature in degrees Fahrenheit. Ignored if WINITH and GINITH are both nonzero, as the modified initial temperature is determined by the modified initial pressure if water exists in both liquid and vapor phases. PINITH and TINITH must be consistent with either WINITH or GINITH if water is present in only a single phase. For example, if the modified initial temperature is set to that of superheated steam and if GINITH is set to zero, the modified initial temperature is clearly inconsistent with the modified initial gas saturation. Must lie between 32 °F and 705 °F.

WINITH Modified initial water saturation. Must lie between zero and one.

GINITH Modified initial gas saturation. Must lie between zero and one. The sum of WINITH and GINITH must be less than unity.

**Time Page Data**

CARD 29  IEHD

The data contained in this record indicates if another time page is to be read.
If IEED is zero, a new time page is read. If IEED is unity, the run is halted. IEED must be zero or one.

The data appearing in this record supplies initial values for time stepping parameters used over this time page.

**FTIME**
Final time in days for the time page. Must be greater than or equal to the current time.

**DT**
Initial time step length for the time page in days. Must be greater than DTHIN and less than DTHMAX.

**DTHMAX**
Maximum time step length in days.

**DTHIN**
Minimum time step length in days. Must be less or equal to than DTHMAX and greater than zero.

**CHMAXD**
Maximum total density change desired over each time step in pounds per cubic feet. Must be greater than zero.

**CHMAXP**
Maximum pressure change desired over each time step in pounds per square inch. Must be greater than zero.

The data found on this record are used to initialize nonlinear iteration parameters used in this time page.

**ERRORE**
Maximum allowed error in the discretized energy equation in btu's per cubic feet. Must be greater than zero.

**ERRORC**
Maximum allowed error in the discretized oil or water material balance equations in pounds per cubic feet. Must be greater than zero.

The value of the parameter REDUC determines if the Jacobian matrix is formed and factored. A variable designated as TEST is computed from the quotient of the infinity norm of the new nonlinear new residual and corresponding norm of the old residual. If REDUC is greater than TEST the Jacobian is formed and factored. REDUC must lie between zero and one. If REDUC is set to one, stationary Newton is used, and if REDUC is set to zero, Newton's method is used. The Jacobian matrix is always formed for the first nonlinear iteration.

The data appearing in this record is used to initialize certain parameters pertaining to wells.

**NW**
The number of active wells in this time page. Must be between one and ten.
OILSTH  Number of cold water equivalent barrels of steam generated by one barrel of oil. Used to determine maximum the net oil recovery. Must be greater than zero.

CARD 33  XWELL(1)  YWELL(1)  QWELL(1)  QWALT(1)  PWELL(1)  TWELL(1)
CARD 34  NPUMP(1)  WELLI(1)  GWELL(1)  FW(1,1)  FW(1,2)  FW(1,3)
CARD 34  FW(1,4)  FW(1,5)  FW(1,6)
CARD 34  . . . . . .  FW(1,NZ)
CARD 35  IWELL(1)
CARD 33  . . . . . .  . . . .
CARD 34  . . . . . .  . . . .
CARD 34  . . . . . .  . . . .
CARD 35  . . . . . .
CARD 33  XWELL(NW)  YWELL(NW)  QWELL(NW)  QWALT(NW)  PWELL(NW)  TWELL(NW)
CARD 34  NPUMP(NW)  WELLI(NW)  GWELL(NW)  FW(NW,1)  FW(NW,2)  FW(NW,3)
CARD 34  FW(NW,4)  FW(NW,5)  FW(NW,6)
CARD 34  . . . . . .  FW(NW,NZ)

Parameters for the wells are supplied by data appearing on these records.

XWELL(I)  Location in feet of the x coordinate of the i'th well.

YWELL(I)  Location in feet of the y coordinate of the i'th well. The wells must lie at x-y nodes of the discretization.

QWELL(I)  Cold water equivalent injection rate in barrels per day. This quantity is positive at injection wells, representing the maximum injection rate. This quantity is negative for production wells. The absolute value of a negative quantity represents the maximum allowed production rate. This quantity is calculated using the full pattern basis. Rate modifications based upon the well location are treated by the parameter QWELL(I).

QWALT(I)  Steam quality at an injection well. Ignored at production wells. Must be greater than zero. Superheated steam injection can be simulated by setting QWALT(I) to a value which is greater than one.

PWELL(I)  Wellbore pressure in pounds per square inch. At an injection well, this quantity represents the maximum allowed wellbore pressure. This parameter should be set to a high value if a constant injection rate is desired, and one should set QWELL(I) to a large value if constant pressure injection is desired. At a production well, PWELL(I) represents the minimum allowed wellbore pressure. If the computed wellbore pressure dips below the PWELL(I), the well is shut in. If the production rate is constrained by the absolute value of QWELL(I), the wellbore pressure is greater than PWELL(I).

TWELL(I)  Injection temperature in degrees Fahrenheit at an injection well. Ignored for a production well. Must be between 32 °F and 705 °F.
**NPUMP(I)** Simulated layer in which the pump is located at a production well. At an injection well, NPUMP(I) is set to one internally, i.e., pressure constraints are enforced at the deepest location of an injection well. NPUMP(I) must lie between one and EZ. As gravity effects within the wellbore are treated, it is imperative to be careful in specifying NPUMP(I) and PWELL(I). For example, if PWELL(I) were to be set to zero at the bottom of the reservoir, an unphysical negative wellbore pressure would be calculated for upper layers of the reservoir.

**WELL(I)** Total productivity or injectivity index of the well calculated using the Peaceman Correction [12]. This parameter is specified in units of barrels - centipoise per day per pounds per square inch at production wells and in units of barrels per day per pounds per square inch at injection wells. Following Peaceman, let \( d \) be the diameter of the smallest circle which can be circumscribed about the support of the basis function associated with a computational molecule containing the well in question. The equivalent well radius \( r_e \) is computed as the product of \( d \) and \( C \), where \( C \) is a correction constant. \( C \) is a function of the discretization procedure and has been experimentally determined. Values of \( C \) are given below as a function of NPROC.

\[
\begin{align*}
\text{NPROC} & = 1 \quad C = 0.08 \\
\text{NPROC} & = 2 \quad C = 0.14 \\
\text{NPROC} & = 3 \quad C = 0.11 \\
\text{NPROC} & = 4 \quad C = 0.11
\end{align*}
\]

**GWELL(I)** Geometric factor for the well. Must lie between zero and one. GWELL(I) is tabulated below as a function of the position of the associated computational molecule with respect to the discretization.

\[
\begin{align*}
\text{INTERIOR} & \quad \text{GWELL}(I) = 1.000 \\
\text{EDGE} & \quad \text{GWELL}(I) = 0.500 \\
\text{CORNER \ (90°)} & \quad \text{GWELL}(I) = 0.250 \\
\text{CORNER \ (60°)} & \quad \text{GWELL}(I) = 0.167 \\
\text{CORNER \ (45°)} & \quad \text{GWELL}(I) = 0.125
\end{align*}
\]

**FW(I,J)** Multiplicative factor for WELL(I) in the j'th layer. Usually should be set to either the fractional height of the height of layer or to zero, depending upon the well completion. Must be nonnegative. Note the special format for EZ greater than three.

**IWELL(I)** Indicates whether the rates associated with this well are stored in the file assigned to Fortran unit eight. If IWELL(I) is one, the cold water equivalent injection rate is saved at an injection well, and the oil production rate is stored at a production well. If IWELL(I) is zero, no rate information is saved at the well. Must be either zero or one.
The data found on this record is used to control the frequency at which output information is generated by the program.

**FSUM**  
Frequency in days at which a summary sheet of model statistics, balance information, and well statistics is added to the file assigned to Fortran unit six. Must be greater than or equal to zero.

**FOUT**  
Frequency in days at which a sheet indicating current reservoir conditions is added to the file assigned to Fortran unit six. Must be greater than or equal to zero.

**FCURVE**  
Frequency in days at which all well rate information and information relating to cumulative oil recovery is added to the file assigned to Fortran unit eight. Must be greater than or equal to zero.

**FPLOT**  
Frequency in days at which contour plots are generated and stored in the file assigned to Fortran unit seven. Must be greater than or equal to zero.

**FREST**  
Frequency in days at which a restart file is written to the file assigned to Fortran unit two. Must be greater than or equal to zero.

**FSTOP**  
Time in days after which at which the program is halted. An interruption by this mechanism is different from a termination caused by reaching the end of a time page, i.e., when **TIME** is equal to **FTIME**. Using this option, the program is allowed to seek the normal time step length and continue until **TIME** is greater than the time associated with **FSTOP**. Must be greater than or equal to zero. A restart file is written to the file assigned to Fortran unit two at termination.

The data appearing on this record controls whether nonlinear iteration statistics are saved on the file associated with Fortran unit eight.

**NEWTON**  
If **NEWTON** is one, nonlinear iteration statistics are added to the file assigned to Fortran unit eight at every time step. If **NEWTON** is zero, these statistics are not saved. **NEWTON** must be either zero or one.

The data found in this record indicates the number of contour plots.

**NP**  
This variable indicates the number of contour plots that are to be made at a frequency of **FPLOT**. **NP** must lie between zero and ten. If **NP** is zero, the next data record appearing in the input data stream must be card 29.
CARD 39 NTYPE( 1) NLAY( 1) NCONT( 1)
CARD 40 CLOW( 1) CHIGH( 1)
CARD 39 NTYPE( 2) NLAY( 2) NCONT( 2)
CARD 40 CLOW( 2) CHIGH( 2)
CARD 39 - - - - - - - - -
CARD 40 - - - - - - - - -
CARD 39 NTYPE(NP) NLAY(NP) NCONT(NP)
CARD 40 CLOW(NP) CHIGH(NP)

The data appearing in this record contains various parameters controlling the contour plotting routine. After exhausting records of this form, the input data stream represents a new time page. The new time page begins with card 29.

**NTYPE(I)** Indicates the fluid property distribution of which the contour plot is to be made. Must lie between one and five. The possible options are listed below.

- **NTYPE(I)** = 1 Pressure plot
- **NTYPE(I)** = 2 Temperature plot
- **NTYPE(I)** = 3 Water saturation plot
- **NTYPE(I)** = 4 Gas saturation plot
- **NTYPE(I)** = 5 Oil saturation plot

**NLAY(I)** Layer in the reservoir for which the contour plot is to be made. Must lie between one and **NZ**.

**NCONT(I)** Number of contours that are used. Must be greater than zero.

**CLOW(I)** Lowest value of **NTYPE(I)** used in forming the contour plot. Must be greater than zero.

**CHIGH(I)** Highest value of **NTYPE(I)** used in forming the contour plot. Must be strictly greater than **CLOW(I)**. An illustration of how **CLOW(I)** and **CHIGH(I)** are used to determine the value of the contours is as follows. Let **NTYPE(I)** be set to two, **NCONT(I)** be set to three, **CLOW(I)** be set to 150 °F, and **CHIGH(I)** be set to 450 °F. The contours are generated at 200 °F, at 300 °F, and at 400 °F for this set of parameters.

### 3.4 Example Input

Example input for a simulated displacement over an eighth of a five spot pattern is presented in Appendix A. The data is a composite of data used in Coats and Ramesh [2], Chu and Trimble [13], and Chu [14]. The 7×7×2 parallel grid illustrated in Figure 1 is used in this simulated displacement. A copy of this file is assigned to Fortran unit five for the example run.
3.5. Example Output

A computational example is run using the input data of Appendix A. The corresponding output data found in the file assigned to Fortran unit six is presented in Appendix B. In the interest of brevity only a single time page summary corresponding to the end of the second simulated year is presented. The representation of the approximating space which is produced by the code is used in Figure 1, although the numbering is not produced by the code. Figures 2 and 3 illustrate contour plots of the 300 °F isotherms after three years of continuous steam displacement. Figures 1 through 3 have been taken directly from the plots found in the file assigned to Fortran unit seven. Figure 4 presents a graph of the water injection rate and the oil production rate as a function of time. The water injection rate is a constant, as the injection well is effectively rate constrained. This plot would be much more interesting for a pressure constrained well. Figure 5 illustrates the total oil recovery as a function of time. Figure 6 illustrates the time step length with respect to time. Figure 7 presents both the number of time step reductions with respect to time and the number of Newton iterations used at each time step. The functions illustrated in Figures 4 through 7 have been obtained by postprocessing information found in the file assigned to Fortran unit eight.

3.6. Code

The source code is written in Fortran and contains about 8,000 Fortran statements. The total length of the code is about 16,000 card images when comment cards are included. Portability of the code has been checked by compiling the program under the VMS, UNIX, and the H extended compiler. The Fortran code attempts to follow the 1966 standard, although minor deviations such as mixed mode expressions and IMPLICIT REAL*8 statements are present in the current version.

The source code contains character strings which must be replaced by the user. The strings begin with the symbol "#" and are listed along with recommended values in Table 1. These character strings are used to reset the maximum dimension of the arrays used by the code and to provide a method of dealing with certain machine dependencies. For example, the character string "#NO" is used to signify the maximum number of nodes allowed by the program. The string "#L3" is used to represent the integer or Hollerith equivalent of "4H$ " on the machine to be used.

Two copies of the routine PRINT are provided in the source code. The version which is commented out is useful for generating bit map plots compatible with one particular dot matrix printer. The version which is not commented out is fully portable. A routine named SETNAME is also provided. The routine and its references are commented out in the source code, as this routine is used to monitor background execution in a VMS environment.
Table 1

User Defined Character Strings
Appearing in the Code

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<th>String</th>
<th>Recommended Value</th>
<th>Description</th>
</tr>
</thead>
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<td>#AR</td>
<td>231</td>
<td>Maximum number of nodes per layer</td>
</tr>
<tr>
<td>#BL</td>
<td>200</td>
<td>Maximum number of grid blocks</td>
</tr>
<tr>
<td>#MA</td>
<td>80000</td>
<td>Maximum number of matrix entries</td>
</tr>
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<td>#NO</td>
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<td>Maximum number of total nodes</td>
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<td>#NX</td>
<td>200</td>
<td>Maximum number of x grid blocks</td>
</tr>
<tr>
<td>#NY</td>
<td>200</td>
<td>Maximum number of y grid blocks</td>
</tr>
<tr>
<td>#N3</td>
<td>5</td>
<td>Maximum number of layers</td>
</tr>
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<td>' '</td>
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4. Acknowledgements

I would like to acknowledge that IBM research funded this work. I would like to thank Dr. Mary Wheeler and Dr. John Dennis of Rice, and Dr. Trond Steihaug, formerly at Rice, for their many helpful suggestions.
5. References


6. Appendix A: Sample Input

CARD 1 EXAMPLE DATA SET FOR THE THERMAL CODE
CARD 1 TODAY'S DATE IS 10 / 12 / 1983
CARD 1 REDUCED 7 X 7 X 2 PARALLEL GRID
CARD 1 UPSTREAM WEIGHTED FINITE ELEMENTS
CARD 1 KINEMATIC MOBILITY WEIGHTING USED
CARD 1 END

CARD 2 0
CARD 3  231.  231.  60.  0.  0.
CARD 4  3  1  1
CARD 5  7  7  2
CARD 6  1  1  1
CARD 10 .00001 .0004 60.5  .5
CARD 11  8
CARD 12  75.  5780.0
CARD 12  100.  1380.0
CARD 12  150.  187.0
CARD 12  200.  47.0
CARD 12  250.  17.6
CARD 12  300.  8.5
CARD 12  350.  5.2
CARD 12  500.  2.5
CARD 13  11  11  3
CARD 14  .00  .000  1.00
CARD 14  .04  .006  .90
CARD 14  .08  .010  .78
CARD 14  .12  .020  .64
CARD 14  .16  .028  .50
CARD 14  .20  .038  .37
CARD 14  .24  .048  .25
CARD 14  .28  .064  .16
CARD 14  .32  .090  .08
CARD 14  .36  .132  .03
CARD 14  .40  .200  .00
CARD 15  .500  .0000  1.00
CARD 15  .520  .0006  .67
CARD 15  .540  .0012  .41
CARD 15  .560  .0020  .23
CARD 15  .580  .0030  .14
CARD 15  .600  .0042  .09
CARD 15  .620  .0058  .06
CARD 15  .640  .0080  .03
CARD 15  .680  .0150  .02
CARD 15  .695  .0185  .01
CARD 15  .700  .0200  .00
CARD 16  75.  0.  40.  .5  .7
CARD 17  1.  .2  1.  .02
CARD 16  400.  0.  25.  .7  .9
CARD 17  1.  .3  1.  .03
CARD 16  500.  0.  25.  .7  .9
CARD 17  1.  .3  1.  .03
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7.
Appendix B: Sample Output

THE FINITE ELEMENT THERMAL MODEL

EXAMPLE DATA SET FOR THE THERMAL CODE
TODAYS DATE IS 10 / 12 / 1983
REDUCED 7 X 7 X 2 PARALLEL GRID
UPSTREAM WEIGHTED FINITE ELEMENTS
KINEMATIC MOBILITY WEIGHTING USED

RESERVOIR DIMENSIONS AND DIP

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DISCRETIZATION INFORMATION

RECTANGULAR REGION
QUARTER PATTERN ELEMENT OF SYMMETRY
FINITE ELEMENT PROCEDURE USED
MASS FRACTIONAL FLOWS UPWINDED
NUMBER OF GRID BLOCKS IN THE X DIRECTION  7
NUMBER OF GRID BLOCKS IN THE Y DIRECTION  7
NUMBER OF GRID BLOCKS IN THE Z DIRECTION  2
UNIFORM DISCRETIZATION X DIRECTION
UNIFORM DISCRETIZATION Y DIRECTION
UNIFORM DISCRETIZATION Z DIRECTION
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### Oil PVT Parameters

- **Oil Isothermal Compressibility**: 0.00001000 1 / psia
- **Oil Coefficient of Thermal Expansion**: 0.00040000 1 / F
- **Oil Stock Tank Density**: 60.50000000 lbs./cu.ft.
- **Oil Specific Heat**: 0.50000000 BTU/lbs./F

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<th>Viscosity (CP)</th>
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ROCK PROPERTIES

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Y DIRECTIONAL PERMEABILITY  3000.00000000  MD.
Z DIRECTIONAL PERMEABILITY  3000.00000000  MD.
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OVERBURDEN HEAT CAPACITY     30.00000000  BTU / CU. FT. / F
UNDERBURDEN HEAT CAPACITY    30.00000000  BTU / CU. FT. / F
FORMATION THERMAL CONDUCTIVITY 30.00000000  BTU / FT. / DAY / F
OVERBURDEN THERMAL CONDUCTIVITY 30.00000000  BTU / FT. / DAY / F
UNDERBURDEN THERMAL CONDUCTIVITY 30.00000000  BTU / FT. / DAY / F
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POROSITY                       0.35000000

PLOTTING INFORMATION

PLOTTING SIZE                  6.00000000  INCHES

RESERVOIR INITIALIZATION DATA

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INITIAL RESERVOIR TEMPERATURE  100.00000000  F
INITIAL LIQUID WATER SATURATION 0.50000000
INITIAL VAPOR WATER SATURATION  0.00000000
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INITIAL WATER IN PLACE         25692.70347544  BBL
INITIAL ENERGY IN PLACE        2454.43336311  MBTU

MATRIX AND DISCRETIZATION CONSTANTS

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NUMBER OF ACTIVE ELEMENTS     32
MATRIX BAND WIDTH             65
TOTAL NUMBER OF MATRIX ENTRIES 7800
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$ denotes irregular element
& denotes triangular element

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### INITIAL GRID INFORMATION FOR LAYER 1

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$ denotes irregular element
& denotes triangular element

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TIME PAGING DATA

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FINAL TIME  
INITIAL TIME STEP LENGTH  
MAXIMUM TIME STEP LENGTH  
MINIMUM TIME STEP LENGTH  
MAXIMUM ALLOWED TOTAL DENSITY CHANGE  
MAXIMUM ALLOWED PRESSURE CHANGE  
NONLINEAR CONVERGENCE CRITERIA ENERGY  
NONLINEAR CONVERGENCE CRITERIA MASS  
EPSILON FOR FIXED NEWTON  

0.00000000 DAYS  
2190.00000000 DAYS  
0.50000000 DAYS  
20.00000000 DAYS  
0.00100000 DAYS  
1.00000000 LBS. / CU. FT.  
1000.00000000 LBS. / SQ. IN.  
0.10000000 BTUS / CU. FT.  
0.00100000 LBS / CU. FT.  
0.00000000

WELL DATA ON A FULL PATTERN BASIS

NUMBER OF WELLS  
STEAM GENERATED PER POUND OIL  

2  
13.36000000 LBS / LBS.

DATA FOR WELL NUMBER  
X LOCATION  
Y LOCATION  
COLD WATER EQUIVALENT INJECTION RATE  
SANDFACE STEAM QUALITY  
SANDFACE TEMPERATURE  
MAXIMUM SANDFACE PRESSURE  
INJECTIVITY INDEX  
GEOMETRY FACTOR  
LAYER ALLOCATION FACTORS  

1  
0.00000000 FEET  
0.00000000 FEET  
300.00000000 BBL / DAY  
0.70000000  
400.00000000 F  
1600.00000000 PSIA  
19.60000000 BBL / DAY / PSIA  
0.12500000  
0.50000000  
0.00000000

RATES LOGGED FOR WELL

DATA FOR WELL NUMBER  
X LOCATION  
Y LOCATION  
COLD WATER EQUIVALENT INJECTION RATE  
FLOWING BOTTOM HOLE PRESSURE  
PUMP LAYER  
PRODUCTIVITY INDEX  
GEOMETRY FACTOR  
LAYER ALLOCATION FACTORS  

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RATES LOGGED FOR WELL
I/O DATA

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PROPERTY OUTPUT FREQUENCY 365.00000000 DAYS
RECOVERY INFORMATION OUTPUT FREQUENCY 30.00000000 DAYS
PLOT OUTPUT FREQUENCY 1095.00000000 DAYS
RESTART FILE OUTPUT FREQUENCY 3000.00000000 DAYS
CHECKPOINT STOP FREQUENCY 3000.00000000 DAYS
TCOND TYPE DATA SAVED

PLOTTING INFORMATION

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LAYER IN SIMULATION 2
NUMBER OF CONTOURS 1
MINIMUM CONTOUR VALUE 300.000000
MAXIMUM CONTOUR VALUE 300.000000

INFORMATION FOR PLOT
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LAYER IN SIMULATION 1
NUMBER OF CONTOURS 1
MINIMUM CONTOUR VALUE 300.000000
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MODEL STATISTICS

TIME 734.77144662 DAYS
TIME STEP LENGTH 19.46245568 DAYS
NUMBER OF TIME STEPS 83
NUMBER OF TIME STEP REDUCTIONS 0
TOTAL NUMBER OF FUNCTION EVALUATIONS 307
NUMBER OF FULL STEPS 224
NUMBER OF FIXED STEPS 0
NUMBER OF NEWTONIAN ITERATIONS 3
NUMBER OF NEWTON ITERATIONS / TIME 2.69879518
INSTANTANEOUS STEAM / OIL RATIO 2.40930026 LBS. / LBS.
CUMULATIVE STEAM / OIL RATIO 4.21870314 LBS. / LBS.
OIL USED TO GENERATE STEAM 2062.41985392 BBLs.
MOBILITY RATIO 115.33931599
GREATEST WATER DENSITY CHANGE 0.28140112 LBS. / CU. FT.
GREATEST OIL DENSITY CHANGE 0.66440733 LBS. / CU. FT.
GREATEST PRESSURE CHANGE 13.33139607 LBS. / SQ. IN.
INDEX OF CELL - LARGEST WATER CHANGE 22
INDEX OF CELL - LARGEST OIL CHANGE 22
INDEX OF CELL - LARGEST PRES. CHANGE 2

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RESERVOIR DATA FOR EACH COMPUTATIONAL MOLECULE
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MAXIMUM NET OIL RECOVERY AT 1596.131 DAYS
PERCENT OF OOIP RECOVERED IS 50.355 %

STEAM BREAK THROUGH AT WELL 2 AT TIME 935.270 DAYS
Figure 1
Internal Ordering Scheme

Bottom Layer

Top Layer

- 40 -
Figure 2
Isotherm of 300 Degrees Farenheit
Top Layer

Figure 3
Isotherm of 300 Degrees Farenheit
Bottom Layer