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Advanced Wellbore Thermal Simulator GEOTEMP2 User Manual

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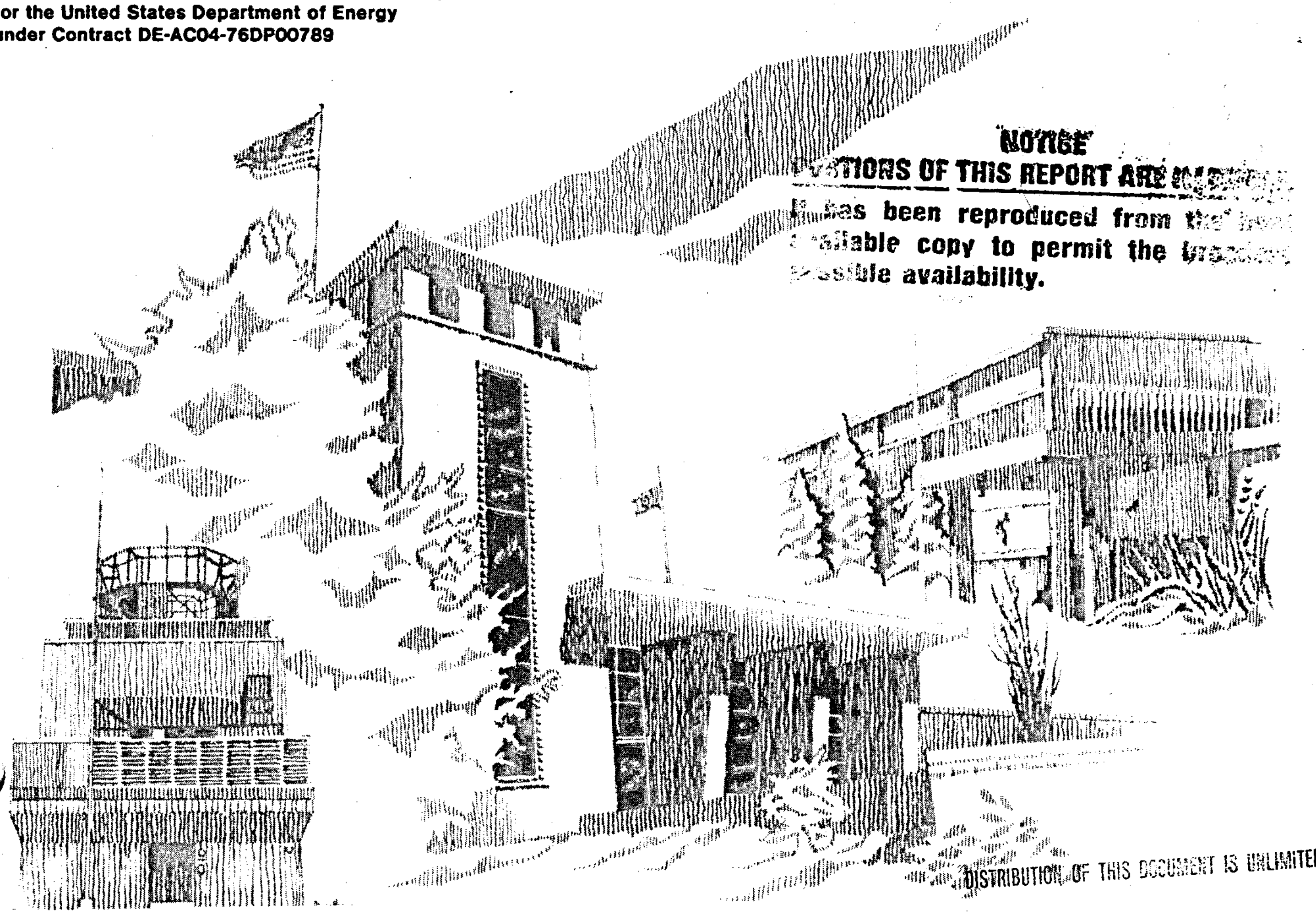

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ADVANCED WELLBORE THERMAL SIMULATOR*

GEOTEMP2

USER MANUAL

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ABSTRACT

GEOTEMP2 is a wellbore thermal simulator computer code designed for geothermal drilling and production applications. The code treats natural and forced convection and conduction within the wellbore and heat conduction within the surrounding rock matrix. A variety of well operations can be modeled including injection, production, forward, and reverse circulation with gas or liquid, gas or liquid drilling, and two-phase steam injection and production. Well completion with several different casing sizes and cement intervals can be modeled. The code allows variables such as flow rate to change with time enabling a realistic treatment of well operations.

This user manual describes the input required to properly operate the code. Ten sample problems are included which illustrate all the code options. Complete listings of the code and the output of each sample problem are provided.

*Work performed under the auspices of the U.S. Dept. of Energy Contract DE-AC04-76DP00789.

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PREFACE

This User Manual is an extensively revised and updated version of the "Advanced Wellbore Thermal Simulator-GEOTEMP2-User Manual", SAND82-7003/2 by R. F. Mitchell, printed in February, 1982. Since the issuance of this previous report numerous corrections and modifications have been made to the computer code, as well as to the User Manual. For this reason, this updated User Manual for GEOTEMP2 Version 2.0 has been published.

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1. INTRODUCTION

GEOTEMP2 is a wellbore thermal simulator designed for geothermal well drilling and production problems. The code includes the following features:

1. Fully transient heat conduction
   a. wellbore flowing stream
   b. formation

2. Wellbore fluid flow options
   a. injection, production
   b. forward and reverse circulation
   c. inlet temperature change
   d. flow rate change
   e. fluid properties change
   f. multiple fluids in wellbore
   g. air or nitrogen drilling
   h. two-phase steam injection/production

3. Well completion options
   a. casing size, weight, setting depth
   b. variable tubing area
   c. length of cement columns
   d. annulus packer fluids
   e. bottom-hole assembly for drilling

4. Drilling-production histories
   a. changes of flow options with time
   b. effects of previous flow history

Figure 1 illustrates some of these features. In this figure, a drilling simulation suitable for GEOTEMP2 is sketched. For instance, the well being drilled has casings already set. In the annuli between these casings, packer fluids (annulus) and cement columns of various heights are circulating. The well is now being drilled below the production casing. Three different fluids are circulating in the wellbore at this time. A bottom-hole assembly is indicated on the end of the drill pipe. The fluids are being circulated forward through the drill pipe and out of the annulus. All of the well completion detail, wellbore fluids, and flow circulation illustrated in Figure 1 can be simulated with GEOTEMP2.

The program is written in the CDC FORTRAN Version 5 language. This language complies with the American National Standards Institute (ANSI) FORTRAN 77 language.

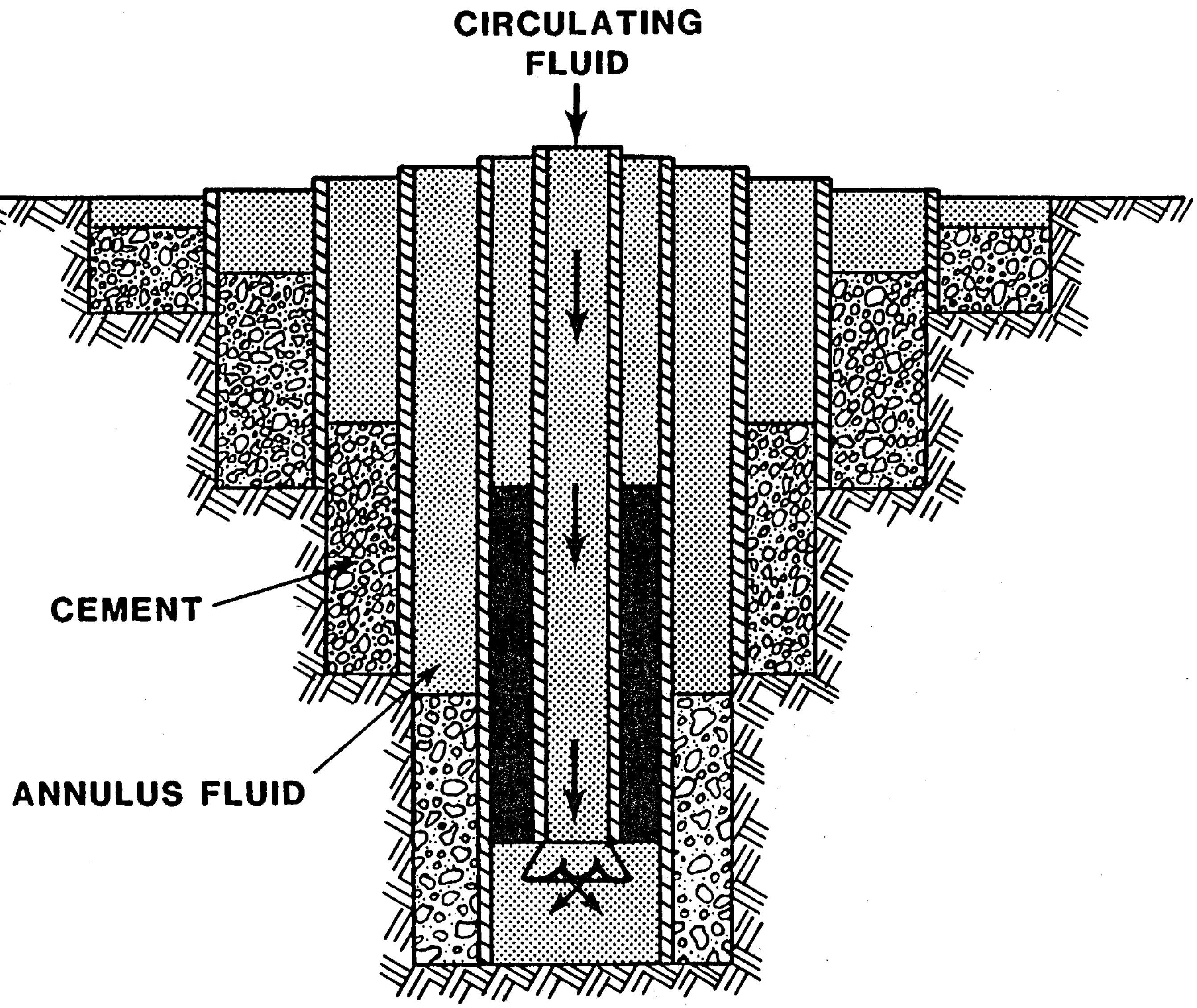

Figure 1. Illustration of the casing options available in GEOTEMP2 for a drilling operation.

GEOTEMP2 is an extensively modified version of a previous wellbore simulator called GEOTEMP (5, 6, 7). For users familiar with the original code, the following list gives the principal changes and additions:

1. Free format input
2. Variable tubing flow area
3. Multiple liquids in the wellbore
4. Deviated wellbore
5. Air or nitrogen drilling
6. Mist drilling
7. Two-phase steam production/injection

Details of the theory of the incompressible flow options handled by GEOTEMP are presented in the References 5 through 7 while the new additions are treated in Reference 3. These details include the description of the energy balances performed on the well and surrounding soil, including the various correlations used for Nusselt number for forced and free convection. For the flow equations, details on the determination of the viscosity of the fluid are given. Also described are the solution scheme and numerical grid employed.

In GEOTEMP2 provision has been made in the flow equations so that the flow areas of the tubing may vary with depth in the wellbore. The effect of variable area on grid formulation, as shown in Figure 2, is to place the radius of the innermost grid points within the smallest tube, and the radius of the next layer of grid points outside of the largest tubing size.

Multiple liquids can exist in GEOTEMP2 simulations. Liquid interfaces are tracked through the tubing and annulus as one liquid displaces another. For example, this allows simulation of cementing processes or changing the type of drilling mud. However, GEOTEMP2 does not attempt to simulate displacement of liquids with a gas or two-phase steam or vice versa. This means that it is not possible to simulate an operation where the type of drilling fluid changes, e.g. mud going to air. To accomplish this type of operation, multiple runs must be made or the code must be modified by the user.

Compared to vertical wells, deviated holes extend both the travel time and distance of fluid in a well. Flowing fluids are therefore more sensitive to surrounding temperatures in deviated holes than in vertical holes. The geometry of a deviated well, illustrated in Figure 3, is defined by three variables: true vertical depth to bottom-hole TVD, measured depth to bottom-hole TMD, and depth to deviation DDVN. If it is assumed that the well is vertical to the deviation depth, the angle of deviation is given by:

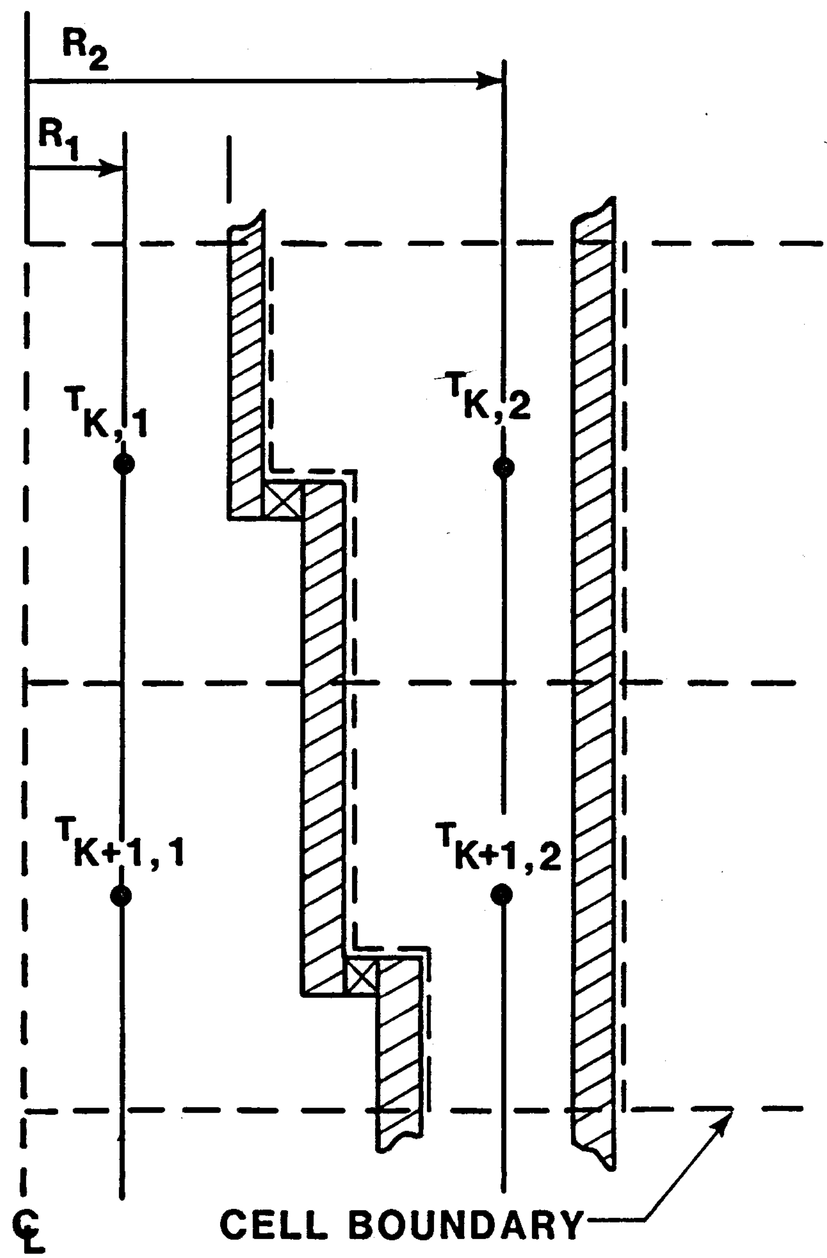

Figure 2. Variable tubing sizes and the mathematical cells within the wellbore.

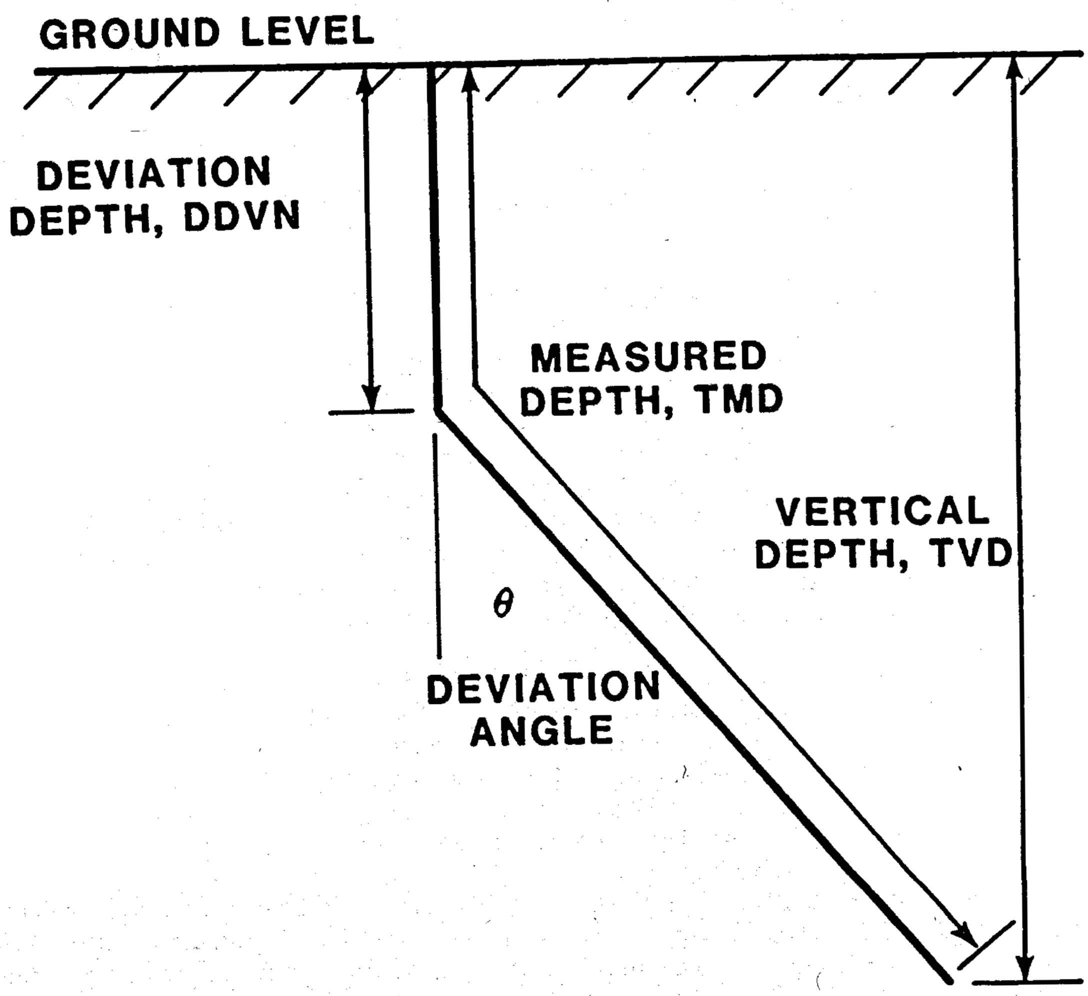

Figure 3. Geometry of a deviated well.

$$\theta = \cos^{-1} \frac{TMD-DDVN}{TVD-DDVN}$$

A deviated hole is then modeled by replacing the vertical depth with the measured depth in grid generation, converting the undisturbed temperature gradient to the measured depth, and appropriately taking into account the angle in calculating pressure drops and densities.

A major part of the new wellbore thermal simulator is the gas-drilling/mist-drilling capability. Previously, one of the few models available for gas drilling applications was that developed by R. R. Angel in the 1950s(1). The GEOTEMP2 gas drilling simulator goes far beyond previously available analysis by including:

1. The balance of aerodynamic drag and buoyancy forces on the cuttings
2. A fully described bottom-hole assembly
3. The effects of mist addition and water influx

Figure 4 illustrates the bottom-hole assembly used in the sample problem that illustrates gas drilling in this manual. The drill collar length, inside diameter, and outside diameter and the drill bit size and nozzle sizes can all be specified and all are important in simulating air drilling. More information is given in the sample problem section.

Another major modification to GEOTEMP is the two-phase steam injection and production model. The empirical flow correlations used to develop the flow model were based on the Orkiszewski vertical two-phase flow equations (8, 9). These correlations are based on field data from over 200 wells and have been further verified by other measurements. The accuracy of the model is considered to be better than 10% for gas/petroleum two-phase systems. However, the correlations were not originally developed for steam/water systems and the accuracy for these may be lower. Furthermore, the correlations are for upward vertical flow in pipes and so may break down in steam injection or in severely deviated wells. The steam thermodynamic correlations use the equations of state published by Keenan and Keyes (4).

In GEOTEMP2 the output for the gas drilling and two-phase flow cases has been expanded to provide flowing stream properties such as densities, flow velocities, and pressures. The original set of four flow options has been expanded to ten to accommodate the changes listed above. Reference 3 includes detailed descriptions of the gas phase and multiphase flow options added to GEOTEMP to form GEOTEMP2.

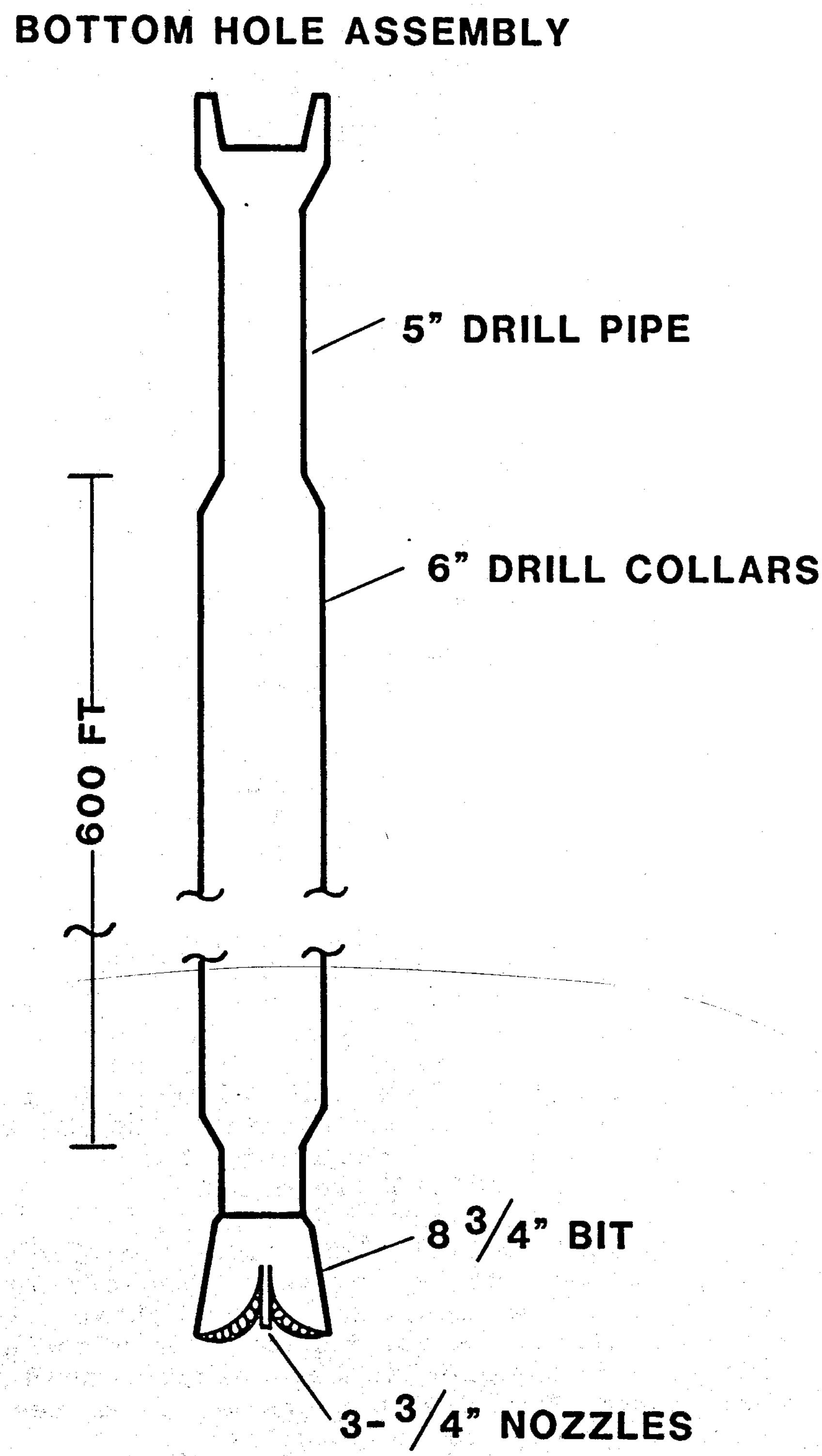

Figure 4. Bottom hole assembly.

GEOTEMP2 was designed primarily for use in predicting the behavior of geothermal wells, but it is flexible enough to handle many typical drilling, production, and injection problems in the oil industry as well. However, in using any code it is important to keep in mind the limitations and assumptions that the code contains. The following is a list of warnings to the user:

1. GEOTEMP2 does not allow the modeling of gas-filled annuli in production or injection problems. In gas or mist drilling, no radiation losses are included in the energy balance. Less serious is the assumption that conduction occurs only in the radial direction in the tubing and casing strings.

2. No attempt is made to model fluid flow in the formation. This could significantly alter the formation temperature near the injection point or the production intake.

3. The time step selector in GEOTEMP2 is very simple and is not coupled to the change in temperature each cell is experiencing. Modification of GEOTEMP2 to include a more sophisticated time step selector may be required in certain situations.

4. The Nusselt number correlations for forced convection in incompressible flow is for turbulent flow (see Reference 7). The correlation for free convection is for annuli, but is also used for the innermost tubing, with the radius used as the characteristic length.

5. In the incompressible flow options, the drilling fluid may be specified as a non-Newtonian fluid. However, the fluid's viscosity is assumed to change with temperature in the same way as the viscosity of water. The ratio of the fluid viscosity to the water viscosity is held constant with change in temperature. GEOTEMP2 does not allow any liquid with a density less than that of water. GEOTEMP2 internally calculates the properties of the fluid based on this density (see the comment on the "FLUIDS" record).

6. The empirical correlations for two-phase steam/water flow are for flow vertically upward. (These correlations may not have an accuracy of 10%, as stated above, for injection where flow is downward). Also, the code only contains the correlations for liquid Reynolds numbers greater than 6000. It is unlikely that lower Reynolds numbers will be seen under most operating conditions of geothermal wells.

7. GEOTEMP2 defines the undisturbed geothermal gradient by one or two linear temperature functions given by the surface temperature, the bottom hole temperature, and (optionally) the temperature at some intermediate depth. Non-linear temperature profiles require some code modification. The format for input of the temperature data may be modified to add a separate temperature for each vertical layer.

Alternatively, a data statement containing the temperature for each layer may be inserted into the main program. An example of this method is given below. A new array variable, TT1(K), must be defined:

```
Dimension TT1 (No. of Layers)
Data TT1/List of temperatures for each layer/
```

In the main program, statement number 28 and the line immediately above should be modified by replacing the variable TT with TT1(K), where K is the vertical layer number.

The number of vertical layers in a given problem is found from

No. of layers = INT(1.5 + TMD/DDEPTH) + 2

where TMD is the total depth, DDEPTH is the vertical height of each layer, and INT means to take the largest integer corresponding to the expression within the parentheses. Unless modified by the user, DDEPTH is set at 200 feet by the code.

In addition to the geothermal gradient, the soil properties for each layer may also be changed. The soil properties are defined in subroutine PROP. A data statement can be similarly used here also to insert different soil properties for each layer.

The remainder of this introduction gives some general comments about the input data required to run this program. Section 2 describes all the data which are required by the program. In Section 3 the various options and necessary data are discussed. Section 4 contains all the sample problems run using the code. Each sample problem contains a brief description and may highlight points to note about the output. The input and output data for each problem are tabulated.

There are two appendices to this report. The first appendix lists addenda to the previously published research report (Ref. 3). The second appendix lists and briefly describes the subroutines contained in GEOTEMP2. A code listing is provided in a microfiche attached to the back cover of this report.

1.1 GENERAL COMMENTS

The input for GEOTEMP2 divides into two parts. The first part consists of the minimum information needed to define a GEOTEMP2 problem and requires the following sets of data:

1. TITLE
2. TUBING
3. CASING
4. WELLBORE
5. TEMPERATURES
6. FLUIDS
7. INITIAL FLUIDS

The second part consists of the control records[1] and options that describe the flow in the wellbore during defined time periods. The following is a partial list of these options:

1. Injection
2. Production
3. Drilling
4. Air drilling
5. Mist drilling
6. Steam production

The numerical data recorded on the data records are given in "free" format. This means that the numbers are listed one after another and separated by commas. The following example shows a typical data record set and illustrates "free" format:

```
'TUBING',1
1,1.995,2.875, 18950.,0.,
```

The key word, delineated by a pair of apostrophes, is any word of 10 or fewer characters that will help the user in understanding the input. The key word is not used by the program, and hence the ordering of the input is not arbitrary. Here, 'TUBING' indicates that this data record and the record immediately following contain information about the well tubing. The number after 'TUBING' indicates the number of different size tubing intervals. The second record gives the tubing interval number, the tubing inside diameter, the tubing outside diameter, the tubing interval length, and the cement column length. The input data are read from the file named TAPE5, while output data are written to file TAPE6.

[1] The term record is used here to denote a single line or card of input data.

2. REQUIRED INPUT

The records listed in this section are required for a complete description of a GEOTEMP2 problem. The required data records consist of:

1. TITLE
2. TUBING
3. CASING
4. WELLBORE
5. TEMPERATURES
6. FLUIDS
7. INITIAL FLUIDS

Each required data record will be explained in the following pages, with comments and examples. A general comment to help understand the input format is that the variable names given use the FORTRAN convention (i.e., variables with names beginning with the letters I-N are integer variables, all others are real variables). A decimal point is necessary for real variables to be properly interpreted on some computer systems; likewise, a decimal point used with an integer variable will cause misreading.

2.1 TITLE Record

Data: 78 character title or identifying comment

The TITLE record is used to identify the problem being run.

EXAMPLE

PRODUCTION SIMULATION: SOUTH MCGOO #3

2.2 TUBING Records

Data: Record 1: 'TUBING',NINT
Record 2: INT,DI,DO,ZC,DZ

where:

NINT = Number of tubing intervals

INT = Interval number

DI = Inside diameter of tubing, inches

DO = Outside diameter of tubing, inches

ZC = Bottom of tubing interval, feet
Top of interval defined by bottom of previous interval.

DZ = Length of cement column outside tubing, feet
The cement column ends at the bottom of the tubing interval specified by ZC.

Record 2 should be repeated for each tubing interval. The total number of Record 2's should equal NINT.

Provision has been made for the flow areas of the tubing to vary with depth in the wellbore. As many as 10 different flow areas can be specified over depth intervals in the well. The top of the first interval is the surface. In the example shown below, two tubing intervals are specified. The first interval (INT=1) extends from the surface to a depth of 6000 ft. with no cement column. The second interval (INT=2) extends from the bottom of the first interval at 6000 ft. to a depth of 18950 ft. A 100 ft. cement column (DZ=100) extends from a depth of 18850 ft. to the bottom of the hole at 18950 ft.

EXAMPLE

```
'TUBING',2
1,1.995,2.875,6000.,0.
2,1.995,2.500,18950.,100.
```

2.3 CASING Records

Data: Record 1: 'CASING',NPIPE
Record 2: ICASE,DI,DO,ZC,DZ,

Where:

NPIPE = Total number of casing strings excluding tubing.

ICASE = Casing number

DI = Casing inside diameter, inches

DO = Casing outside diameter, inches

ZC = Casing setting depth, feet

DZ = Cement column length outside casing, feet (see Figure 1). The cement column begins at the bottom of casing ICASE specified by the setting depth, ZC.

Record 2 should be repeated for each casing in the well. The total number of Record 2's should equal NPIPE.

The casing data records (Record 2) must be arranged in order of smallest diameter to largest diameter so that the completion will be properly nested. The casings are numbered consecutively, beginning with 1. NPIPE must be at least 1 but no more than 4.

Note that all casings extend to the surface.

EXAMPLE

```
CASING',2
1,4.670,5.500,23000.,23000.
2,6.435,7.765,19100.,200.0
```

2.4 WELLBORE Record

Data: 'WELLBORE',DEPTH,TMD,TVD,DDVN,DIA

Where:

DEPTH = Initial depth for drilling, otherwise DEPTH = TMD.

TMD = Total measured depth, feet

TVD = True vertical depth, feet

DDVN = Depth at which ~~well~~ is deviated, feet

DIA = Hole maximum diameter, inches (greater than the largest casing O.D.)

This record describes the well geometry. The well is assumed to have been drilled vertically to the depth DDVN. At this depth, the well is deviated and drilled at an angle to the true depth TVD. The total length of the wellbore TMD is therefore greater than TVD for a deviated well and equal to TVD for a straight well. This is illustrated in Figure 3.

If the well is deviated from the vertical by angle Θ at depth DDVN to a true vertical depth TVD, then TMD can be evaluated from the following formula:

$$TMD = DDVN + (TVD - DDVN)\sin\Theta$$

EXAMPLE

'WELLBORE',25000.,25000.,23000.,2000.,20.

2.5 TEMP Record

Data: 'TEMP',TSUR,BHT,TD1,D1

Where:

TSUR = The undisturbed surface temperature, ^{o}F

BHT = The bottom-hole temperature, ^{o}F

TD1 = The temperature at depth D1, ^{o}F

D1 = The depth corresponding to TD1, feet

This record sets the initial temperature conditions and the far-field or undisturbed temperature gradient.

The bottom-hole temperature BHT corresponds to the depth TVD given on the WELLBORE record.

GEOTEMP2 assumes linear temperature profiles in the undisturbed formation, as depicted in Figure 5. Two different geothermal gradients can be specified through use of the variables given on this record.

EXAMPLE

'TEMP',70.,150.,117.,8000.

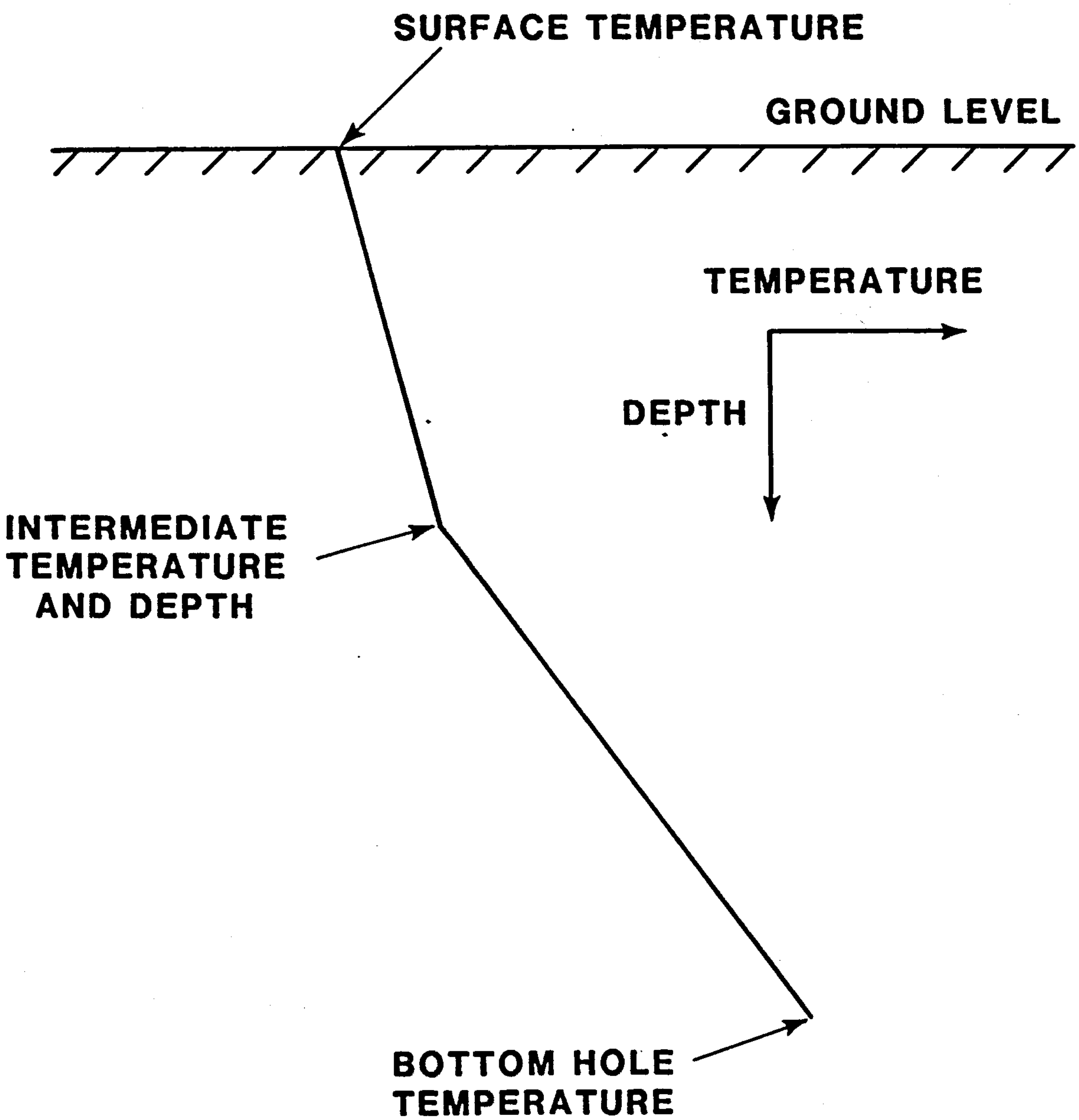

Figure 5. Illustration of the initial and boundary temperature profiles available in GEOTEMP2.

2.6 FLUIDS Record

Data: Record 1: 'FLUIDS',NFLUID

Record 2: ID,DEN,PVIS,YPT

Where:

NFLUID = Number of fluids to be defined

ID = The fluid identification number

DEN = The fluid density, lbm/gal

PVIS = Plastic viscosity, centipoise

YPT = Yield point, lbf/100 ft2

The total number of Record 2 data records following Record 1 should be equal to NFLUID. The ID numbers should be numbered consecutively starting with 1.

The FLUID records are used to define the following properties of liquid systems such as water-based drilling mud. The density DEN must be greater than or equal to that of water at standard conditions (8.33 lbm/gal). The value of heat capacity for a particular fluid is determined from the solids fraction in the fluid. It is assumed that all fluids are derived by adding solid to water. The solids fraction is computed as follows:

$SF = 0.0798 \times (DEN - 8.33),$ for $8.33 < DEN \leqslant 10.3$
$SF = 0.0318 \times (DEN - 10.3) + 0.162,$ for $DEN > 10.3$

The heat capacity is in BTU/lbm^{o}F and the thermal conductivity is in BTU/hr ft ^{o}F are computed as:

$Cp = 1.0 - (0.777 \times SF)$
$k = 0.399 + (9.6 \times SF)$

EXAMPLE

```
'FLUIDS',4
1,9.5,9.0,12.
2,11.,18.,7.
3,18.5,28.,2.
4,18.5,100.,30.
```

2.7 INITIAL FLUIDS Record

Data: 'INITIAL',IPF,IAF

Where:

IPF = I.D. number of wellbore fluid

IAF = I.D. number of annulus fluid

This record is used to initialize the fluids in the well. The number IPF designates the fluid type that is in the well tubing and annulus outside of the tubing. The number IAF indicates the fluid type used as a packer fluid in all the other annuli (see Figure 1). If all the annuli are cemented to surface, IAF will be ignored, however, a number must be entered for IAF. Note that gas filled annuli are not allowed in GEOTEMP2 (except, of course, when gas is used as the circulating fluid).

EXAMPLE

'INITIAL',3,1

3. CONTROL AND OPTION INPUT

This section describes the control records and options used to produce GEOTEMP2 simulations. These records serve two major functions. First, they describe the flowing stream in the wellbore; and second, they specify the time interval when the flowing stream data are to be used. As many sets of control records as desired can be stacked to describe the flowing history of a well.

3.1 CHANGE Record

The principal control record is called the CHANGE record. The CHANGE record has the following format:

```
'CHANGE',IFLOW,ISEC,IPF,TIN,VFR,DAYCH
```

where:

```
IFLOW =  1 for liquid systems injection
      =  2 for liquid systems production
      =  3 for liquid systems forward circulation
      =  4 for liquid systems reverse circulation
      =  5 for gas system forward circulation
      =  6 for liquid systems drilling
      =  7 for gas systems drilling
      =  8 for mist drilling
      =  9 for steam production
      = 10 for steam injection
```

```
ISEC  =  0 no secondary flow change
      =  1 read secondary flow record
```

IPF = fluid I.D. number (see FLUIDS record)

TIN = fluid inlet temperature, °F

VFR = fluid volume flow rate, gal/min(gas flow rates in SCFM)

DAYCH = defines the end of this flow period in days. Beginning is defined by previous 'CHANGE' record or is zero for first CHANGE record.

Flow options 1-4 are completely defined by the CHANGE record and require no additional control records unless ISEC equals 1 (in this case, the SECONDARY FLOW record will immediately follow the CHANGE record). The secondary flow record will be discussed later.

Flow options 5-10 will be discussed individually because of their special input requirements.

3.2 FLOW OPTIONS 1-4

The following examples illustrate how a CHANGE record is prepared for flow options 1-4 which are listed on the previous page.

Flow option 1.

Fluid #2 injected at 100 gal/min at 80 degrees F for 20 days starting at day 12:

```
'CHANGE',1,0,2,80.,100.,32.
```

Note that DAYCH is cumulative time, not incremental time.

Flow Option 2.

Fluid #5 is produced at 2000 gal/hr (33.3 gal/min) for 1-1/2 years. The bottom-hole temperature is 150 degrees F.

```
'CHANGE',2,0,5,150.,33.3,547.
```

Flow Option 3.

Fluid #1 is circulated at 10 bbl/min (420 gal/min) for 8 hours. Inlet temperature is 70 degrees F.

```
'CHANGE',3,0,1,70.,420.,.333
```

Flow Option 4.

Fluid #4 is reverse circulated for 4 days at 500 gal/min. Inlet temperature is 75 degrees F.

```
'CHANGE',4,0,4,75.,500.,4.
```

3.3 FLOW OPTION 5: Gas Forward Circulation

The 'CHANGE' record format is the same as for previous options, however, the IPF variable is given a different interpretation. In options 1-4 IPF designated the fluid I.D. number defined in the FLUIDS records of the setup data. For the convenience of the user, all gas properties are defined internally and are not specified in the FLUIDS records. Two common gases used for gas drilling are defined in this program: air and nitrogen. They are selected by choosing IFLOW equal to 5 and by setting:

```
IPF = 1  for air
    = 2  for nitrogen
```

One additional datum is necessary to define the gas flow. This is the inlet or standpipe pressure. When flow option 5 is selected, the CHANGE record must be followed by the GAS record:

```
'GAS',PSTAND
```

where PSTAND is the standpipe pressure in psia. If this pressure is too low to be consistent with the inlet temperature and flow rate, the program will automatically increase the pressure to an adequate value.

EXAMPLE

Air is being circulated at 1000 standard cubic feet per minute. The inlet temperature is 65 degrees F and the standpipe pressure is 50 psia. Circulate for two days.

```
'CHANGE',5,0,1,65.,1000.,2.
'GAS',50.
```

3.4 FLOW OPTION 6: Drilling with Liquid Systems

Option 6 is used to simulate the drilling of a well using water-based drilling fluids. Since GEOTEMP2 simulates the increase of well depth with time and allows daily shut-in periods during drilling, more control information is needed. Thus, a DRILL record is required following the CHANGE record in option 6:

```
'DRILL',IBH,HRC,DDCHG
```

where

```
IBH   = 0 no bottom-hole assembly change
      = 1 change bottom-hole assembly
          (requires BHA record)

HRC   = hours of circulation daily
        (hours of shut-in daily = 24.-HRC)

DDCHG = drilling depth reached at time
        DAYCH, feet
```

When IBH is set equal to 1, the bottom-hole assembly (BHA) record must immediately follow:

```
'BHA',DCL,DCOD DCID,BITD,BN1,BN2,BN3
```

where:

DCL = drill collar length, ft

DCOD = drill collar outside diameter, inches

DCID = drill collar inside diameter, inches

BITD = bit diameter, inches

BN1 = bit nozzle diameter, inches

BN2 = bit nozzle diameter, inches

BN3 = bit nozzle diameter, inches

The bottom-hole assembly is initialized with no drill collars and with no bit attached to the drill pipe. The actual bottom-hole assembly is redefined every time the BHA record is used, but the BHA record does not have to be used with every DRILL record.

EXAMPLES: Drilling

Simulate a well being drilled to a depth of 3000 feet in three days. Drilling fluid number 1 (defined in FLUIDS) is to be used, with inlet temperature 80 degrees F. The well is normally shut-in 8 hours each evening. The bottom-hole assembly consists of 600 feet of 6" drill collars, a 9-7/8" bit with two 3/4" nozzles and one 1/2" nozzle. Circulation rate is 300 gallons per minute.

```
'CHANGE',6,0,1,80.,300.,3.
'DRILL',1,16.,3000.
'BHA',600.,6.0,2.5,9.88,.75,.75,.50
```

At 3000 feet, the penetration rate slowed and it took 2 days to drill an additional 1000 feet. The nightly shut-in increased to 10 hours because of equipment problems. The bottom-hole assembly was not changed. The following is the complete simulation from spud-in to 4000 feet:

```
'CHANGE',6,0,1,80.,300.,3.
'DRILL',1,16.,3000.
'BHA',600.,6.0,2.5,9.88,.75,.75,.50
'CHANGE',6,0,1,80.,300.,5.
'DRILL',0,14.,4000.
```

Notice that it was not necessary to repeat the bottom-hole assembly information. The BHA record will only be needed when bit, bit nozzles, or drill collars are changed.

3.5 FLOW OPTION 7: Gas Drilling

Option 7 is used to simulate the drilling of a well with air or nitrogen as the drilling fluid. Air drilling parameters are specified using the GAS record defined for option 5 and the DRILL and BHA records defined for option 6. These records must be used in the following order:

```
'CHANGE',IFLOW,ISEC,IPF,TIN,VFR,DAYCH
'GAS',PSTAND
'DRILL',IBH,HRC,DDCHG
'BHA',DCL,DCOD,DCID,BITD,BN1,BN2,BN3 (opt.)
```

The variables in the CHANGE, GAS, DRILL, and BHA records have been defined previously. Note that the units for VFR are SCFM instead of gal/min since this is a gas system. The BHA record is optional, as noted in flow option 6.

EXAMPLE: Air Drilling

The drilling example from option 6 is repeated here, with the changes necessary to replace the water-based fluid with air. The standpipe pressure is given as 50 psia. The required input is:

```
'CHANGE',7,0,1,80.,300.,3.
'GAS',50.
'DRILL',1,16.,3000.
'BHA',600.,6.0,2.5,9.88,.75,.75,.50
'CHANGE',7,0,1,80.,300.,5.
'GAS',50.
'DRILL',0,14.,4000.
```

The CHANGE record now has flow option 7 designated. Note that the volume flow rate is interpreted as SCFM rather than gal/min. A GAS record follows the CHANGE record with a standpipe pressure of 50 psia indicated. The DRILL and BHA records are unchanged.

3.6 FLOW OPTION 8: Mist Drilling

As in option 7, the mist drilling option builds on previous options. The input needed to specify a mist drilling simulation is the following set of records:

```
'CHANGE',IFLOW,ISEC,IPF,TIN,VFR,DAYCH
'GAS',PSTAND
'MIST',VFRM
'DRILL',IBH,HRC,DDCHG
'BHA',DCL,DCOD,DCID,BITD,BN1,BN2,BN3
```

This input differs from the option 7 input because of the addition of the MIST record. The parameter VFRM on the MIST record specifies the rate at which water is added to the air in gallons per minute. Again, the air volume is specified in SCFM. All other variables are unchanged from previous definitions.

EXAMPLE: Mist Drilling

The gas drilling example in option 7 is modified by the addition of 2 bbl/hr (1.4 gal/min) of water to the air to control minor water influx:

```
'CHANGE',8,0,1,80.,300.,3.
'GAS',50.
'MIST',1.40
'DRILL',1,16.,3000.
'BHA',600.,6.0,2.5,9.88,.75,.75,.50
'CHANGE',8,0,1,80.,300.,5.
'GAS',50.
'MIST',1.4
'DRILL',0,14.,4000.
```

3.7 FLOW OPTION 9: Steam Production

The 'CHANGE' record format is the same as previous options, however, the IPF variable has no meaning in this context since the produced fluid is always steam, wet steam, or water. Set IPF to any number desired. It will be ignored by the program.

One additional datum is required to complete the description of two-phase steam flow. If the inlet fluid is single phase, then the inlet (bottom-hole) pressure must be defined. If the inlet fluid is wet steam, then the pressure is defined by the inlet temperature. However, the "quality" of the steam must be specified. The required additional information is given on the STEAM record.

If the mixture is wet steam, the STEAM record used is

'STEAM',1,QUAL

where 1 indicates wet steam, and QUAL is the steam quality (ratio of the mass of the vapor to the mass of the total mixture). Note that QUAL must lie between 1 and 0. If the mixture is single phase, the following STEAM record is used:

'STEAM',2,PIN

where 2 indicates single phase and PIN is the inlet pressure. If PIN is greater than the saturation pressure, the inlet fluid is assumed to be water. If PIN is less than or equal to the saturation pressure, the inlet fluid is assumed to be vapor.

The volume flow rate used in the CHANGE record is gal/min. When the inlet fluid is steam or wet steam, the volume flow rate is defined to be the volume flow rate of liquid water at standard temperature and pressure equivalent to the mass flow rate of steam.

The volume flow rates and bottom-hole pressures specified may not be consistent, that is, the flow may be choked before it reaches the surface. If this happens, the program will automatically exit and print a summary of the flow conditions that caused the exit. The printout will indicate in which interval the problem occurred, such as between K = y and K = x. The ground surface is K = 1. K is incremented every 200 feet (i.e., K = 2 is 200 ft, K = 3 is 400 ft). In production the code calculates the pressures from the bottom of the hole to the surface; therefore, the pressure in this error printout is that at the bottom (inlet) of this interval. If the frictional pressure drop term is dominant, the usual cause is an overly high flow rate. If the gravitational pressure drop is too large, the bottom-hole pressure is probably too low. It was decided not to automatically adjust these parameters because of the complex nature of two phase flow. Manual correction of these difficulties is more reliable, especially since the operator is fully aware of the effects of the changes.

EXAMPLE

Two-phase steam is produced, with inlet quality equal to 0.80 at the equivalent volume flow rate of 40 gallons of water per minute. Inlet temperature is 200 degrees F. Circulate for two days.

```
'CHANGE',9,0,1,200.,40.,2.
'STEAM',1,.80
```

The input for the same problem with single phase inlet conditions and bottom-hole pressure of 2000 psia is:

```
'CHANGE',9,0,1,200.,40.,2.
'STEAM',2,2000.
```

3.8 FLOW OPTION 10: Steam Injection

The 'CHANGE' record format is the same as previous options, however, the IPF variable has no meaning in this context since the produced fluid is always steam, wet steam, or water. Set IPF to any number desired, it will be ignored by the program.

One additional datum is required to complete the description of two-phase steam flow. If the inlet fluid is single phase, then the inlet (wellhead) pressure must be defined. If the inlet fluid is wet steam, then the pressure is defined by the inlet temperature. However, the "quality" of the steam must be specified. The required additional information is given on the STEAM record.

If the mixture is wet steam, the STEAM record used is

'STEAM',1,QUAL

where 1 indicates wet steam, and QUAL is the steam quality (ratio of the mass of the vapor to the mass of the total mixture). Note that QUAL must lie between 1 and 0. If the mixture is single phase, the following STEAM record is used:

'STEAM',2,PIN

where 2 indicates single phase and PIN is the inlet pressure. If PIN is greater than the saturation pressure, the inlet fluid is assumed to be water. If PIN is less than or equal to the saturation pressure, the inlet fluid is assumed to be vapor.

The volume flow rate used in the CHANGE record is gal/min. When the inlet fluid is steam or wet steam, the volume flow rate is defined to be the volume flow rate of liquid water at standard temperature and pressure equivalent to the mass flow rate of steam.

The volume flow rates and bottom-hole pressures specified may not be consistent, that is, the flow may be choked before it reaches the surface. If this happens, the program will automatically exit and print a summary of the flow conditions that caused the exit. The printout will indicate in which interval the problem occurred, such as between K = x and K = y. The ground surface is K = 1. K is incremented every 200 feet (i.e., K = 2 is 200 ft, K = 3 is 400 ft). In modeling injection the code calculates the pressures from the wellhead to the bottom of the hole; therefore, the pressure in this error printout is that at the top (inlet) of this interval. The frictional pressure drop term is the usual cause of choking in this situation. The cure is to reduce the flow rate. An alternate cure is to increase the injection pressure. It was decided not to automatically adjust these parameters because of the complex nature of two-phase flow. Manual correction of these difficulties is more reliable, especially since the operator is fully aware of the effects of the changes.

EXAMPLE

Two-phase steam is injected, with inlet quality equal to 0.80 at the equivalent volume flow rate of 40 gallons of water per minute. Inlet temperature is 200 degrees F. Inject for two days.

```
'CHANGE',10,0,1,200.,40.,2.
'STEAM',1,.80
```

The input for the same problem with single-phase inlet conditions and inlet pressure of 2000 psia is:

```
'CHANGE',10,0,1,200.,40.,2.
'STEAM',2,2000.
```

3.9 SECONDARY FLOW Record

The parameter ISEC on the CHANGE record has been defined previously:

```
ISEC = 0 no secondary flow change
     = 1 read secondary flow record
```

The purpose of the secondary flow option is to simulate the effect of fluid influx on the temperature and flow predictions in GEOTEMP2. Secondary flow may be selected with any flow option; however, only in options 2-8 is the concept of secondary flow meaningful. Secondary flow is initialized at zero flow rate. To specify different secondary flow parameters, ISEC must be set to 1 and the SECFLOW record added following all other records in a CHANGE record sequence. The SECFLOW record has the format

```
'SECFLOW',ISF,TIN2,VFR2
```

where:

ISF = fluid I.D. number of secondary fluid

TIN2 = inlet temperature of secondary fluid, degrees F.

VFR2 = volume flow rate of secondary fluid, gal/min.

The secondary flow option is similar to the BHA record in that the secondary flow parameters remain unchanged until a new secondary fluid record is read. Thus, secondary flow can be turned on or off as desired, but the secondary flow record does not have to be repeated for every CHANGE record sequence.

EXAMPLE: Secondary Flow

The mist drilling example is repeated here with the addition of 1 bbl/hr (0.7 gal/min) of secondary fluid influx. The fluid temperature is assumed to be 100 degrees F and fluid #2 defines the properties of the secondary flow.

```
'CHANGE',8,1,1,80.,300.,3.
'GAS',50.
'MIST',1.40
'DRILL',1,16.,3000.
'BHA',600.,6.0,2.5,9.88,.75,.75,.50
'SECFLOW',2,100.,.70
'CHANGE',8,0,1,80.,300.,5.
'GAS',50.
'MIST',1.4
'DRILL',0,14.,4000.
```

Notice that SECFLOW follows all other option records in the first change record sequence. The SECFLOW record is not repeated for the next CHANGE record sequence because the secondary flow parameters remain unchanged.

4. SAMPLE PROBLEMS

Ten sample problems, illustrating the use of the many flow options available with GEOTEMP2, have been assembled in this section. The problems are representative of real geothermal operations. The full input data and output are listed in each case. Each problem is introduced with some brief comments, and in some cases figures are included.

As an aid to estimating the execution time for a given problem, the execution times for each of the ten sample problems are given in Table 4.1.

TABLE 4.1 Execution times for sample problems run on a CDC CYBER 170 Model 855.

Problem No.	Execution Time(s)
1	2.4
2	2.5
3	2.7
4	2.7
5	4.8
6	7.6
7	9.8
8	17.2
9	12.4
10	6.5

4.1 SAMPLE PROBLEM 1: Production with Flow Rate Change

The following tabulated results represent the GEOTEMP2 input (Table 4.2) and output (Table 4.3) for fluid production in a well. The five strings of pipe are described in the output after printing the problem title. In this example, production tubing is 4-1/2" and casing is 9-5/8" set at 5000 ft, a 13-3/8" intermediate casing is set at 3000 ft, and a 20" surface casing is 1000 ft deep. A 30" conductor pipe is set at 100 ft.

Hole deviation and grid data are printed next. In this case, the well is vertical.

The undisturbed geothermal gradient in this problem gives temperatures of 70°F at the surface and 150°F at the bottom of the well.

Fluid properties are printed next. In this problem, only one fluid type is used. These values apply to both the flowing fluid and the annular fluid above the cement columns. This fluid has a density of 10 lbm/gal, a plastic viscosity of 15 cp, and a yield point of 5 lbf/100 ft^2. Thermal properties are computed in GEOTEMP2 from these basic properties.

The flow data and predicted temperatures are then printed for each time interval specified in the input data. At time zero, the flow conditions are defined by production with inlet temperature of 150°F and flow rate of 500 bbl/day (15 gal/min). These conditions are set for 10 days, at which time the flow rate is changed to 5000 bbl/day as shown by the data in Table 4.2.

The computed temperature distribution is printed at the end of each time interval, in this case 10 days and 20 days. Temperatures are given at six radial positions, the tubing and annulus temperatures (as shown in Figure 2), the temperature at the wellbore/soil interface, the first two formation temperatures, and the undisturbed temperature. These six temperatures are printed at every depth level in 200 ft. increments.

The second column, representing the tubing centerline, gives the produced fluid temperature as the fluid travels up the well. Fluid enters at 150°F and cools to 114°F by the time it reaches the surface. As the produced fluid travels up the well, it heats the annulus and the surrounding formation.

Figure 6 shows the temperature profile from the surface to the bottom of the well. Three curves are plotted, one is the undisturbed temperature distribution, one gives the produced fluid profile after 10 days with the lower flow rate, and the

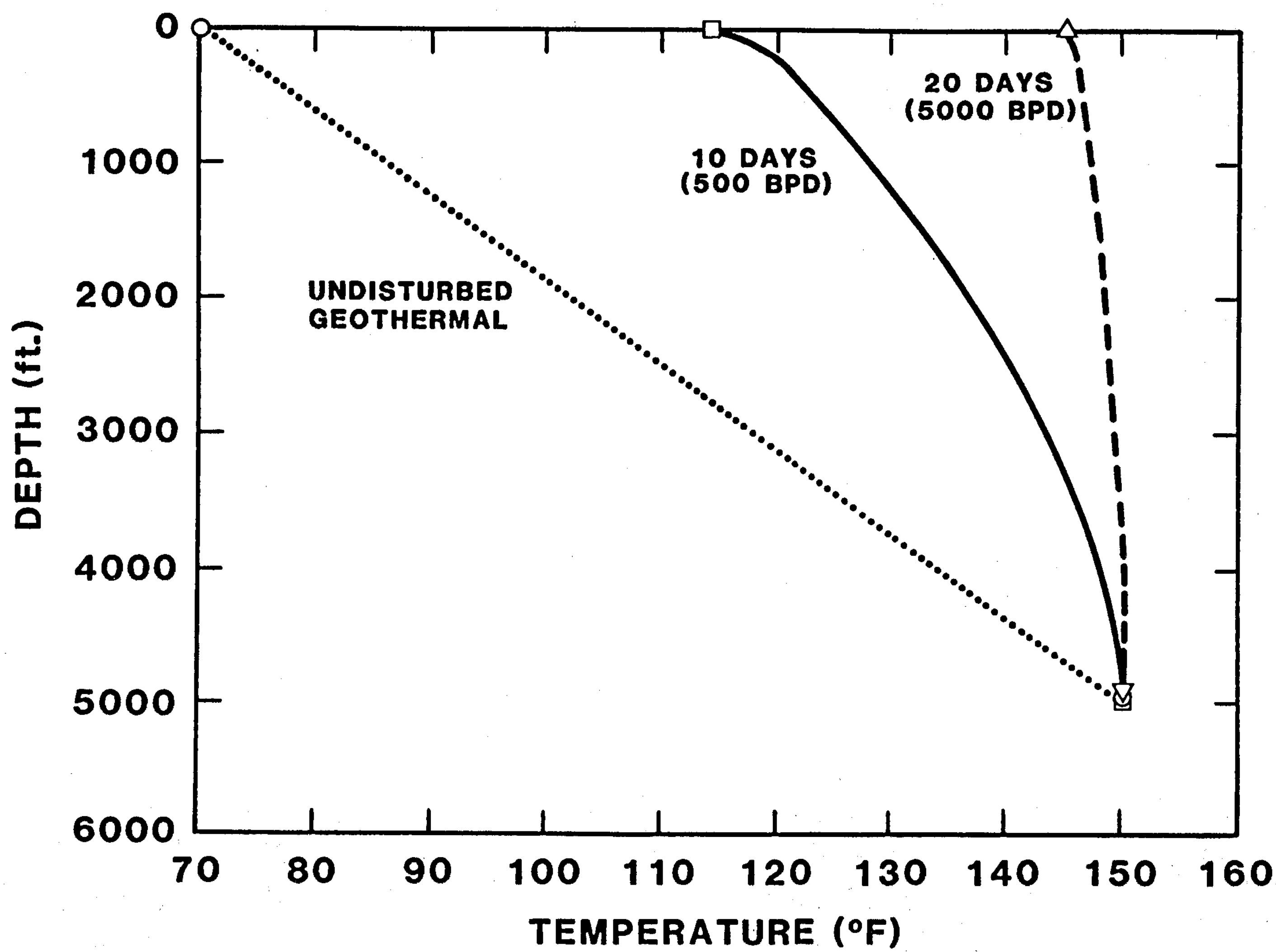

Figure 6. Temperature profile for produced fluid.

third curve is the fluid temperature profile after 20 days with the higher flow rate. Clearly, the increased velocity at the higher flow rate allows less time for the surrounding temperatures to affect the flowing fluid temperature.

TABLE 4.2 Input Data for Sample Problem 1

```
SAMPLE PROBLEM #1:  PRODUCTION WITH FLOW RATE CHANGE
'TUBING',1
1,3.958,4.5,5000.,5000.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.,1000.,1000.
4,29.,30.,100.,100.
'WELLBORE',5000.,5000.,5000.,5000.,31.
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.
'INITIAL',1,1
'CHANGE',2,0,1,150.,15.,10.
'CHANGE',2,0,1,150.,150.,20.
```

Table 4.3 Output Data for Sample Problem 1.

SAMPLE PROBLEM #1: PRODUCTION WITH FLOW RATE CHANGE

T U B I N G   C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	3.958	4.500	0.	5000.	5000.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

S E T V A R I A B L E S AT TIME = 0.000 DAYS
FLOWING OPTION = PRODUCTION
FLUID # 1 PRODUCED
FLUID # 1 IN WELL
INLET TEMPERATURE = 150. F
FLOW RATE = 15. GAL/MIN
TIME TO CHANGE DATA = 10.000 DAYS

TIME = 10.000 DAYS   ITERATIONS = 4

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	114.3	70.0	70.0	70.0	70.0	70.0
200.	119.4	107.3	83.8	79.1	75.9	73.2
400.	121.6	109.8	86.8	82.2	79.1	76.4
600.	123.8	112.2	89.7	85.3	82.2	79.6
800.	125.8	114.7	92.6	88.3	85.3	82.8
1000.	127.8	117.3	95.2	91.2	88.4	86.0
1200.	129.7	119.5	98.1	94.2	91.5	89.2
1400.	131.5	121.7	101.1	97.2	94.6	92.4
1600.	133.3	123.8	103.9	100.3	97.8	95.6
1800.	135.0	125.9	106.8	103.3	100.9	98.8
2000.	136.6	127.9	109.7	106.3	104.0	102.0
2200.	138.2	129.9	112.5	109.3	107.1	105.2
2400.	139.6	131.8	115.3	112.3	110.2	108.4
2600.	141.0	133.7	118.1	115.3	113.3	111.6
2800.	142.3	135.6	120.8	118.2	116.4	114.8
3000.	143.5	137.0	123.8	121.3	119.5	118.0
3200.	144.7	138.7	126.6	124.2	122.6	121.2
3400.	145.7	140.3	129.3	127.1	125.7	124.4
3600.	146.7	141.8	132.0	130.0	128.7	127.6
3800.	147.5	143.3	134.6	132.9	131.8	130.8
4000.	148.3	144.6	137.3	135.8	134.9	134.0
4200.	148.9	145.9	139.9	138.7	137.9	137.2
4400.	149.4	147.1	142.4	141.6	140.9	140.4
4600.	149.7	148.1	145.0	144.4	144.0	143.6
4800.	149.9	149.1	147.5	147.2	147.0	146.8
5000.	150.0	150.0	150.0	150.0	150.0	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

S E T   V A R I A B L E S   AT TIME =   10.000 DAYS
FLOWING OPTION = PRODUCTION
FLUID # 1 PRODUCED
FLUID # 1 IN WELL
INLET TEMPERATURE = 150. F
FLOW RATE = 150. GAL/MIN
TIME TO CHANGE DATA =   20.000 DAYS

TIME =   20.000 DAYS   ITERATIONS = 4

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	145.0	70.0	70.0	70.0	70.0	70.0
200.	145.9	128.6	92.1	84.6	79.3	73.2
400.	146.2	129.7	94.5	87.4	82.3	76.4
600.	146.6	130.7	97.0	90.2	85.3	79.6
800.	146.9	131.9	99.3	92.9	88.2	82.8
1000.	147.2	133.3	101.3	95.3	91.0	86.0
1200.	147.4	134.2	103.8	98.1	94.0	89.2
1400.	147.7	135.2	106.3	100.9	97.0	92.4
1600.	147.9	136.1	108.7	103.7	100.0	95.6
1800.	148.2	137.0	111.2	106.4	102.9	98.8
2000.	148.4	137.9	113.7	109.2	105.9	102.0
2200.	148.6	138.8	116.1	111.9	108.9	105.2
2400.	148.8	139.7	118.6	114.7	111.8	108.4
2600.	149.0	140.5	121.0	117.4	114.8	111.6
2800.	149.1	141.5	123.3	120.1	117.7	114.8
3000.	149.3	142.1	126.1	123.0	120.8	118.0
3200.	149.4	142.9	128.5	125.8	123.7	121.2
3400.	149.5	143.8	131.0	128.5	126.7	124.4
3600.	149.6	144.6	133.4	131.2	129.6	127.6
3800.	149.7	145.4	135.8	133.9	132.5	130.8
4000.	149.8	146.2	138.2	136.6	135.5	134.0
4200.	149.9	147.0	140.5	139.3	138.4	137.2
4400.	149.9	147.7	142.9	142.0	141.3	140.4
4600.	150.0	148.5	145.3	144.7	144.2	143.6
4800.	150.0	149.3	147.6	147.3	147.1	146.8
5000.	150.0	150.0	150.0	150.0	150.0	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

4.2 SAMPLE PROBLEM 2: Injection with Flow Rate Change

Results from GEOTEMP2 for a fluid injection problem are presented in this section. All conditions are precisely the same as those for the production problem presented in the previous section, except for the direction of flow.

Fluid enters the well at the surface at a temperature of 70°F and leaves the well at a depth of 5000 ft. Injection rate begins at 500 bbl/day and increases to 5000 bbl/day after 10 days, continuing until 20 days. The second column of the output temperature distribution gives the injected fluid temperature profile. Figure 7 shows the profiles after 10 days and 20 days. The effect of flow rate is evident again as it was for production.

TABLE 4.4 Input Data for Sample Problem 2

```
SAMPLE PROBLEM #2:  INJECTION WITH FLOW RATE CHANGE
'TUBING', 1
1,3.958,4.5,5000.,5000.
'CASING', 4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2000.
3,19.124,20.,1000.,1000.
4,29.,30.,100.,100.
'WELLBORE',5000.,5000.,5000.,5000.,31.
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.
'INITIAL',1,1
'CHANGE',1,0,1,70.,15.,10.
'CHANGE',1,0,1,70.,150.,20.
```

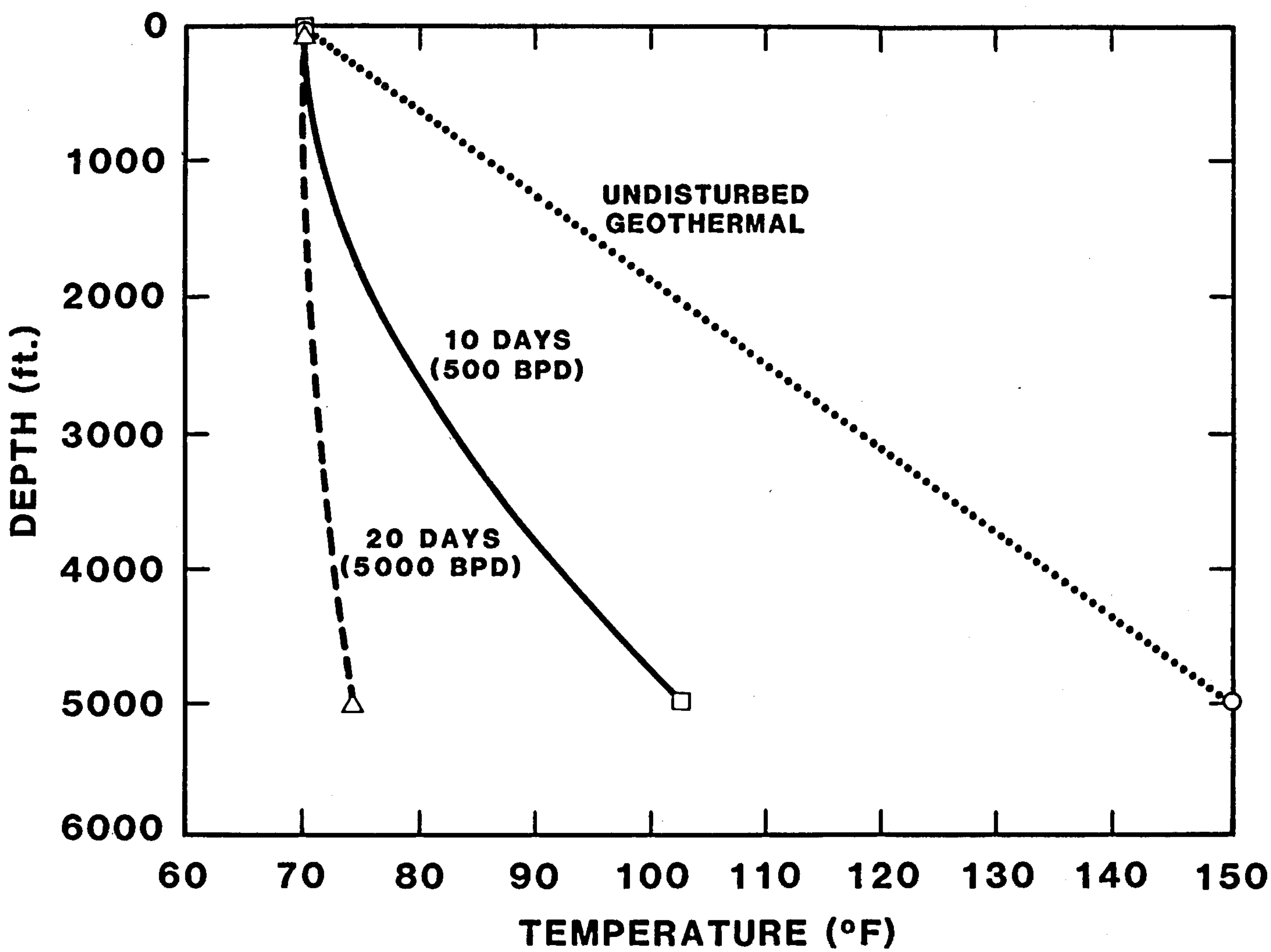

Figure 7. Injected fluid downhole temperature profile.

Table 4.5 Output Data for Sample Problem 2.

SAMPLE PROBLEM #2: INJECTION WITH FLOW RATE CHANGE

T U B I N G C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	3.958	4.500	0.	5000.	5000.0

C A S I N G P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E F L U I D P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

W E L L B O R E I N I T I A L S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

S E T   V A R I A B L E S   AT TIME =   0.000 DAYS

FLOWING OPTION = INJECTION

FLUID # 1 INJECTED INTO TUBING

FLUID # 1 IN WELL

INLET TEMPERATURE = 70. F

FLOW RATE = 15. GAL/MIN

TIME TO CHANGE DATA = 10.000 DAYS

TIME = 10.000 DAYS   ITERATIONS = 4

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	1.3	2.5	4.3	50.0
0.	70.0	70.0	70.0	70.0	70.0	70.0
200.	70.1	70.8	72.5	72.8	73.0	73.2
400.	70.3	71.8	75.0	75.6	76.0	76.4
600.	70.6	72.9	77.6	78.5	79.1	79.6
800.	71.1	74.0	80.2	81.3	82.1	82.8
1000.	71.7	75.2	82.8	84.2	85.2	86.0
1200.	72.4	76.5	85.5	87.1	88.2	89.2
1400.	73.2	77.9	88.2	90.0	91.3	92.4
1600.	74.1	79.4	90.9	92.9	94.4	95.6
1800.	75.2	81.0	93.6	95.9	97.4	98.8
2000.	76.3	82.6	96.3	98.8	100.5	102.0
2200.	77.5	84.6	99.1	101.8	103.6	105.2
2400.	78.8	86.4	101.9	104.8	106.7	108.4
2600.	80.2	88.2	104.7	107.7	109.8	111.6
2800.	81.6	90.0	107.7	110.8	112.9	114.8
3000.	83.2	92.3	110.2	113.6	116.0	118.0
3200.	84.9	94.4	113.0	116.6	119.1	121.2
3400.	86.6	96.5	115.9	119.6	122.2	124.4
3600.	88.4	98.7	118.8	122.7	125.3	127.6
3800.	90.3	100.9	121.7	125.7	128.4	130.8
4000.	92.2	103.1	124.6	128.7	131.6	134.0
4200.	94.2	105.4	127.5	131.8	134.7	137.2
4400.	96.2	107.8	130.4	134.8	137.8	140.4
4600.	98.3	110.1	133.4	137.9	141.0	143.6
4800.	100.5	112.5	136.4	141.0	144.1	146.8
5000.	102.7	115.0	139.3	144.0	147.3	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

S E T V A R I A B L E S AT TIME = 10.000 DAYS
FLOWING OPTION = INJECTION
FLUID # 1 INJECTED INTO TUBING
FLUID # 1 IN WELL
INLET TEMPERATURE = 70. F
FLOW RATE = 150. GAL/MIN
TIME TO CHANGE DATA = 20.000 DAYS

TIME = 20.000 DAYS ITERATIONS = 4

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	70.0	70.0	70.0	70.0	70.0	70.0
200.	70.0	70.7	72.4	72.7	72.9	73.2
400.	70.0	71.5	74.7	75.4	75.8	76.4
600.	70.1	72.2	77.1	78.0	78.7	79.6
800.	70.1	73.0	79.5	80.8	81.7	82.8
1000.	70.2	73.7	82.0	83.5	84.6	86.0
1200.	70.3	74.5	84.4	86.2	87.5	89.2
1400.	70.3	75.3	86.8	88.9	90.5	92.4
1600.	70.5	76.1	89.2	91.6	93.4	95.6
1800.	70.6	76.9	91.7	94.4	96.3	98.8
2000.	70.7	77.7	94.1	97.1	99.3	102.0
2200.	70.9	78.6	96.6	99.9	102.3	105.2
2400.	71.0	79.5	99.0	102.6	105.2	108.4
2600.	71.2	80.3	101.4	105.3	108.2	111.6
2800.	71.4	81.0	104.1	108.2	111.2	114.8
3000.	71.6	82.4	106.1	110.7	114.0	118.0
3200.	71.8	83.3	108.5	113.4	117.0	121.2
3400.	72.0	84.2	111.0	116.2	119.9	124.4
3600.	72.3	85.2	113.5	118.9	122.9	127.6
3800.	72.5	86.1	115.9	121.7	125.9	130.8
4000.	72.8	87.1	118.4	124.5	128.9	134.0
4200.	73.1	88.1	120.9	127.3	131.8	137.2
4400.	73.4	89.0	123.4	130.0	134.8	140.4
4600.	73.7	90.0	125.9	132.8	137.8	143.6
4800.	74.1	91.0	128.4	135.6	140.8	146.8
5000.	74.4	92.1	130.9	138.4	143.8	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

4.3 SAMPLE PROBLEM 3: Forward Circulation with Inlet Temp Change

Results for forward circulation with inlet temperature of 70°F for 10 days, changing to 100°F between 10 days and 20 days, are presented in the following printout (Table 4.7). Well completion, fluid type, and geothermal gradient are all unchanged from the production and injection examples. Circulation rate is 10 gpm. Fluid enters the well at the surface and travels down the tubing at temperatures given in column two of the temperature printout. With inlet temperature of 70°F, the temperature profile after 10 days indicates that the fluid reaches the bottom of the hole at about 133.4°F, crosses over to the annulus, travels up the well, and returns to the surface with a temperature of 72.4°F. At 20 days, after circulating for 10 days at the increased temperature, the bottom-hole temperature is 132.9°F, nearly the same as before, and the return temperature is 92.2°F. These results indicate that the flow rate is slow enough to allow the bottom-hole temperature to reach approximately the same value for the two different inlet temperatures. Note that the maximum circulating temperature occurs in the annulus above the bottom of the well.

Predicted results are plotted in Figure 8. These curves may be compared to those for injection to determine the influence of the returning annulus fluid during circulation.

TABLE 4.6 Input Data for Sample Problem 3

```
SAMPLE PROBLEM #3:  FORWARD CIRCULATION WITH INLET TEMP CHANGE
'TUBING',1
1,3.958,4.5,5000.,0.
'CASING',4
1,8,681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.,1000.,1000.
4,29.,30.,100.,100.
'WELLBORE',5000.,5000.,5000.,5000.,31.
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.
'INITIAL',1,1
'CHANGE',3,0,1,70.,10.,10.
'CHANGE',3,0,1,100.,10.,20.
```

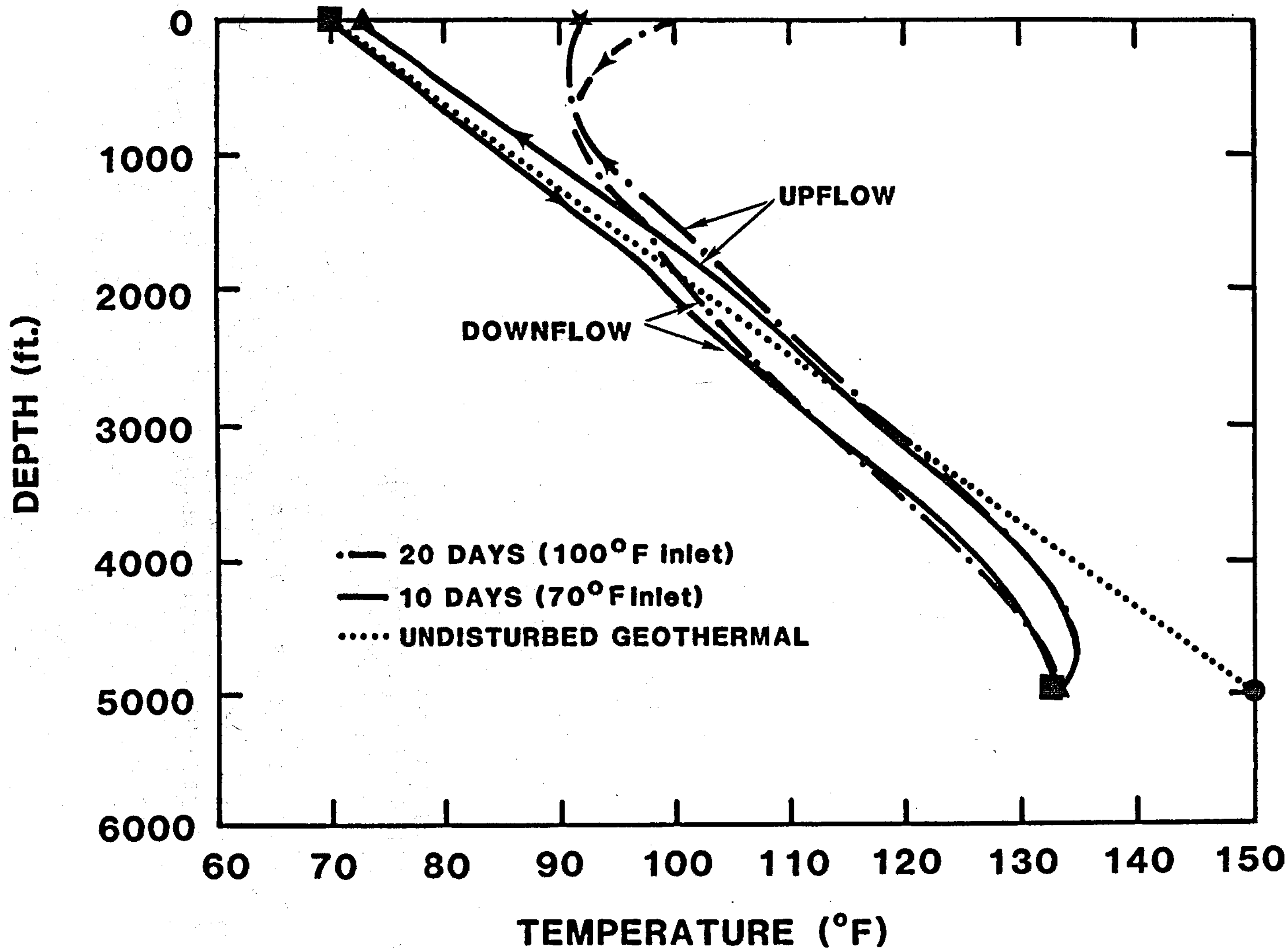

Figure 8. Downhole temperature profiles for circulation.

Table 4.7 Output Data for Sample Problem 3.

SAMPLE PROBLEM #3: FORWARD CIRCULATION W/ INLET TEMP CHANGE

T U B I N G   C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	3.958	4.500	0.	5000.	5000.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

```
S E T   V A R I A B L E S   AT TIME =      0.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   FLUID # 1 INJECTED INTO TUBING
                   FLUID # 1 IN WELL
        INLET TEMPERATURE =   70. F
        FLOW RATE =   10. GAL/MIN
        TIME TO CHANGE DATA =    10.000 DAYS
```

TIME = 10.000 DAYS ITERATIONS = 3

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	70.0	72.4	70.0	70.0	70.0	70.0
200.	72.5	75.2	74.0	73.6	73.4	73.2
400.	75.2	78.2	77.1	76.8	76.6	76.4
600.	78.2	81.5	80.3	80.0	79.8	79.6
800.	81.4	84.9	83.6	83.2	83.0	82.8
1000.	84.5	88.3	86.8	86.5	86.2	86.0
1200.	87.4	91.5	90.0	89.7	89.4	89.2
1400.	90.6	94.9	93.3	92.9	92.6	92.4
1600.	94.0	98.7	96.8	96.3	95.9	95.6
1800.	96.9	101.9	99.8	99.4	99.1	98.8
2000.	99.1	104.5	102.8	102.5	102.2	102.0
2200.	101.5	107.1	105.8	105.6	105.4	105.2
2400.	104.0	109.8	108.9	108.7	108.5	108.4
2600.	106.7	112.5	111.9	111.8	111.7	111.6
2800.	109.3	115.2	114.9	114.9	114.8	114.8
3000.	112.1	118.0	118.0	118.0	118.0	118.0
3200.	114.8	120.7	121.0	121.1	121.2	121.2
3400.	117.6	123.4	124.0	124.2	124.3	124.4
3600.	120.3	125.9	127.0	127.3	127.5	127.6
3800.	123.0	128.4	129.9	130.3	130.6	130.8
4000.	125.6	130.6	132.8	133.3	133.7	134.0
4200.	127.9	132.4	135.5	136.3	136.8	137.2
4400.	130.0	133.9	138.0	139.1	139.8	140.4
4600.	131.7	134.7	140.3	141.8	142.8	143.6
4800.	132.9	134.6	142.3	144.3	145.6	146.8
5000.	133.4	133.4	143.9	146.5	148.4	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

S E T   V A R I A B L E S   AT TIME =   10.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
FLUID # 1 INJECTED INTO TUBING
FLUID # 1 IN WELL
INLET TEMPERATURE = 100. F
FLOW RATE =   10. GAL/MIN
TIME TO CHANGE DATA =   20.000 DAYS

TIME =   20.000 DAYS   ITERATIONS = 3

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	100.0	92.2	70.0	70.0	70.0	70.0
200.	95.3	90.9	80.5	77.4	75.2	73.2
400.	92.7	90.3	82.1	79.7	78.0	76.4
600.	91.5	90.7	84.1	82.2	80.9	79.6
800.	91.3	91.8	86.3	84.8	83.8	82.8
1000.	92.0	93.5	88.9	87.7	86.8	86.0
1200.	93.4	95.7	91.7	90.7	89.9	89.2
1400.	95.5	98.5	94.8	93.8	93.1	92.4
1600.	97.4	101.1	97.6	96.8	96.2	95.6
1800.	99.1	103.3	100.4	99.8	99.3	98.8
2000.	101.0	105.6	103.3	102.8	102.4	102.0
2200.	103.1	108.0	106.2	105.8	105.5	105.2
2400.	105.4	110.5	109.2	108.9	108.6	108.4
2600.	107.8	113.1	112.1	111.9	111.8	111.6
2800.	110.2	115.7	115.1	115.0	114.9	114.8
3000.	112.8	118.3	118.1	118.1	118.0	118.0
3200.	115.4	120.9	121.1	121.1	121.2	121.2
3400.	118.0	123.5	124.0	124.2	124.3	124.4
3600.	120.6	126.0	126.9	127.2	127.4	127.6
3800.	123.2	128.3	129.8	130.2	130.4	130.8
4000.	125.6	130.4	132.5	133.1	133.5	134.0
4200.	127.8	132.1	135.1	135.9	136.5	137.2
4400.	129.8	133.5	137.6	138.6	139.4	140.4
4600.	131.4	134.2	139.8	141.2	142.2	143.6
4800.	132.5	134.1	141.6	143.5	144.9	146.8
5000.	132.9	132.9	143.0	145.6	147.5	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

4.4 SAMPLE PROBLEM 4: Reverse Circulation with Secondary Flow

Use of the secondary flow option is demonstrated by the example problem in this section. The well is circulated down the annulus and up the tubing for 10 days, and then a second fluid joins the circulating fluid at the bottom of the well and the two fluids travel together up the well. As shown in the following input data (Table 4.8), the SECFLOW record is inserted with the CHANGE record in the last time interval, namely between 10 and 20 days. The data records for the two fluid types are listed under the FLUIDS record. The property data for the two fluids are printed in the output (Table 4.9).

Flow rate of the circulating fluid is 10 gpm. Flow rate of the secondary fluid is 5000 bbl/day. This system can be used to model circulation of treating fluids (such as corrosion inhibitors) into a production stream, or for modeling circulation of cement or heavy fluids for well-killing purposes.

With the increased flow rate in the tubing string, the temperature printout at the end of 20 days shows that the tubing fluid temperature does not change much from top to bottom. The effect on the annulus temperature, however, demonstrates a strong influence from the tubing. The injected fluid shows a significant temperature rise in the upper section of the well.

TABLE 4.8 Input Data for Sample Problem 4

```
SAMPLE PROBLEM #4:  REVERSE CIRCULATION WITH SECONDARY FLOW
'TUBING',1
1,3.958,4.5,5000.,0.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.,1000.,1000.
4,29.,30.,100.,100.
'WELLBORE',5000.,5000.,5000.,5000.,31.
'TEMP',70.,150.,110.,2500.
'FLUIDS',2
1,10.,15.,5.
2,8.34,15.,5.
'INITIAL',1,1
'CHANGE',4,0,1,70.,10.,10.
'CHANGE',4,1,1,100.,10.,20.
'SECFLOW',2,150.,146.
```

Table 4.9 Output Data for Sample Problem 4.

SAMPLE PROBLEM #4: REVERSE CIRCULATION W/ SECONDARY FLOW

T U B I N G   C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	3.958	4.500	0.	5000.	0.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

FLUID TYPE NO. 2

DENSITY= 8.3 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

S E T   V A R I A B L E S   AT TIME =   0.000 DAYS
FLOWING OPTION = REVERSE CIRCULATION
FLUID # 1 INJECTED INTO ANNULUS
FLUID # 1 IN WELL
INLET TEMPERATURE =   70. F
FLOW RATE =   10. GAL/MIN
TIME TO CHANGE DATA =   10.000 DAYS

TIME =   10.000 DAYS   ITERATIONS =   1

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	74.0	70.0	70.0	70.0	70.0	70.0
200.	77.8	73.7	73.4	73.3	73.2	73.2
400.	81.7	77.5	76.8	76.6	76.5	76.4
600.	85.2	80.9	80.1	79.9	79.7	79.6
800.	88.5	84.0	83.2	83.0	82.9	82.8
1000.	91.9	87.3	86.5	86.3	86.1	86.0
1200.	95.5	90.7	89.7	89.5	89.3	89.2
1400.	99.3	94.3	93.1	92.8	92.6	92.4
1600.	103.3	98.0	96.5	96.1	95.8	95.6
1800.	106.6	101.0	99.5	99.2	99.0	98.8
2000.	109.0	103.3	102.4	102.2	102.1	102.0
2200.	111.6	105.8	105.4	105.3	105.2	105.2
2400.	114.2	108.4	108.4	108.4	108.4	108.4
2600.	116.9	111.1	111.4	111.5	111.6	111.6
2800.	119.6	113.8	114.5	114.6	114.7	114.8
3000.	122.2	116.6	117.5	117.7	117.9	118.0
3200.	124.8	119.4	120.6	120.9	121.0	121.2
3400.	127.3	122.2	123.6	124.0	124.2	124.4
3600.	129.7	124.9	126.6	127.1	127.4	127.6
3800.	132.0	127.5	129.6	130.2	130.5	130.8
4000.	134.1	130.0	132.6	133.2	133.6	134.0
4200.	136.0	132.4	135.5	136.3	136.8	137.2
4400.	137.5	134.7	138.4	139.3	139.9	140.4
4600.	138.8	136.7	141.1	142.2	143.0	143.6
4800.	139.6	138.4	143.8	145.1	146.0	146.8
5000.	139.9	139.8	146.4	148.0	149.1	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

```
S E T   V A R I A B L E S   AT TIME =     10.000 DAYS
        FLOWING OPTION = REVERSE CIRCULATICN
                   FLUID # 1 INJECTED INTO ANNULUS
                   FLUID # 1 IN WELL
        SECONDARY FLOW
                  FLUID # 2
                  INLET TEMPERATURE=  150. F
                  FLOW RATE=  146. GAL/MIN
        INLET TEMPERATURE =  100. F
        FLOW RATE =   10. GAL/MIN
        TIME TO CHANGE DATA =    20.000 DAYS
```

TIME =   20.000 DAYS   ITERATIONS = 4

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	141.2	100.0	70.0	70.0	70.0	70.0
200.	142.4	111.7	87.8	81.5	77.1	73.2
400.	143.3	119.9	93.0	85.9	80.9	76.4
600.	144.0	125.1	97.1	89.5	84.3	79.6
800.	144.6	128.5	100.1	92.6	87.4	82.8
1000.	145.1	131.0	102.2	95.2	90.3	86.0
1200.	145.6	132.9	105.0	98.1	93.4	89.2
1400.	146.0	134.4	107.6	101.0	96.5	92.4
1600.	146.4	135.6	110.1	103.8	99.5	95.6
1800.	146.7	136.7	112.5	106.6	102.5	98.8
2000.	147.1	137.7	114.9	109.3	105.5	102.0
2200.	147.4	138.6	117.2	112.0	108.4	105.2
2400.	147.7	139.5	119.6	114.7	111.4	108.4
2600.	148.0	140.3	121.9	117.4	114.3	111.6
2800.	148.3	141.2	124.0	120.0	117.2	114.8
3000.	148.5	141.9	126.9	123.0	120.3	118.0
3200.	148.7	142.6	129.2	125.7	123.2	121.2
3400.	149.0	143.4	131.4	128.3	126.2	124.4
3600.	149.1	144.1	133.7	131.0	129.1	127.6
3800.	149.3	144.8	135.9	133.6	132.0	130.8
4000.	149.5	145.6	138.2	136.3	135.0	134.0
4200.	149.6	146.3	140.4	138.9	137.9	137.2
4400.	149.7	146.9	142.6	141.5	140.8	140.4
4600.	149.8	147.6	144.8	144.1	143.7	143.6
4800.	149.9	148.2	147.0	146.7	146.5	146.8
5000.	149.9	148.9	149.2	149.3	149.4	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

4.5 SAMPLE PROBLEM 5: Gas Forward Circulation with Inlet Temperature Change

Sample problem 5 is constructed to be the gas flow analog of sample problem 3. The volume flow rate of 327 SCFM was chosen to give the same mass flow rate as the 10 gallons per minute used in problem 3. Results for forward circulation with inlet temperature of 70°F for 10 days, changing to 100°F between 10 days and 20 days, are presented in the following printout (Table 4.11). Well completion and geothermal gradient are all unchanged from the production and injection examples. Fluid enters the well at the surface and travels down the tubing at temperatures given in column two of the temperature printout. With inlet temperature of 70°F, the temperature profile after 10 days indicates that the fluid reaches the bottom of the well at about 147°F, with an exit temperature at the surface of 70.7°F. This compares to 133.2°F at the bottom of the hole and 72.4°F exit temperatures in the liquid flow case. At 20 days, after circulating for 10 days at the increased temperature, the bottom-hole temperature is 149.9°F, nearly the same as before, and the return temperature is 83.5°F. These temperatures compare with 132.9°F at the bottom of the well and 92.2°F exit for the liquid flow case of example 3. The results indicate that the flow rate is low enough to allow the bottom-hole temperature to each approximately the same value, independent of the inlet temperatures. Note that the maximum circulating temperature occurs in the annulus above the bottom of the well in the liquid flow case but at the bottom of the well in the gas flow case.

TABLE 4.10 Input Data for Sample Problem 5

```
 SAMPLE PROBLEM 5:  GAS FORWARD CIRCULATION WITH INLET TEMP CHANGE
'TUBING',1
1,3.958,4.5,5000.,0
'CASING',4
1,8.681,9.625,5000.,2200
2,12.347,13.375,3000.,2200
3,19.124,20.,1000.,1000
4,29.,30.,100.,100
'WELLBORE',5000.,5000.,5000.,5000.,31
'TEMP',70.,150.,110.,2500
'FLUIDS',1
1,10.,15.,5
'INITIAL',1,1
'CHANGE',5,0,1,70.,327.,10
'GAS',50
'CHANGE',5,0,1,100.,327.,20
'GAS',50
```

Table 4.11 Output Data for Sample Problem 5.

SAMPLE PROBLEM #5: GAS FORWARD CIRCULATION W/ INLET TEMP CHANGE

T U B I N G   C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	3.958	4.500	0.	5000.	5000.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

S E T V A R I A B L E S AT TIME = 0.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 70. F
FLOW RATE = 327. SCF/MIN
TIME TO CHANGE DATA = 10.000 DAYS

TIME = 10.000 DAYS ITERATIONS = 1

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	70.0	70.7	70.0	70.0	70.0	70.0
200.	72.0	73.5	73.3	73.2	73.2	73.2
400.	74.9	76.5	76.4	76.4	76.4	76.4
600.	78.0	79.6	79.6	79.6	79.6	79.6
800.	81.1	82.8	82.8	82.8	82.8	82.8
1000.	84.3	86.0	86.0	86.0	86.0	86.0
1200.	87.5	89.2	89.2	89.2	89.2	89.2
1400.	90.7	92.4	92.4	92.4	92.4	92.4
1600.	93.9	95.6	95.6	95.6	95.6	95.6
1800.	97.1	98.8	98.8	98.8	98.8	98.8
2000.	100.3	102.0	102.0	102.0	102.0	102.0
2200.	103.5	105.2	105.2	105.2	105.2	105.2
2400.	106.7	108.4	108.4	108.4	108.4	108.4
2600.	109.9	111.6	111.6	111.6	111.6	111.6
2800.	113.1	114.8	114.8	114.8	114.8	114.8
3000.	116.3	118.0	118.0	118.0	118.0	118.0
3200.	119.5	121.2	121.2	121.2	121.2	121.2
3400.	122.7	124.4	124.4	124.4	124.4	124.4
3600.	125.9	127.6	127.6	127.6	127.6	127.6
3800.	129.1	130.8	130.8	130.8	130.8	130.8
4000.	132.3	134.0	134.0	134.0	134.0	134.0
4200.	135.5	137.2	137.2	137.2	137.2	137.2
4400.	138.7	140.4	140.4	140.4	140.4	140.4
4600.	141.9	143.6	143.6	143.6	143.6	143.6
4800.	145.2	147.0	146.8	146.8	146.8	146.8
5000.	147.0	147.0	149.3	149.6	149.8	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

GAS & MIST DRILLING
FLOWING STREAM PRCPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	50.0	70.0	.255	0.000	0.000	19.1
200.	50.2	72.0	.255	0.000	0.000	19.1
400.	50.4	74.9	.255	0.000	0.000	19.1
600.	50.7	78.0	.254	0.000	0.000	19.1
800.	50.9	81.1	.254	0.000	0.000	19.2
1000.	51.1	84.3	.254	0.000	0.000	19.2
1200.	51.3	87.5	.253	0.000	0.000	19.2
1400.	51.5	90.7	.253	0.000	0.000	19.3
1600.	51.7	93.9	.252	0.000	0.000	19.3
1800.	52.0	97.1	.252	0.000	0.000	19.3
2000.	52.2	100.3	.251	0.000	0.000	19.4
2200.	52.4	103.5	.251	0.000	0.000	19.4
2400.	52.6	106.7	.251	0.000	0.000	19.4
2600.	52.8	109.9	.250	0.000	0.000	19.5
2800.	53.0	113.1	.250	0.000	0.000	19.5
3000.	53.2	116.3	.249	0.000	0.000	19.5
3200.	53.4	119.5	.249	0.000	0.000	19.6
3400.	53.6	122.7	.249	0.000	0.000	19.6
3600.	53.9	125.9	.248	0.000	0.000	19.6
3800.	54.1	129.1	.248	0.000	0.000	19.7
4000.	54.3	132.3	.247	0.000	0.000	19.7
4200.	54.5	135.5	.247	0.000	0.000	19.7
4400.	54.7	138.7	.247	0.000	0.000	19.7
4600.	54.9	141.9	.246	0.000	0.000	19.8
4800.	55.1	145.2	.246	0.000	0.000	19.8
5000.	55.3	147.0	.246	0.000	0.000	19.8

A N N U L U S

DEPTH	PRESSURE	TEMP		DENSITY-LBM/CF			VELOCITY-FT/SEC	
FT	PSIA	F	GAS	WATER	VAPOR	ROCKS	GAS	ROCKS
0.	46.6	70.7	.237	0.000	0.000	0.000	5.8	0.0
200.	46.9	73.5	.238	0.000	0.000	0.000	5.8	0.0
400.	47.3	76.5	.238	0.000	0.000	0.000	5.8	0.0
600.	47.6	79.6	.238	0.000	0.000	0.000	5.8	0.0
800.	48.0	82.8	.239	0.000	0.000	0.000	5.8	0.0
1000.	48.3	86.0	.239	0.000	0.000	0.000	5.8	0.0
1200.	48.7	89.2	.239	0.000	0.000	0.000	5.8	0.0
1400.	49.0	92.4	.240	0.000	0.000	0.000	5.8	0.0
1600.	49.3	95.6	.240	0.000	0.000	0.000	5.8	0.0
1800.	49.7	98.8	.240	0.000	0.000	0.000	5.8	0.0
2000.	50.0	102.0	.240	0.000	0.000	0.000	5.8	0.0
2200.	50.4	105.2	.241	0.000	0.000	0.000	5.7	0.0
2400.	50.7	108.4	.241	0.000	0.000	0.000	5.7	0.0
2600.	51.1	111.6	.241	0.000	0.000	0.000	5.7	0.0
2800.	51.4	114.8	.242	0.000	0.000	0.000	5.7	0.0
3000.	51.8	118.0	.242	0.000	0.000	0.000	5.7	0.0
3200.	52.1	121.2	.242	0.000	0.000	0.000	5.7	0.0
3400.	52.5	124.4	.242	0.000	0.000	0.000	5.7	0.0
3600.	52.8	127.6	.243	0.000	0.000	0.000	5.7	0.0
3800.	53.2	130.8	.243	0.000	0.000	0.000	5.7	0.0
4000.	53.5	134.0	.243	0.000	0.000	0.000	5.7	0.0
4200.	53.9	137.2	.244	0.000	0.000	0.000	5.7	0.0
4400.	54.2	140.4	.244	0.000	0.000	0.000	5.7	0.0
4600.	54.6	143.6	.244	0.000	0.000	0.000	5.7	0.0
4800.	54.9	147.0	.244	0.000	0.000	0.000	5.7	0.0
5000.	55.3	147.0	.246	0.000	0.000	0.000	5.6	0.0

S E T   V A R I A B L E S   AT TIME =   10.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 100. F
FLOW RATE = 327. SCF/MIN
TIME TO CHANGE DATA = 20.000 DAYS

TIME = 20.000 DAYS   ITERATIONS = 1

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.5	4.3	50.0
0.	100.0	83.5	70.0	70.0	70.0	70.0
200.	81.2	77.7	74.2	73.7	73.5	73.2
400.	77.9	77.9	76.7	76.6	76.5	76.4
600.	78.9	80.1	79.7	79.7	79.6	79.6
800.	81.4	83.0	82.8	82.8	82.8	82.8
1000.	84.4	86.1	86.0	86.0	86.0	86.0
1200.	87.5	89.2	89.2	89.2	89.2	89.2
1400.	90.7	92.4	92.4	92.4	92.4	92.4
1600.	93.9	95.6	95.6	95.6	95.6	95.6
1800.	97.1	98.8	98.8	98.8	98.8	98.8
2000.	100.3	102.0	102.0	102.0	102.0	102.0
2200.	103.5	105.2	105.2	105.2	105.2	105.2
2400.	106.7	108.4	108.4	108.4	108.4	108.4
2600.	109.9	111.6	111.6	111.6	111.6	111.6
2800.	113.1	114.8	114.8	114.8	114.8	114.8
3000.	116.3	118.0	118.0	118.0	118.0	118.0
3200.	119.5	121.2	121.2	121.2	121.2	121.2
3400.	122.7	124.4	124.4	124.4	124.4	124.4
3600.	125.9	127.6	127.6	127.6	127.6	127.6
3800.	129.1	130.8	130.8	130.8	130.8	130.8
4000.	132.3	134.0	134.0	134.0	134.0	134.0
4200.	135.5	137.2	137.2	137.2	137.2	137.2
4400.	138.7	140.4	140.4	140.4	140.4	140.4
4600.	141.9	143.6	143.6	143.6	143.6	143.6
4800.	145.2	146.9	146.8	146.8	146.8	146.8
5000.	146.9	146.9	149.2	149.5	149.7	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	50.0	100.0	.241	0.000	0.000	20.2
200.	50.2	81.2	.251	0.000	0.000	19.4
400.	50.4	77.9	.253	0.000	0.000	19.2
600.	50.6	78.9	.254	0.000	0.000	19.2
800.	50.9	81.4	.254	0.000	0.000	19.2
1000.	51.1	84.4	.253	0.000	0.000	19.2
1200.	51.3	87.5	.253	0.000	0.000	19.2
1400.	51.5	90.7	.253	0.000	0.000	19.3
1600.	51.7	93.9	.252	0.000	0.000	19.3
1800.	51.9	97.1	.252	0.000	0.000	19.3
2000.	52.1	100.3	.251	0.000	0.000	19.4
2200.	52.4	103.5	.251	0.000	0.000	19.4
2400.	52.6	106.7	.251	0.000	0.000	19.4
2600.	52.8	109.9	.250	0.000	0.000	19.5
2800.	53.0	113.1	.250	0.000	0.000	19.5
3000.	53.2	116.3	.249	0.000	0.000	19.5
3200.	53.4	119.5	.249	0.000	0.000	19.6
3400.	53.6	122.7	.248	0.000	0.000	19.6
3600.	53.8	125.9	.248	0.000	0.000	19.6
3800.	54.0	129.1	.248	0.000	0.000	19.7
4000.	54.2	132.3	.247	0.000	0.000	19.7
4200.	54.4	135.5	.247	0.000	0.000	19.7
4400.	54.6	138.7	.246	0.000	0.000	19.8
4600.	54.8	141.9	.246	0.000	0.000	19.8
4800.	55.0	145.2	.246	0.000	0.000	19.8
5000.	55.2	146.9	.246	0.000	0.000	19.8

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	46.6	83.5	.231	0.000	0.000	0.000	6.0	0.0
200.	46.9	77.7	.236	0.000	0.000	0.000	5.9	0.0
400.	47.3	77.9	.237	0.000	0.000	0.000	5.8	0.0
600.	47.6	80.1	.238	0.000	0.000	0.000	5.8	0.0
800.	47.9	83.0	.238	0.000	0.000	0.000	5.8	0.0
1000.	48.3	86.1	.239	0.000	0.000	0.000	5.8	0.0
1200.	48.6	89.2	.239	0.000	0.000	0.000	5.8	0.0
1400.	49.0	92.4	.239	0.000	0.000	0.000	5.8	0.0
1600.	49.3	95.6	.240	0.000	0.000	0.000	5.8	0.0
1800.	49.7	98.8	.240	0.000	0.000	0.000	5.8	0.0
2000.	50.0	102.0	.240	0.000	0.000	0.000	5.8	0.0
2200.	50.4	105.2	.241	0.000	0.000	0.000	5.8	0.0
2400.	50.7	108.4	.241	0.000	0.000	0.000	5.7	0.0
2600.	51.1	111.6	.241	0.000	0.000	0.000	5.7	0.0
2800.	51.4	114.8	.241	0.000	0.000	0.000	5.7	0.0
3000.	51.7	118.0	.242	0.000	0.000	0.000	5.7	0.0
3200.	52.1	121.2	.242	0.000	0.000	0.000	5.7	0.0
3400.	52.4	124.4	.242	0.000	0.000	0.000	5.7	0.0
3600.	52.8	127.6	.243	0.000	0.000	0.000	5.7	0.0
3800.	53.1	130.8	.243	0.000	0.000	0.000	5.7	0.0
4000.	53.5	134.0	.243	0.000	0.000	0.000	5.7	0.0
4200.	53.8	137.2	.243	0.000	0.000	0.000	5.7	0.0
4400.	54.2	140.4	.244	0.000	0.000	0.000	5.7	0.0
4600.	54.5	143.6	.244	0.000	0.000	0.000	5.7	0.0
4800.	54.9	146.9	.244	0.000	0.000	0.000	5.7	0.0
5000.	55.3	146.9	.246	0.000	0.000	0.000	5.6	0.0

4.6 SAMPLE PROBLEM 6: Drilling with Multiple Fluids

Drilling is modeled as a special application of circulation. The depth of circulation varies with time and each day is divided into a circulating and shut-in period to simulate the actual drilling procedure. The circulating and shut-in periods are specified as input data on the DRILL option data record (see Table 4.12).

In the example presented in this section, three different fluids are used in the drilling simulation, namely mud, cement, and water which are defined as fluids 1, 2 and 3 in the printout. Note that interfaces can exist as one liquid displaces another. The drilling is described with six sets of CHANGE records. The six sets include three drilling (depth penetration) time intervals, each followed by a cementing time interval. The drilling reaches 1000 ft on day 3, 3000 ft on day 9, and the bottom of the well at 5000 ft on day 20.

In this example, 8 hours per day is specified as the circulation period while drilling. For cementing, 4 hours per day is used. The remaining time of each day is the shut in period. The drilling rate is computed in GEOTEMP2 based on the drilling time, depth, and hours per day of circulation. From the drilling rate, the depth of circulation is computed at each time step in the numerical procedure.

A temperature distribution is printed twice for each time interval, once at the end of circulation and once after shut in on the last day of each time interval (See Table 4.13). The first temperature printout in the example occurs on day 3 and shows the distribution down to 1000 ft for 2.33 days (end of 8 hours of circulation). The next printout occurs at the end of shut in on day 3. The two printouts on day 4 represent the cement circulating temperature and waiting-on-cement (WOC) temperature, respectively, for the 20" casing. Similar results are printed for the other two drilling intervals and for the cementing of the 13-3/8" and 9-5/8" casings.

The temperatures in the tubing during the cementing periods for each of the three casings are plotted in Figure 9.

Table 4.12 Input Data for Sample Problem 6

```
SAMPLE PROBLEM 6:  DRILLING WITH MULTIPLE FLUIDS
'TUBING',1
1,3.958,4.5,5000.,0.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.,1000.,1000.
4,29.,30.,100.,100.
'WELLBORE',0.,5000.,5000.,5000.,32.
'TEMP',70.,150.,110.,2500.
'FLUIDS',3
1,10.,15.,5.
2,15.,30.,50.
3,8.34,1.,0.
'INITIAL',1,1
'CHANGE',6,0,1,70.,100.,3.
'DRILL',1,8.,100.
'BHA',600.,6.,2.5,22.,.75,.75,.75
'CHANGE',6,0,2,70.,100.,4.
'DRILL',0,4.,1000.
'CHANGE',6,0,3,70.,100.,9.
'DRILL',1,8.,3000.
'BHA',600.,6.,2.5,15.,.75,.75,.75
'CHANGE',6,0,2,70.,100.,10.
'DRILL',0,4.,3000.
'CHANGE',6,0,1,70.,100.,20.
'DRILL',1,8.0,5000.
'BHA',600.,6.,2.5,9.875,.75,.75,.75
'CHANGE',6,0,2,70.,100.,21.
'DRILL',0,4.,5000.
```

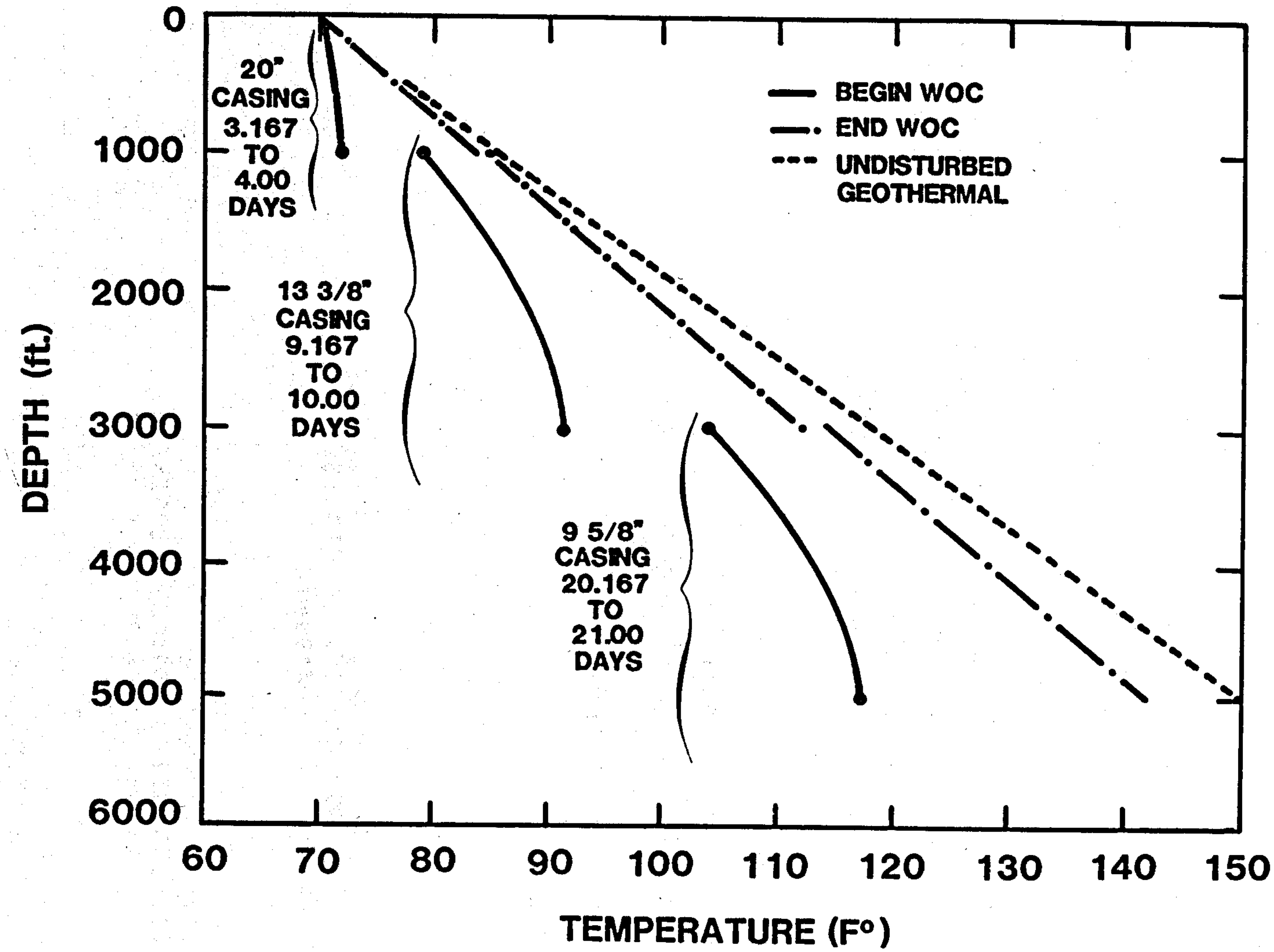

Figure 9. Downhole temperature profiles during cementing periods for drilling.

Table 4.13 Output Data for Sample Problem 6.

SAMPLE PROBLEM #6: DRILLING WITH MULTIPLE FLUIDS

T U B I N G   C O N F I G U R A T I O N

TUBING	ID, IN.	OD, IN.	TOP, FT.	BASE, FT.	CEMENT, FT.
1	3.958	4.500	0.	5000.	0.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.681	9.625	5000.	2200.
2	12.347	13.375	3000.	2200.
3	19.124	20.000	1000.	1000.
4	29.000	30.000	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH= 5000. FT.
BORE DIAMETER= 32.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 10.0 LBM/GAL
PLASTIC VISCOSITY= 15. CENTIPOISE
YIELD POINT= 5. LBF/100FT2

FLUID TYPE NO. 2

DENSITY= 15.0 LBM/GAL
PLASTIC VISCOSITY= 30. CENTIPOISE
YIELD POINT= 50. LBF/100FT2

FLUID TYPE NO. 3

DENSITY= 8.3 LBM/GAL
PLASTIC VISCOSITY= 1. CENTIPOISE
YIELD POINT= 0. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

```
S E T   V A R I A B L E S   AT TIME =      0.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                 FLUID # 1 INJECTED INTO TUBING
                 FLUID # 1 IN WELL
        INLET TEMPERATURE =   70. F
        FLOW RATE =  100. GAL/MIN
        TIME TO CHANGE DATA =     3.000 DAYS
        DEPTH TO CHANGE DATA = 1000. FT
        CIRCULATION TIME PER DAY =   8.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,   I.D.= 6.000 IN,   O.D.= 2.500 IN
          DRILL BIT:
            DIAMETER= 22.000 IN, NOZZLE SIZES=   .750   .750   .750 IN
```

```
TIME =      2.333 DAYS                              ITERATIONS =  5
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE = 100. GAL/MIN    CIRCULATION DEPTH = 1000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

RADIAL POSITIONS, FEET

DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	71.6	70.0	70.0	70.0	70.0
200.	70.5	72.1	72.2	72.8	73.1	73.2
400.	70.9	72.5	73.2	75.5	76.2	76.4
600.	71.3	72.7	74.0	78.5	79.5	79.6
800.	71.7	72.7	74.8	81.9	82.8	82.8
1000.	71.9	71.9	76.5	85.6	86.0	86.0
1200.	89.2	89.2	89.2	89.2	89.2	89.2
1400.	92.4	92.4	92.4	92.4	92.4	92.4

```
TIME =      3.000 DAYS                              ITERATIONS =  6
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =   0. GAL/MIN    CIRCULATION DEPTH = 1000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

RADIAL POSITIONS, FEET

DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	70.0	70.0	70.0	70.0	70.0
200.	72.7	72.7	72.8	72.8	73.1	73.2
400.	75.2	75.2	75.3	75.6	76.2	76.4
600.	77.9	77.9	78.1	78.5	79.4	79.6
800.	80.8	81.0	81.2	81.8	82.7	82.8
1000.	84.0	84.2	84.5	85.3	85.9	86.0
1200.	89.2	89.2	89.2	89.2	89.2	89.2
1400.	92.4	92.4	92.4	92.4	92.4	92.4

```
S E T   V A R I A B L E S   AT TIME =      3.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                 FLUID # 2 INJECTED INTO TUBING
                 FLUID # 1 IN WELL
        INLET TEMPERATURE =   70. F
        FLOW RATE =  100. GAL/MIN
        TIME TO CHANGE DATA =      4.000 DAYS
        DEPTH TO CHANGE DATA = 1000. FT
        CIRCULATION TIME PER DAY =   4.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,   I.D.= 6.000 IN,   O.D.= 2.500 IN
          DRILL BIT:
            DIAMETER= 22.000 IN, NOZZLE SIZES=   .750   .750   .750 IN

FLUIDS IN WELL UPDATED AT TIME=     3.056 DAYS
               FLUIDS IN TUBING
                 FLUID # 2 FROM      0. FT.  TO   1000. FT.
               FLUIDS IN ANNULUS
                 FLUID # 2 FROM      0. FT.  TO   1000. FT.

TIME =      3.167 DAYS                             ITERATIONS =  5
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE = 100. GAL/MIN     CIRCULATION DEPTH = 1000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET					
	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	71.7	70.0	70.0	70.0	70.0
200.	70.5	72.2	72.5	72.8	73.1	73.2
400.	71.0	72.6	73.4	75.5	76.2	76.4
600.	71.5	72.6	74.1	78.4	79.3	79.6
800.	71.8	72.5	74.6	81.6	82.6	82.8
1000.	71.9	71.9	74.9	84.9	85.9	86.0
1200.	89.2	89.2	89.2	89.2	89.2	89.2
1400.	92.4	92.4	92.4	92.4	92.4	92.4

```
TIME =      4.000 DAYS                             ITERATIONS =  6
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =   0. GAL/MIN     CIRCULATION DEPTH = 1000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET					
	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	70.0	70.0	70.0	70.0	70.0
200.	72.8	72.8	72.8	72.9	73.1	73.2
400.	75.3	75.4	75.4	75.6	76.1	76.4
600.	77.9	78.0	78.1	78.5	79.3	79.6
800.	80.7	80.9	81.1	81.6	82.5	82.8
1000.	83.6	83.9	84.1	84.7	85.7	86.0
1200.	89.2	89.2	89.2	89.2	89.2	89.2
1400.	92.4	92.4	92.4	92.4	92.4	92.4

```
S E T   V A R I A B L E S   AT TIME =      4.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   FLUID # 3 INJECTED INTO TUBING
                   FLUID # 2 IN WELL
        INLET TEMPERATURE =   70. F
        FLOW RATE =  100. GAL/MIN
        TIME TO CHANGE DATA =      9.000 DAYS
        DEPTH TO CHANGE DATA = 3000. FT
        CIRCULATION TIME PER DAY =   8.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,   I.D.= 6.000 IN,   O.D.= 2.500 IN
          DRILL BIT:
            DIAMETER= 15.000 IN, NOZZLE SIZES=   .750   .750   .750 IN

FLUIDS IN WELL UPDATED AT TIME=     4.111 DAYS
                  FLUIDS IN TUBING
                    FLUID # 3 FROM      0. FT.  TO   1133. FT.
                  FLUIDS IN ANNULUS
                    FLUID # 3 FROM      0. FT.  TO   1133. FT.


TIME =      8.333 DAYS                                ITERATIONS =  9
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE = 100. GAL/MIN     CIRCULATION DEPTH = 3000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	1.3	2.6	4.5	50.0
0.	70.0	73.9	70.0	70.0	70.0	70.0
200.	72.0	76.0	74.0	73.3	73.1	73.2
400.	74.0	78.0	76.7	76.1	76.1	76.4
600.	76.0	80.1	79.4	79.0	79.2	79.6
800.	78.1	82.2	82.1	82.1	82.3	82.8
1000.	80.2	84.3	84.6	84.8	85.4	86.0
1200.	82.3	86.3	87.2	88.0	88.7	89.2
1400.	84.4	88.3	89.6	91.0	91.9	92.4
1600.	86.4	90.1	92.0	94.1	95.1	95.6
1800.	88.3	91.8	94.3	97.1	98.3	98.8
2000.	90.2	93.4	96.6	100.2	101.6	102.0
2200.	91.8	94.7	98.8	103.4	104.8	105.2
2400.	93.3	95.7	100.8	106.7	108.2	108.4
2600.	94.5	96.5	102.7	110.1	111.4	111.6
2800.	95.5	96.8	104.5	113.8	114.8	114.8
3000.	96.0	96.0	108.5	117.6	118.0	118.0
3200.	121.2	121.2	121.2	121.2	121.2	121.2
3400.	124.4	124.4	124.4	124.4	124.4	124.4

TIME = 9.000 DAYS ITERATIONS = 7
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. GAL/MIN CIRCULATION DEPTH = 3000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.5	70.4	70.0	70.0	70.0	70.0
200.	73.7	73.6	73.4	73.3	73.1	73.2
400.	76.4	76.3	76.2	76.1	76.1	76.4
600.	79.1	79.1	79.1	79.1	79.2	79.6
800.	81.9	81.9	82.1	82.1	82.3	82.8
1000.	84.7	84.8	84.9	85.0	85.4	86.0
1200.	87.8	87.8	88.0	88.2	88.7	89.2
1400.	90.6	90.7	91.0	91.2	91.8	92.4
1600.	93.6	93.6	94.0	94.2	95.0	95.6
1800.	96.5	96.6	97.0	97.3	98.2	98.8
2000.	99.4	99.5	100.0	100.4	101.5	102.0
2200.	102.4	102.5	103.1	103.5	104.7	105.2
2400.	105.4	105.5	106.2	106.8	108.0	108.4
2600.	108.4	108.6	109.4	110.1	111.3	111.6
2800.	111.6	111.8	112.7	113.5	114.6	114.8
3000.	114.5	114.8	116.0	117.2	117.9	118.0
3200.	121.2	121.2	121.2	121.2	121.2	121.2
3400.	124.4	124.4	124.4	124.4	124.4	124.4

S E T   V A R I A B L E S   AT TIME = 9.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
FLUID # 2 INJECTED INTO TUBING
FLUID # 3 IN WELL
INLET TEMPERATURE = 70. F
FLOW RATE = 100. GAL/MIN
TIME TO CHANGE DATA = 10.000 DAYS
DEPTH TO CHANGE DATA = 3000. FT
CIRCULATION TIME PER DAY = 4.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT, I.D.= 6.000 IN, O.D.= 2.500 IN
DRILL BIT:
DIAMETER= 15.000 IN, NOZZLE SIZES= .750 .750 .750 IN

FLUIDS IN WELL UPDATED AT TIME= 9.056 DAYS
FLUIDS IN TUBING
FLUID # 2 FROM 0. FT. TO 3000. FT.
FLUIDS IN ANNULUS
FLUID # 3 FROM 0. FT. TO 295. FT.
FLUID # 2 FROM 295. FT. TO 3000. FT.

FLUIDS IN WELL UPDATED AT TIME= 9.111 DAYS
FLUIDS IN TUBING
FLUID # 2 FROM 0. FT. TO 3000. FT.
FLUIDS IN ANNULUS
FLUID # 2 FROM 0. FT. TO 3000. FT.

TIME = 9.167 DAYS ITERATIONS = 12
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 100. GAL/MIN CIRCULATION DEPTH = 3000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	76.0	70.0	70.0	70.0	70.0
200.	71.8	77.9	74.2	73.3	73.2	73.2
400.	73.7	79.7	76.9	76.2	76.2	76.4
600.	75.5	81.6	79.6	79.1	79.2	79.6
800.	77.4	83.4	82.4	82.1	82.3	82.8
1000.	79.2	85.1	85.2	85.0	85.4	86.0
1200.	81.0	86.7	88.1	88.2	88.7	89.2
1400.	82.8	88.1	90.8	91.2	91.8	92.4
1600.	84.5	89.5	93.6	94.2	95.0	95.6
1800.	86.0	90.6	96.2	97.3	98.2	98.8
2000.	87.4	91.4	98.9	100.4	101.5	102.0
2200.	88.7	92.0	101.5	103.5	104.7	105.2
2400.	89.7	92.4	104.1	106.7	108.0	108.4
2600.	90.6	92.4	106.6	110.0	111.3	111.6
2800.	91.1	92.1	109.1	113.5	114.6	114.8
3000.	91.4	91.4	111.5	117.1	117.9	118.0
3200.	121.2	121.2	121.2	121.2	121.2	121.2
3400.	124.4	124.4	124.4	124.4	124.4	124.4

TIME = 10.000 DAYS ITERATIONS = 7
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. GAL/MIN CIRCULATION DEPTH = 3000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.6	70.5	70.0	70.0	70.0	70.0
200.	73.9	73.8	73.5	73.3	73.2	73.2
400.	76.6	76.6	76.3	76.2	76.2	76.4
600.	79.3	79.3	79.2	79.2	79.2	79.6
800.	82.1	82.1	82.2	82.2	82.4	82.8
1000.	84.8	84.8	85.0	85.1	85.4	86.0
1200.	87.7	87.7	88.1	88.3	88.7	89.2
1400.	90.4	90.5	91.1	91.3	91.8	92.4
1600.	93.1	93.3	94.0	94.3	95.0	95.6
1800.	95.8	96.0	97.0	97.4	98.2	98.8
2000.	98.5	98.7	100.0	100.5	101.4	102.0
2200.	101.1	101.4	103.0	103.6	104.6	105.2
2400.	103.8	104.1	106.1	106.8	107.9	108.4
2600.	106.4	106.8	109.1	110.0	111.1	111.6
2800.	109.1	109.5	112.3	113.3	114.5	114.8
3000.	111.8	112.3	115.5	116.7	117.8	118.0
3200.	121.2	121.2	121.2	121.2	121.2	121.2
3400.	124.4	124.4	124.4	124.4	124.4	124.4

```
S E T   V A R I A B L E S   AT TIME =     10.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   FLUID # 1 INJECTED INTO TUBING
                   FLUID # 2 IN WELL
        INLET TEMPERATURE =   70. F
        FLOW RATE =  100. GAL/MIN
        TIME TO CHANGE DATA =    20.000 DAYS
        DEPTH TO CHANGE DATA = 5000. FT
        CIRCULATION TIME PER DAY =   8.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,   I.D.= 6.000 IN,   O.D.= 2.500 IN
          DRILL BIT:
            DIAMETER=  9.875 IN, NOZZLE SIZES=   .750   .750   .750 IN

FLUIDS IN WELL UPDATED AT TIME=    10.111 DAYS
                 FLUIDS IN TUBING
                   FLUID # 1 FROM      0. FT.  TO   3067. FT.
                 FLUIDS IN ANNULUS
                   FLUID # 1 FROM      0. FT.  TO   3067. FT.

TIME =    19.333 DAYS                               ITERATIONS = 15
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE = 100. GAL/MIN     CIRCULATION DEPTH = 5000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

RADIAL POSITIONS, FEET

DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	76.8	70.0	70.0	70.0	70.0
200.	71.9	78.8	75.1	73.9	73.5	73.2
400.	73.9	80.8	77.7	76.8	76.5	76.4
600.	75.8	82.8	80.5	79.7	79.5	79.6
800.	77.9	84.9	83.2	82.7	82.6	82.8
1000.	79.9	86.9	86.0	85.6	85.6	86.0
1200.	82.0	88.9	88.8	88.7	88.8	89.2
1400.	84.1	91.0	91.6	91.7	91.8	92.4
1600.	86.1	93.0	94.4	94.6	94.9	95.6
1800.	88.2	95.0	97.2	97.6	98.0	98.8
2000.	90.3	96.9	99.9	100.6	101.1	102.0
2200.	92.4	98.8	102.7	103.6	104.2	105.2
2400.	94.4	100.7	105.5	106.6	107.3	108.4
2600.	96.4	102.4	108.2	109.6	110.4	111.6
2800.	98.3	104.1	111.0	112.6	113.5	114.8
3000.	100.2	105.7	112.7	114.9	116.3	118.0
3200.	102.0	107.2	115.3	117.9	119.4	121.2
3400.	103.7	108.5	117.9	120.9	122.6	124.4
3600.	105.3	109.7	120.5	124.0	125.9	127.6
3800.	106.7	110.7	123.0	127.1	129.2	130.8
4000.	108.0	111.5	125.6	130.2	132.5	134.0
4200.	109.2	112.1	128.1	133.5	135.9	137.2
4400.	110.1	112.4	130.6	136.9	139.4	140.4
4600.	110.9	112.5	133.2	140.5	143.0	143.6
4800.	111.4	112.2	136.1	144.5	146.5	146.8
5000.	111.6	111.6	140.0	149.2	150.0	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

TIME = 20.000 DAYS ITERATIONS = 9
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. GAL/MIN CIRCULATION DEPTH = 5000. FT

T E M P E R A T U R E D I S T R I B U T I O N

RADIAL POSITIONS, FEET

DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.8	70.8	70.0	70.0	70.0	70.0
200.	74.6	74.6	74.0	73.9	73.5	73.2
400.	77.3	77.3	76.9	76.8	76.5	76.4
600.	80.1	80.0	79.8	79.7	79.5	79.6
800.	82.8	82.8	82.7	82.7	82.6	82.8
1000.	85.6	85.6	85.6	85.6	85.6	86.0
1200.	88.4	88.4	88.6	88.7	88.8	89.2
1400.	91.1	91.2	91.6	91.7	91.9	92.4
1600.	93.9	93.9	94.5	94.7	94.9	95.6
1800.	96.7	96.7	97.4	97.7	98.0	98.8
2000.	99.4	99.5	100.4	100.7	101.1	102.0
2200.	102.2	102.3	103.3	103.7	104.2	105.2
2400.	104.9	105.0	106.3	106.7	107.3	108.4
2600.	107.6	107.7	109.2	109.7	110.4	111.6
2800.	110.2	110.4	112.1	112.7	113.5	114.8
3000.	112.8	112.9	114.5	115.1	116.3	118.0
3200.	115.4	115.6	117.4	118.1	119.4	121.2
3400.	118.1	118.3	120.4	121.1	122.6	124.4
3600.	120.8	121.0	123.3	124.2	125.8	127.6
3800.	123.5	123.7	126.3	127.3	129.1	130.8
4000.	126.1	126.4	129.4	130.4	132.4	134.0
4200.	128.8	129.1	132.5	133.7	135.8	137.2
4400.	131.6	131.9	135.6	137.0	139.2	140.4
4600.	134.4	134.7	139.0	140.5	142.7	143.6
4800.	137.4	137.8	142.6	144.3	146.3	146.8
5000.	140.8	141.3	146.8	148.7	149.8	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

S E T V A R I A B L E S AT TIME = 20.000 DAYS
FLOWING OPTION = FORWARD CIRCULATICN
FLUID # 2 INJECTED INTO TUBING
FLUID # 1 IN WELL
INLET TEMPERATURE = 70. F
FLOW RATE = 100. GAL/MIN
TIME TO CHANGE DATA = 21.000 DAYS
DEPTH TO CHANGE DATA = 5000. FT
CIRCULATION TIME PER DAY = 4.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT, I.D.= 6.000 IN, O.D.= 2.500 IN
DRILL BIT:
DIAMETER= 9.875 IN, NOZZLE SIZES= .750 .750 .750 IN

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FLUIDS IN WELL UPDATED AT TIME=    20.056 DAYS
                  FLUIDS IN TUBING
                    FLUID # 2 FROM       0. FT.   TO   5000. FT.
                  FLUIDS IN ANNULUS
                    FLUID # 1 FROM       0. FT.   TO   2863. FT.
                    FLUID # 2 FROM    2863. FT.   TO   5000. FT.

FLUIDS IN WELL UPDATED AT TIME=    20.111 DAYS
                  FLUIDS IN TUBING
                    FLUID # 2 FROM       0. FT.   TO   5000. FT.
                  FLUIDS IN ANNULUS
                    FLUID # 2 FROM       0. FT.   TO   5000. FT.


TIME =     20.167 DAYS                                    ITERATIONS = 13
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE = 100. GAL/MIN     CIRCULATION DEPTH = 5000. FT
```

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.0	77.4	70.0	70.0	70.0	70.0
200.	72.2	79.6	74.8	73.9	73.5	73.2
400.	74.5	81.9	77.6	76.8	76.5	76.4
600.	76.8	84.2	80.5	79.7	79.5	79.6
800.	79.1	86.6	83.3	82.7	82.6	82.8
1000.	81.3	88.9	86.1	85.6	85.6	86.0
1200.	83.6	91.2	89.1	88.7	88.8	89.2
1400.	86.0	93.5	91.9	91.7	91.9	92.4
1600.	88.3	95.8	94.8	94.7	94.9	95.6
1800.	90.6	98.1	97.7	97.7	98.0	98.8
2000.	92.9	100.3	100.6	100.7	101.1	102.0
2200.	95.2	102.5	103.4	103.7	104.2	105.2
2400.	97.5	104.6	106.3	106.7	107.3	108.4
2600.	99.7	106.7	109.2	109.7	110.4	111.6
2800.	101.9	108.7	112.0	112.7	113.5	114.8
3000.	104.0	110.5	114.3	115.1	116.3	118.0
3200.	106.1	112.2	117.1	118.1	119.4	121.2
3400.	108.0	113.8	119.8	121.1	122.6	124.4
3600.	109.8	115.1	122.6	124.2	125.8	127.6
3800.	111.5	116.2	125.4	127.3	129.1	130.8
4000.	113.0	117.1	128.1	130.5	132.4	134.0
4200.	114.3	117.7	130.9	133.7	135.8	137.2
4400.	115.4	118.0	133.7	137.0	139.2	140.4
4600.	116.2	118.0	136.6	140.5	142.7	143.6
4800.	116.8	117.7	139.6	144.3	146.3	146.8
5000.	117.0	117.0	143.0	148.6	149.8	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

TIME = 21.000 DAYS ITERATIONS = 7
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. GAL/MIN CIRCULATION DEPTH = 5000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	1.3	2.6	4.5	50.0
0.	70.8	70.7	70.0	70.0	70.0	70.0
200.	74.7	74.6	74.0	73.8	73.5	73.2
400.	77.5	77.4	76.9	76.8	76.5	76.4
600.	80.3	80.3	79.9	79.7	79.6	79.6
800.	83.2	83.1	82.8	82.7	82.6	82.8
1000.	86.0	85.9	85.7	85.7	85.7	86.0
1200.	88.9	88.9	88.8	88.7	88.8	89.2
1400.	91.7	91.7	91.7	91.7	91.9	92.4
1600.	94.6	94.6	94.7	94.8	95.0	95.6
1800.	97.4	97.4	97.7	97.8	98.0	98.8
2000.	100.2	100.3	100.7	100.8	101.1	102.0
2200.	103.1	103.2	103.6	103.8	104.2	105.2
2400.	105.9	106.0	106.6	106.8	107.3	108.4
2600.	108.7	108.8	109.6	109.8	110.4	111.6
2800.	111.4	111.6	112.5	112.8	113.5	114.8
3000.	114.0	114.2	115.0	115.3	116.3	118.0
3200.	116.8	116.9	118.0	118.4	119.4	121.2
3400.	119.5	119.7	120.9	121.4	122.6	124.4
3600.	122.3	122.5	123.9	124.5	125.8	127.6
3800.	125.1	125.3	127.0	127.6	129.1	130.8
4000.	127.8	128.1	130.0	130.8	132.4	134.0
4200.	130.5	130.9	133.1	134.0	135.7	137.2
4400.	133.3	133.7	136.3	137.3	139.1	140.4
4600.	136.1	136.5	139.5	140.7	142.5	143.6
4800.	139.0	139.5	143.0	144.3	146.1	146.8
5000.	142.2	142.7	146.8	148.3	149.6	150.0
5200.	153.2	153.2	153.2	153.2	153.2	153.2
5400.	156.4	156.4	156.4	156.4	156.4	156.4

4.7 SAMPLE PROBLEMS 7 and 8: Air and Mist Drilling

Sample problems 7 and 8 are combined in one section because this allows a direct illustration of the effect of water addition to air drilling. The following problem is simulated for both air and mist drilling:

5" drill pipe
8-3/4" hole diameter
3 3/4" bit nozzles
600 ft. 6" drill collars
90 ft/hr drilling rate

Water is added at the rate of 2 barrels per hour in the mist drilling case. The following two cases are considered here: For sample problem 7, the simulation is air drilling from the surface to 9000 ft. For sample problem 8, the simulation is exactly the same to a depth of 3600 ft. At this point, mist drilling is started and continued to 9000 ft.

GEOTEMP2 automatically adjusts the standpipe pressure if it is not sufficient to maintain the flow (i.e. if choked flow is encountered). This capability is illustrated in sample problem 7 where the standpipe pressure was adjusted at each 'CHANGE' record interval. A word of caution is necessary here. The code will calculate a new standpipe pressure until it finds one that does not produce choked flow. A comparison of the input pres- sures given by the 'GAS' record with the pressures calculated by the program is presented in Figure 10. Note the large pressure increase for the calculated pressure at a depth of 7200 ft. These calculated pressures are not necessarily the minimum pressures which maintain the flow. For example, sample problem 7 can be run with input standpipe pressures on the 'GAS' record of 85, 100, 125, 160, and 180 psia for the five drilling depths without obtaining a choked flow condition. The pressure of 160 psia at 7200 ft is much less than the 190 psia calculated by the code for this depth.

In addition to this adjustment, the code will also increase the volume flow rate if there is insufficient lifting capacity for the cuttings in the annulus. This modification is illustrated in the mist drilling problem at drilling depths of 5400, 7200, and 9000 ft. Again caution is advised since these new flow rates, as in the case of the standpipe pressures, are just those found to satisfy the requirements of the code and are not necessarily the minimum values needed.

Significant increases in the volume flow rate and the standpipe pressure are needed with the addition of mist. The downhole pressures at the final drilling depth of 9000 ft. for both air and mist drilling are shown in Figure 11. Both curves show a linear pressure increase down the tubing until a depth of 8400 ft. At this depth the reduction in the inside diameter from the tubing to the drill collar increases the frictional losses, resulting in a pressure drop to the bottom of the hole. The effects of the drill collar on the pressure in the annulus are most pronounced for mist drilling.

TABLE 4.14 Input Data for Sample Problem 7

```
SAMPLE PROBLEM 7: AIR DRILLING
'TUBING',1
1,4.408,5.,9000.,0.
'CASING',1
1,8.921,9.625,100.,100.
'WELLBORE',0.,9000.,9000.,0.,20.
'TEMP',80.,170.,105.,2500.
'FLUIDS',2
1,8.330,1.,0.
2,9.25,10.,3.
'INITIAL',2,2
'CHANGE',7,0,1,80.,1028.,2.
'GAS',40.
'DRILL',1,10.,1800.
'BHA',600.,6.,2.5,8.75,.75,.75,.75
'CHANGE',7,0,1,80.,1230.,4.
'GAS',55.
'DRILL',0,10.,3600.
'CHANGE'1,7,0,1,80.,1432.,6.
'GAS',70.
'DRILL',0,10.,5400.
'CHANGE',7,0,1,80.,1633.,8.
'GAS',90.
'DRILL',0,10.,7200.
'CHANGE',7,0,1,80.,1835.,10.
'GAS',110.
'DRILL',0,10.,9000.
```

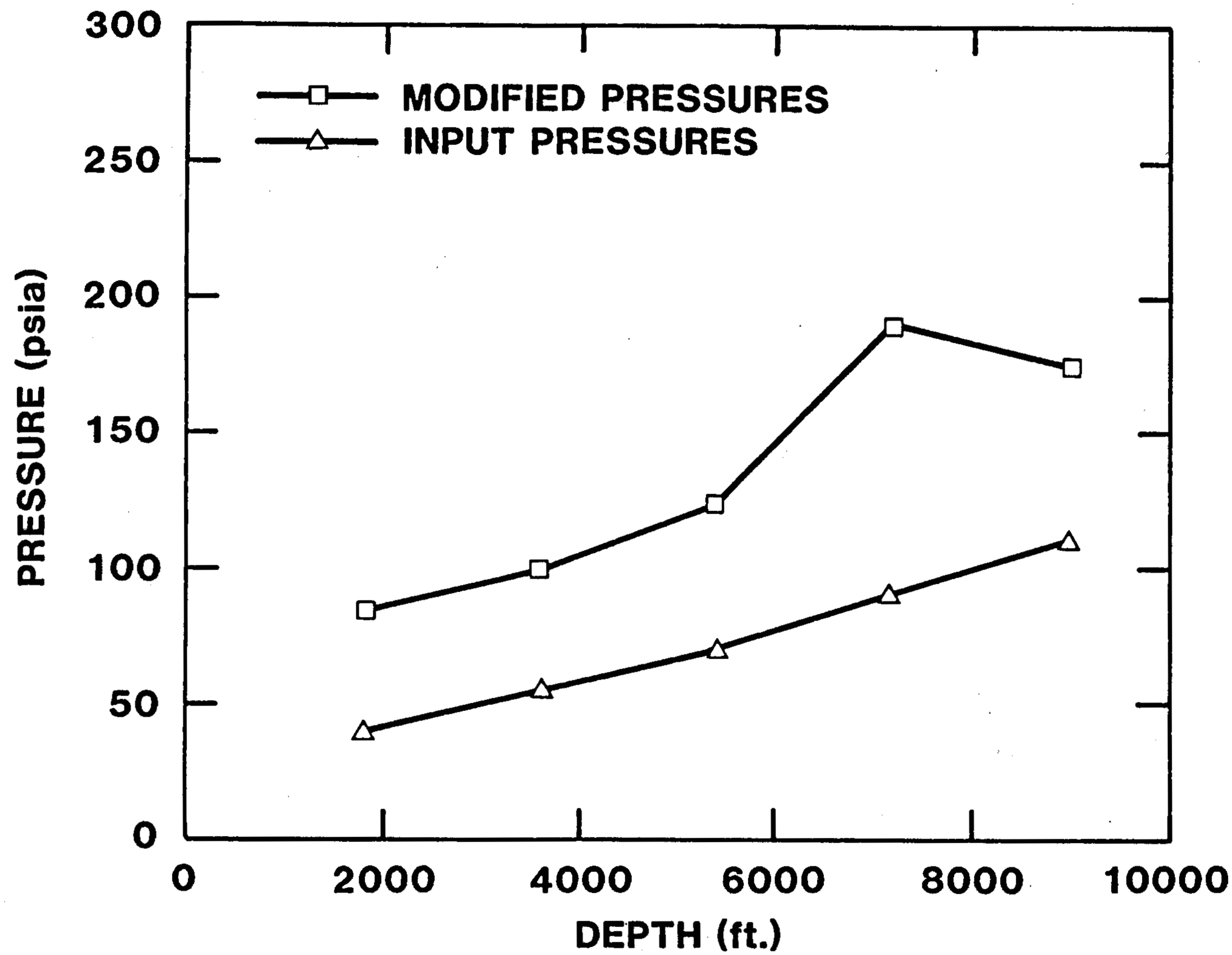

Figure 10. Comparision of input and GEOTEMP2 modified pressures for gas drilling.

Table 4.15 Output Data for Sample Problem 7.

SAMPLE PROBLEM #7: AIR DRILLING

T U B I N G   C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	4.408	5.000	0.	9000.	0.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.921	9.625	100.	100.

W E L L   G E O M E T R Y

TOTAL DEPTH=   9000. FT.
BORE DIAMETER=   20.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO.   1

DENSITY=   8.3 LBM/GAL
PLASTIC VISCOSITY=   1. CENTIPOISE
YIELD POINT=   0. LBF/100FT2

FLUID TYPE NO.   2

DENSITY=   9.3 LBM/GAL
PLASTIC VISCOSITY=   10. CENTIPOISE
YIELD POINT=   3. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 2 IN TUBING & TUBING ANNULUS
FLUID # 2 IN CASING - CASING ANNULI

```
S E T   V A R I A B L E S   AT TIME =      0.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   AIR INJECTED INTO TUBING
        INLET TEMPERATURE=   80. F
        FLOW RATE = 1028. SCF/MIN
        TIME TO CHANGE DATA =      2.000 DAYS
        DEPTH TO CHANGE DATA = 1800. FT
        CIRCULATION TIME PER DAY =  10.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,    I.D.= 2.500 IN,    O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER=  8.750 IN, NOZZLE SIZES=    .750    .750    .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    52.1 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    64.3 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    75.4 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    83.4 PSI



TIME =      1.417 DAYS                                    ITERATIONS =  3
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =1028. SCF/MIN     CIRCULATION DEPTH = 1800. FT

                T E M P E R A T U R E   D I S T R I B U T I O N
```

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.1	82.1	82.0	82.0
400.	83.2	84.1	84.0	84.0	84.0	84.0
600.	85.1	86.2	86.0	86.0	86.0	86.0
800.	87.2	88.3	88.1	88.0	88.0	88.0
1000.	89.2	90.0	90.0	90.0	90.0	90.0
1200.	91.1	91.7	91.8	92.0	92.0	92.0
1400.	93.2	94.0	94.0	94.0	94.0	94.0
1600.	95.4	96.2	96.0	96.0	96.0	96.0
1800.	96.9	97.2	97.6	98.0	98.0	98.0
2000.	100.0	100.0	100.0	100.0	100.0	100.0
2200.	102.0	102.0	102.0	102.0	102.0	102.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	83.4	80.0	.417	0.000	0.000	29.6
200.	83.5	81.4	.417	0.000	0.000	29.6
400.	83.7	83.2	.416	0.000	0.000	29.7
600.	83.8	85.1	.415	0.000	0.000	29.7
800.	84.0	87.2	.414	0.000	0.000	29.8
1000.	84.1	89.2	.414	0.000	0.000	29.8
1200.	84.3	91.1	.413	0.000	0.000	29.9
1400.	75.6	93.2	.369	0.000	0.000	103.9
1600.	66.3	95.4	.323	0.000	0.000	119.0
1800.	55.2	96.9	.267	0.000	0.000	143.5

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	GAS	DENSITY-LBM/CF WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	29.8	80.6	.149	0.000	0.000	.821	32.2	5.3
200.	31.7	82.3	.158	0.000	0.000	.800	31.9	5.8
400.	33.6	84.1	.166	0.000	0.000	.956	30.2	4.8
600.	35.7	86.2	.176	0.000	0.000	1.208	28.5	3.8
800.	38.3	88.3	.188	0.000	0.000	1.608	26.7	2.9
1000.	41.1	90.0	.201	0.000	0.000	2.964	25.0	1.6
1200.	43.0	91.7	.210	0.000	0.000	7.250	24.0	.6
1400.	48.4	94.0	.235	0.000	0.000	1.385	25.6	4.3
1600.	51.5	96.2	.250	0.000	0.000	1.738	24.1	3.4
1800.	55.2	97.2	.267	0.000	0.000	2.354	22.5	2.5

TIME = 2.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 1800. FT

T E M P E R A T U R E D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.0	82.0	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.7	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.8	90.0	90.0	90.0	90.0
1200.	91.5	91.8	92.0	92.0	92.0	92.0
1400.	93.7	93.9	94.0	94.0	94.0	94.0
1600.	95.8	95.9	96.0	96.0	96.0	96.0
1800.	97.3	97.7	98.0	98.0	98.0	98.0
2000.	100.0	100.0	100.0	100.0	100.0	100.0
2200.	102.0	102.0	102.0	102.0	102.0	102.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.7	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.5	.075	0.000	0.000	0.0
1400.	15.4	93.7	.075	0.000	0.000	0.0
1600.	15.5	95.8	.075	0.000	0.000	0.0
1800.	15.6	97.3	.076	0.000	0.000	0.0

ANNULUS

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.8	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.8	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.7	.076	0.000	0.000	0.000	0.0	0.0

SET VARIABLES AT TIME = 2.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 80. F
FLOW RATE = 1230. SCF/MIN
TIME TO CHANGE DATA = 4.000 DAYS
DEPTH TO CHANGE DATA = 3600. FT
CIRCULATION TIME PER DAY = 10.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT, I.D.= 2.500 IN, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES= .750 .750 .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 65.4 PSI

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 93.9 PSI

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 99.0 PSI

TIME = 3.417 DAYS ITERATIONS = 3

CONDITIONS SINCE LAST TIME STEP:

FLOW RATE =1230. SCF/MIN CIRCULATION DEPTH = 3600. FT

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.2	82.1	82.0	82.0
400.	83.1	84.2	84.1	84.0	84.0	84.0
600.	85.0	86.1	86.1	86.0	86.0	86.0
800.	87.0	88.1	88.1	88.0	88.0	88.0
1000.	89.0	90.1	90.1	90.0	90.0	90.0
1200.	91.0	92.1	92.1	92.0	92.0	92.0
1400.	93.0	94.1	94.1	94.0	94.0	94.0
1600.	95.0	96.1	96.1	96.0	96.0	96.0
1800.	97.0	98.1	98.1	98.0	98.0	98.0
2000.	99.0	100.1	100.1	100.0	100.0	100.0
2200.	101.0	102.1	102.0	102.0	102.0	102.0
2400.	103.0	104.1	104.0	104.0	104.0	104.0
2600.	105.0	106.1	106.1	106.0	106.0	106.0
2800.	107.0	108.0	108.0	108.0	108.0	108.0
3000.	109.0	109.8	109.9	110.0	110.0	110.0
3200.	111.1	112.0	112.0	112.0	112.0	112.0
3400.	113.3	114.1	114.0	114.0	114.0	114.0
3600.	114.8	115.2	115.6	116.0	116.0	116.0
3800.	118.0	118.0	118.0	118.0	118.0	118.0
4000.	120.0	120.0	120.0	120.0	120.0	120.0

G A S & M I S T D R I L L I N G
F L O W I N G   S T R E A M   P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	99.0	80.0	.495	0.000	0.000	29.8
200.	99.1	81.4	.495	0.000	0.000	29.9
400.	99.3	83.1	.494	0.000	0.000	29.9
600.	99.5	85.0	.493	0.000	0.000	30.0
800.	99.6	87.0	.492	0.000	0.000	30.0
1000.	99.8	89.0	.491	0.000	0.000	30.1
1200.	100.0	91.0	.490	0.000	0.000	30.1
1400.	100.1	93.0	.489	0.000	0.000	30.2
1600.	100.3	95.0	.488	0.000	0.000	30.3
1800.	100.4	97.0	.487	0.000	0.000	30.3
2000.	100.6	99.0	.486	0.000	0.000	30.4
2200.	100.7	101.0	.485	0.000	0.000	30.5
2400.	100.9	103.0	.484	0.000	0.000	30.5
2600.	101.0	105.0	.483	0.000	0.000	30.6
2800.	101.2	107.0	.482	0.000	0.000	30.6
3000.	101.3	109.0	.481	0.000	0.000	30.7
3200.	90.7	111.1	.429	0.000	0.000	107.1
3400.	79.2	113.3	.373	0.000	0.000	123.1
3600.	65.3	114.8	.307	0.000	0.000	149.6

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	27.6	80.6	.137	0.000	0.000	.368	39.9	11.9
200.	28.8	82.3	.143	0.000	0.000	.357	40.4	13.0
400.	30.1	84.2	.149	0.000	0.000	.389	38.8	11.9
600.	31.5	86.1	.155	0.000	0.000	.425	37.2	10.9
800.	32.8	88.1	.161	0.000	0.000	.463	35.8	10.0
1000.	34.2	90.1	.168	0.000	0.000	.507	34.5	9.1
1200.	35.7	92.1	.174	0.000	0.000	.556	33.2	8.3
1400.	37.2	94.1	.181	0.000	0.000	.614	31.9	7.5
1600.	38.9	96.1	.188	0.000	0.000	.680	30.7	6.8
1800.	40.6	98.1	.196	0.000	0.000	.764	29.5	6.1
2000.	42.5	100.1	.204	0.000	0.000	.862	28.3	5.4
2200.	44.5	102.1	.213	0.000	0.000	1.000	27.1	4.6
2400.	46.8	104.1	.224	0.000	0.000	1.171	25.9	4.0
2600.	49.4	106.1	.235	0.000	0.000	1.464	24.6	3.2
2800.	52.6	108.0	.249	0.000	0.000	1.881	23.2	2.5
3000.	56.0	109.8	.265	0.000	0.000	3.361	21.8	1.4
3200.	60.0	112.0	.283	0.000	0.000	1.015	25.3	5.8
3400.	62.6	114.1	.294	0.000	0.000	1.132	24.3	5.2
3600.	65.3	115.2	.307	0.000	0.000	1.281	23.3	4.6

TIME = 4.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 3600. FT

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.0	82.0	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.9	92.0	92.0	92.0	92.0
1400.	93.6	93.9	94.0	94.0	94.0	94.0
1600.	95.6	95.9	96.0	96.0	96.0	96.0
1800.	97.6	97.9	98.0	98.0	98.0	98.0
2000.	99.6	99.9	100.0	100.0	100.0	100.0
2200.	101.6	101.9	102.0	102.0	102.0	102.0
2400.	103.6	103.8	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.5	107.8	108.0	108.0	108.0	108.0
3000.	109.5	109.8	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.7	113.9	114.0	114.0	114.0	114.0
3600.	115.3	115.7	116.0	116.0	116.0	116.0
3800.	118.0	118.0	118.0	118.0	118.0	118.0
4000.	120.0	120.0	120.0	120.0	120.0	120.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.1	105.6	.077	0.000	0.000	0.0
2800.	16.2	107.5	.077	0.000	0.000	0.0
3000.	16.3	109.5	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.7	.078	0.000	0.000	0.0
3600.	16.6	115.3	.078	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.9	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.9	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.9	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.9	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.8	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.8	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.8	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.9	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.7	.078	0.000	0.000	0.000	0.0	0.0

S E T V A R I A B L E S AT TIME = 4.000 DAYS

FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 80. F
FLOW RATE = 1432. SCF/MIN
TIME TO CHANGE DATA = 6.000 DAYS
DEPTH TO CHANGE DATA = 5400. FT
CIRCULATION TIME PER DAY = 10.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT, I.D.= 2.500 IN, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES= .750 .750 .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 82.9 PSI
CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 103.9 PSI
CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 123.3 PSI
TIME = 5.417 DAYS ITERATIONS = 3
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =1432. SCF/MIN CIRCULATION DEPTH = 5400. FT

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.2	82.1	82.0	82.0
400.	83.1	84.2	84.1	84.0	84.0	84.0
600.	85.0	86.1	86.1	86.0	86.0	86.0
800.	87.0	88.1	88.1	88.0	88.0	88.0
1000.	89.0	90.1	90.1	90.0	90.0	90.0
1200.	91.0	92.1	92.1	92.0	92.0	92.0
1400.	93.0	94.1	94.1	94.0	94.0	94.0
1600.	95.0	96.1	96.1	96.0	96.0	96.0
1800.	97.0	98.1	98.1	98.0	98.0	98.0
2000.	99.0	100.1	100.1	100.0	100.0	100.0
2200.	101.0	102.1	102.1	102.0	102.0	102.0
2400.	103.0	104.1	104.1	104.0	104.0	104.0
2600.	105.0	106.1	106.1	106.0	106.0	106.0
2800.	107.0	108.1	108.1	108.0	108.0	108.0
3000.	109.0	110.1	110.1	110.0	110.0	110.0
3200.	111.0	112.1	112.1	112.0	112.0	112.0
3400.	113.0	114.1	114.1	114.0	114.0	114.0
3600.	115.0	116.1	116.1	116.0	116.0	116.0
3800.	117.0	118.1	118.1	118.0	118.0	118.0
4000.	119.0	120.1	120.1	120.0	120.0	120.0
4200.	121.0	122.1	122.1	122.0	122.0	122.0
4400.	123.0	124.2	124.1	124.0	124.0	124.0
4600.	124.9	125.9	125.9	126.0	126.0	126.0
4800.	126.9	127.8	127.9	127.9	128.0	128.0
5000.	129.1	129.9	130.0	130.0	130.0	130.0
5200.	131.2	132.0	132.0	132.0	132.0	132.0
5400.	132.7	133.0	133.5	133.9	134.0	134.0
5600.	136.0	136.0	136.0	136.0	136.0	136.0
5800.	138.0	138.0	138.0	138.0	138.0	138.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	123.3	80.0	.617	0.000	0.000	27.9
200.	123.6	81.4	.617	0.000	0.000	27.9
400.	123.9	83.1	.616	0.000	0.000	27.9
600.	124.2	85.0	.615	0.000	0.000	27.9
800.	124.5	87.0	.615	0.000	0.000	28.0
1000.	124.8	89.0	.614	0.000	0.000	28.0
1200.	125.1	91.0	.613	0.000	0.000	28.0
1400.	125.4	93.0	.612	0.000	0.000	28.1
1600.	125.7	95.0	.611	0.000	0.000	28.1
1800.	125.9	97.0	.611	0.000	0.000	28.2
2000.	126.2	99.0	.610	0.000	0.000	28.2
2200.	126.5	101.0	.609	0.000	0.000	28.2
2400.	126.8	103.0	.608	0.000	0.000	28.3
2600.	127.1	105.0	.607	0.000	0.000	28.3
2800.	127.3	107.0	.607	0.000	0.000	28.3
3000.	127.6	109.0	.606	0.000	0.000	28.4
3200.	127.9	111.0	.605	0.000	0.000	28.4
3400.	128.2	113.0	.604	0.000	0.000	28.5
3600.	128.4	115.0	.603	0.000	0.000	28.5
3800.	128.7	117.0	.602	0.000	0.000	28.5
4000.	128.9	119.0	.601	0.000	0.000	28.6
4200.	129.2	121.0	.601	0.000	0.000	28.6
4400.	129.5	123.0	.600	0.000	0.000	28.7
4600.	129.7	124.9	.599	0.000	0.000	28.7
4800.	130.0	126.9	.598	0.000	0.000	28.7
5000.	118.7	129.1	.544	0.000	0.000	98.2
5200.	106.8	131.2	.488	0.000	0.000	109.5
5400.	93.2	132.7	.424	0.000	0.000	125.9

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	32.0	80.6	.159	0.000	0.000	.303	40.4	14.4
200.	33.1	82.3	.165	0.000	0.000	.295	41.3	15.7
400.	34.4	84.2	.171	0.000	0.000	.314	39.9	14.7
600.	35.7	86.1	.176	0.000	0.000	.334	38.6	13.9
800.	37.0	88.1	.182	0.000	0.000	.356	37.3	13.0
1000.	38.3	90.1	.188	0.000	0.000	.378	36.2	12.3
1200.	39.7	92.1	.194	0.000	0.000	.402	35.1	11.5
1400.	41.0	94.1	.200	0.000	0.000	.427	34.0	10.8
1600.	42.4	96.1	.206	0.000	0.000	.455	33.0	10.2
1800.	43.9	98.1	.212	0.000	0.000	.484	32.1	9.6
2000.	45.3	100.1	.218	0.000	0.000	.517	31.1	9.0
2200.	46.9	102.1	.225	0.000	0.000	.553	30.2	8.4
2400.	48.5	104.1	.232	0.000	0.000	.593	29.4	7.8
2600.	50.1	106.1	.239	0.000	0.000	.637	28.5	7.3
2800.	51.8	108.1	.246	0.000	0.000	.688	27.6	6.7
3000.	53.7	110.1	.254	0.000	0.000	.745	26.8	6.2
3200.	55.6	112.1	.262	0.000	0.000	.815	25.9	5.7
3400.	57.7	114.1	.271	0.000	0.000	.893	25.1	5.2
3600.	59.9	116.1	.281	0.000	0.000	.995	24.2	4.7
3800.	62.4	118.1	.291	0.000	0.000	1.112	23.4	4.2
4000.	65.1	120.1	.303	0.000	0.000	1.281	22.5	3.6
4200.	68.2	122.1	.316	0.000	0.000	1.488	21.5	3.1
4400.	71.7	124.2	.331	0.000	0.000	1.845	20.6	2.5
4600.	75.9	125.9	.349	0.000	0.000	2.354	19.5	2.0
4800.	80.2	127.8	.368	0.000	0.000	4.344	18.5	1.1
5000.	86.2	129.9	.394	0.000	0.000	1.261	21.2	4.7
5200.	89.6	132.0	.408	0.000	0.000	1.395	20.4	4.2
5400.	93.2	133.0	.424	0.000	0.000	1.567	19.7	3.8

TIME = 6.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 5400. FT

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.1	82.1	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.9	92.0	92.0	92.0	92.0
1400.	93.6	93.9	94.0	94.0	94.0	94.0
1600.	95.6	95.9	96.0	96.0	96.0	96.0
1800.	97.6	97.9	98.0	98.0	98.0	98.0
2000.	99.6	99.9	100.0	100.0	100.0	100.0
2200.	101.6	101.9	102.0	102.0	102.0	102.0
2400.	103.6	103.9	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.6	107.9	108.0	108.0	108.0	108.0
3000.	109.6	109.9	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.6	113.9	114.0	114.0	114.0	114.0
3600.	115.6	115.9	116.0	116.0	116.0	116.0
3800.	117.6	117.9	118.0	118.0	118.0	118.0
4000.	119.6	119.8	120.0	120.0	120.0	120.0
4200.	121.6	121.8	122.0	122.0	122.0	122.0
4400.	123.6	123.9	124.0	124.0	124.0	124.0
4600.	125.5	125.8	126.0	126.0	126.0	126.0
4800.	127.5	127.8	128.0	128.0	128.0	128.0
5000.	129.6	129.8	130.0	130.0	130.0	130.0
5200.	131.7	131.9	132.0	132.0	132.0	132.0
5400.	133.3	133.6	134.0	134.0	134.0	134.0
5600.	136.0	136.0	136.0	136.0	136.0	136.0
5800.	138.0	138.0	138.0	138.0	138.0	138.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.0	105.6	.077	0.000	0.000	0.0
2800.	16.2	107.6	.077	0.000	0.000	0.0
3000.	16.3	109.6	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.6	.078	0.000	0.000	0.0
3600.	16.6	115.6	.078	0.000	0.000	0.0
3800.	16.7	117.6	.078	0.000	0.000	0.0
4000.	16.8	119.6	.078	0.000	0.000	0.0
4200.	16.9	121.6	.079	0.000	0.000	0.0
4400.	17.0	123.6	.079	0.000	0.000	0.0
4600.	17.1	125.5	.079	0.000	0.000	0.0
4800.	17.2	127.5	.079	0.000	0.000	0.0
5000.	17.4	129.6	.079	0.000	0.000	0.0
5200.	17.5	131.7	.080	0.000	0.000	0.0
5400.	17.6	133.3	.080	0.000	0.000	0.0

A N N U L U S

DEPTH	PRESSURE	TEMP	DENSITY-LBM/CF				VELOCITY-FT/SEC	
FT	PSIA	F	GAS	WATER	VAPOR	ROCKS	GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.9	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.9	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.9	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.9	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.9	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.9	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.9	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.9	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.9	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.9	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.8	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.8	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.9	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.8	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.8	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.8	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.9	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.6	.080	0.000	0.000	0.000	0.0	0.0

1

S E T   V A R I A B L E S   AT TIME =   6.000 DAYS

FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE=   80. F
FLOW RATE = 1633. SCF/MIN
TIME TO CHANGE DATA =   8.000 DAYS
DEPTH TO CHANGE DATA = 7200. FT
CIRCULATION TIME PER DAY =   10.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT,   I.D.= 2.500 IN,   O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES=   .750   .750   .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO   190.0 PSI

TIME = 7.417 DAYS ITERATIONS = 4
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =1633. SCF/MIN CIRCULATION DEPTH = 7200. FT

T E M P E R A T U R E D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.2	82.1	82.0	82.0
400.	83.1	84.2	84.1	84.0	84.0	84.0
600.	85.0	86.1	86.1	86.0	86.0	86.0
800.	87.0	88.1	88.1	88.0	88.0	88.0
1000.	89.0	90.1	90.1	90.0	90.0	90.0
1200.	91.0	92.1	92.1	92.0	92.0	92.0
1400.	93.0	94.1	94.1	94.0	94.0	94.0
1600.	95.0	96.1	96.1	96.0	96.0	96.0
1800.	97.0	98.1	98.1	98.0	98.0	98.0
2000.	99.0	100.1	100.1	100.0	100.0	100.0
2200.	101.0	102.1	102.1	102.0	102.0	102.0
2400.	103.0	104.1	104.1	104.0	104.0	104.0
2600.	105.0	106.1	106.1	106.0	106.0	106.0
2800.	107.0	108.1	108.1	108.0	108.0	108.0
3000.	109.0	110.1	110.1	110.0	110.0	110.0
3200.	111.0	112.1	112.1	112.0	112.0	112.0
3400.	113.0	114.1	114.1	114.0	114.0	114.0
3600.	115.0	116.1	116.1	116.0	116.0	116.0
3800.	117.0	118.1	118.1	118.0	118.0	118.0
4000.	119.0	120.1	120.1	120.0	120.0	120.0
4200.	121.0	122.1	122.1	122.0	122.0	122.0
4400.	123.0	124.1	124.1	124.0	124.0	124.0
4600.	125.0	126.1	126.1	126.0	126.0	126.0
4800.	127.0	128.1	128.1	128.0	128.0	128.0
5000.	129.0	130.1	130.1	130.0	130.0	130.0
5200.	131.0	132.2	132.1	132.0	132.0	132.0
5400.	133.1	134.2	134.1	134.0	134.0	134.0
5600.	135.1	136.2	136.1	136.1	136.0	136.0
5800.	137.2	138.3	138.1	138.0	138.0	138.0
6000.	139.2	140.4	140.2	140.0	140.0	140.0
6200.	141.5	142.8	142.4	142.1	142.0	142.0
6400.	143.5	144.1	144.0	144.0	144.0	144.0
6600.	144.9	145.5	145.7	145.9	146.0	146.0
6800.	147.0	148.2	148.1	148.0	148.0	148.0
7000.	149.7	150.4	150.2	150.0	150.0	150.0
7200.	150.9	151.1	151.6	151.9	152.0	152.0
7400.	154.0	154.0	154.0	154.0	154.0	154.0
7600.	156.0	156.0	156.0	156.0	156.0	156.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH	PRESSURE	TEMP	DENSITY-LBM/CF			VELOCITY
FT	PSIA	F	GAS	WATER	VAPOR	FT/SEC
0.	190.0	80.0	.950	0.000	0.000	20.6
200.	190.9	81.4	.952	0.000	0.000	20.6
400.	191.7	83.1	.953	0.000	0.000	20.6
600.	192.6	85.0	.954	0.000	0.000	20.5
800.	193.4	87.0	.955	0.000	0.000	20.5
1000.	194.3	89.0	.956	0.000	0.000	20.5
1200.	195.2	91.0	.957	0.000	0.000	20.5
1400.	196.0	93.0	.957	0.000	0.000	20.5
1600.	196.9	95.0	.958	0.000	0.000	20.5
1800.	197.8	97.0	.959	0.000	0.000	20.4
2000.	198.6	99.0	.960	0.000	0.000	20.4
2200.	199.5	101.0	.960	0.000	0.000	20.4
2400.	200.4	103.0	.961	0.000	0.000	20.4
2600.	201.2	105.0	.962	0.000	0.000	20.4
2800.	202.1	107.0	.963	0.000	0.000	20.4
3000.	203.0	109.0	.963	0.000	0.000	20.4
3200.	203.9	111.0	.964	0.000	0.000	20.3
3400.	204.7	113.0	.965	0.000	0.000	20.3
3600.	205.6	115.0	.966	0.000	0.000	20.3
3800.	206.5	117.0	.967	0.000	0.000	20.3
4000.	207.4	119.0	.967	0.000	0.000	20.3
4200.	208.3	121.0	.968	0.000	0.000	20.3
4400.	209.2	123.0	.969	0.000	0.000	20.2
4600.	210.0	125.0	.970	0.000	0.000	20.2
4800.	210.9	127.0	.970	0.000	0.000	20.2
5000.	211.8	129.0	.971	0.000	0.000	20.2
5200.	212.7	131.0	.972	0.000	0.000	20.2
5400.	213.6	133.1	.973	0.000	0.000	20.2
5600.	214.5	135.1	.973	0.000	0.000	20.1
5800.	215.4	137.2	.974	0.000	0.000	20.1
6000.	216.3	139.2	.975	0.000	0.000	20.1
6200.	217.2	141.5	.975	0.000	0.000	20.1
6400.	218.1	143.5	.976	0.000	0.000	20.1
6600.	219.0	144.9	.978	0.000	0.000	20.1
6800.	211.0	147.0	.939	0.000	0.000	64.9
7000.	203.2	149.7	.900	0.000	0.000	67.7
7200.	195.0	150.9	.862	0.000	0.000	70.7

ANNULUS

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	55.6	80.6	.277	0.000	0.000	.396	30.7	11.1
200.	57.1	82.3	.284	0.000	0.000	.379	31.7	12.2
400.	58.5	84.2	.290	0.000	0.000	.394	31.0	11.8
600.	60.0	86.1	.296	0.000	0.000	.409	30.4	11.3
800.	61.4	88.1	.303	0.000	0.000	.425	29.7	10.9
1000.	63.0	90.1	.309	0.000	0.000	.442	29.1	10.5
1200.	64.5	92.1	.315	0.000	0.000	.460	28.5	10.1
1400.	66.1	94.1	.322	0.000	0.000	.478	27.9	9.7
1600.	67.7	96.1	.329	0.000	0.000	.498	27.4	9.3
1800.	69.4	98.1	.335	0.000	0.000	.519	26.8	8.9
2000.	71.1	100.1	.343	0.000	0.000	.541	26.3	8.6
2200.	72.8	102.1	.350	0.000	0.000	.564	25.7	8.2
2400.	74.6	104.1	.357	0.000	0.000	.590	25.2	7.9
2600.	76.5	106.1	.365	0.000	0.000	.617	24.7	7.5
2800.	78.4	108.1	.373	0.000	0.000	.646	24.1	7.2
3000.	80.5	110.1	.381	0.000	0.000	.677	23.6	6.8
3200.	82.5	112.1	.389	0.000	0.000	.713	23.1	6.5
3400.	84.7	114.1	.398	0.000	0.000	.750	22.6	6.2
3600.	87.0	116.1	.408	0.000	0.000	.792	22.1	5.9
3800.	89.4	118.1	.417	0.000	0.000	.837	21.6	5.5
4000.	91.9	120.1	.427	0.000	0.000	.890	21.1	5.2
4200.	94.5	122.1	.438	0.000	0.000	.946	20.5	4.9
4400.	97.3	124.1	.450	0.000	0.000	1.015	20.0	4.6
4600.	100.2	126.1	.462	0.000	0.000	1.088	19.5	4.3
4800.	103.4	128.1	.475	0.000	0.000	1.181	19.0	3.9
5000.	106.8	130.1	.489	0.000	0.000	1.282	18.4	3.6
5200.	110.5	132.2	.504	0.000	0.000	1.418	17.9	3.3
5400.	114.5	134.2	.520	0.000	0.000	1.570	17.3	3.0
5600.	119.0	136.2	.539	0.000	0.000	1.794	16.7	2.6
5800.	124.1	138.3	.560	0.000	0.000	2.057	16.1	2.3
6000.	129.9	140.4	.584	0.000	0.000	2.517	15.4	1.8
6200.	137.0	142.8	.613	0.000	0.000	3.122	14.7	1.5
6400.	142.9	144.1	.639	0.000	0.000	5.870	14.1	.8
6600.	142.8	145.5	.637	0.000	0.000	14.114	14.1	.3
6800.	170.3	148.2	.756	0.000	0.000	3.864	13.4	1.5
7000.	181.7	150.4	.804	0.000	0.000	5.434	12.6	1.1
7200.	195.0	151.1	.862	0.000	0.000	9.271	11.8	.6

TIME = 8.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 7200. FT

T E M P E R A T U R E D I S T R I B U T I O N

DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
	RADIAL POSITIONS, FEET					
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.1	82.1	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.9	92.0	92.0	92.0	92.0
1400.	93.6	93.9	94.0	94.0	94.0	94.0
1600.	95.6	95.9	96.0	96.0	96.0	96.0
1800.	97.6	97.9	98.0	98.0	98.0	98.0
2000.	99.6	99.9	100.0	100.0	100.0	100.0
2200.	101.6	101.9	102.0	102.0	102.0	102.0
2400.	103.6	103.9	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.6	107.9	108.0	108.0	108.0	108.0
3000.	109.6	109.9	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.6	113.9	114.0	114.0	114.0	114.0
3600.	115.6	115.9	116.0	116.0	116.0	116.0
3800.	117.6	117.9	118.0	118.0	118.0	118.0
4000.	119.6	119.9	120.0	120.0	120.0	120.0
4200.	121.6	121.9	122.0	122.0	122.0	122.0
4400.	123.6	123.9	124.0	124.0	124.0	124.0
4600.	125.6	125.9	126.0	126.0	126.0	126.0
4800.	127.6	127.9	128.0	128.0	128.0	128.0
5000.	129.6	129.9	130.0	130.0	130.0	130.0
5200.	131.6	131.9	132.0	132.0	132.0	132.0
5400.	133.7	133.9	134.0	134.0	134.0	134.0
5600.	135.7	135.9	136.0	136.0	136.0	136.0
5800.	137.7	137.9	138.0	138.0	138.0	138.0
6000.	139.8	140.0	140.0	140.0	140.0	140.0
6200.	142.0	142.1	142.1	142.0	142.0	142.0
6400.	143.8	143.9	144.0	144.0	144.0	144.0
6600.	145.4	145.7	146.0	146.0	146.0	146.0
6800.	147.7	147.9	148.0	148.0	148.0	148.0
7000.	149.9	150.0	150.0	150.0	150.0	150.0
7200.	151.4	151.7	152.0	152.0	152.0	152.0
7400.	154.0	154.0	154.0	154.0	154.0	154.0
7600.	156.0	156.0	156.0	156.0	156.0	156.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.0	105.6	.077	0.000	0.000	0.0
2800.	16.2	107.6	.077	0.000	0.000	0.0
3000.	16.3	109.6	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.6	.078	0.000	0.000	0.0
3600.	16.6	115.6	.078	0.000	0.000	0.0
3800.	16.7	117.6	.078	0.000	0.000	0.0
4000.	16.8	119.6	.078	0.000	0.000	0.0
4200.	16.9	121.6	.079	0.000	0.000	0.0
4400.	17.0	123.6	.079	0.000	0.000	0.0
4600.	17.1	125.6	.079	0.000	0.000	0.0
4800.	17.2	127.6	.079	0.000	0.000	0.0
5000.	17.3	129.6	.079	0.000	0.000	0.0
5200.	17.5	131.6	.080	0.000	0.000	0.0
5400.	17.6	133.7	.080	0.000	0.000	0.0
5600.	17.7	135.7	.080	0.000	0.000	0.0
5800.	17.8	137.7	.080	0.000	0.000	0.0
6000.	17.9	139.8	.081	0.000	0.000	0.0
6200.	18.0	142.0	.081	0.000	0.000	0.0
6400.	18.1	143.8	.081	0.000	0.000	0.0
6600.	18.2	145.4	.081	0.000	0.000	0.0
6800.	18.4	147.7	.082	0.000	0.000	0.0
7000.	18.5	149.9	.082	0.000	0.000	0.0
7200.	18.6	151.4	.082	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.9	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.9	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.9	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.9	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.9	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.9	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.9	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.9	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.9	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.9	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.9	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.9	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.9	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.9	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.9	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.9	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.9	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.9	.080	0.000	0.000	0.000	0.0	0.0
5600.	17.7	135.9	.080	0.000	0.000	0.000	0.0	0.0
5800.	17.8	137.9	.080	0.000	0.000	0.000	0.0	0.0
6000.	17.9	140.0	.081	0.000	0.000	0.000	0.0	0.0
6200.	18.0	142.1	.081	0.000	0.000	0.000	0.0	0.0
6400.	18.1	143.9	.081	0.000	0.000	0.000	0.0	0.0
6600.	18.2	145.7	.081	0.000	0.000	0.000	0.0	0.0
6800.	18.4	147.9	.082	0.000	0.000	0.000	0.0	0.0
7000.	18.5	150.0	.082	0.000	0.000	0.000	0.0	0.0
7200.	18.6	151.7	.082	0.000	0.000	0.000	0.0	0.0

S E T   V A R I A B L E S   AT TIME =   8.000 DAYS
FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 80. F
FLOW RATE = 1835. SCF/MIN
TIME TO CHANGE DATA =   10.000 DAYS
DEPTH TO CHANGE DATA = 9000. FT
CIRCULATION TIME PER DAY = 10.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT,   I.D.= 2.500 IN,   O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES=   .750   .750   .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 175.2 PSI

TIME = 9.417 DAYS ITERATIONS = 3
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =1835. SCF/MIN CIRCULATION DEPTH = 9000. FT

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.7	80.0	80.0	80.0	80.0
200.	81.4	82.4	82.2	82.1	82.1	82.0
400.	83.1	84.2	84.1	84.1	84.0	84.0
600.	85.0	86.2	86.1	86.0	86.0	86.0
800.	86.9	88.1	88.1	88.0	88.0	88.0
1000.	88.9	90.1	90.1	90.0	90.0	90.0
1200.	90.9	92.1	92.1	92.0	92.0	92.0
1400.	92.9	94.1	94.1	94.0	94.0	94.0
1600.	94.9	96.1	96.1	96.0	96.0	96.0
1800.	96.9	98.1	98.1	98.0	98.0	98.0
2000.	98.9	100.1	100.1	100.0	100.0	100.0
2200.	100.9	102.1	102.1	102.0	102.0	102.0
2400.	102.9	104.1	104.1	104.0	104.0	104.0
2600.	104.9	106.1	106.1	106.0	106.0	106.0
2800.	106.9	108.1	108.1	108.0	108.0	108.0
3000.	108.9	110.1	110.1	110.0	110.0	110.0
3200.	110.9	112.1	112.1	112.0	112.0	112.0
3400.	112.9	114.1	114.1	114.0	114.0	114.0
3600.	114.9	116.1	116.1	116.0	116.0	116.0
3800.	116.9	118.1	118.1	118.0	118.0	118.0
4000.	118.9	120.1	120.1	120.0	120.0	120.0
4200.	120.9	122.1	122.1	122.0	122.0	122.0
4400.	122.9	124.1	124.1	124.0	124.0	124.0
4600.	124.9	126.1	126.1	126.0	126.0	126.0
4800.	126.9	128.1	128.1	128.0	128.0	128.0
5000.	128.9	130.1	130.1	130.0	130.0	130.0
5200.	130.9	132.1	132.1	132.0	132.0	132.0
5400.	132.9	134.1	134.1	134.0	134.0	134.0
5600.	134.9	136.1	136.1	136.0	136.0	136.0
5800.	136.9	138.1	138.1	138.0	138.0	138.0
6000.	138.9	140.1	140.1	140.0	140.0	140.0
6200.	140.9	142.1	142.1	142.0	142.0	142.0
6400.	142.9	144.1	144.1	144.0	144.0	144.0
6600.	144.9	146.1	146.1	146.0	146.0	146.0
6800.	146.9	148.1	148.1	148.0	148.0	148.0
7000.	148.9	150.1	150.1	150.0	150.0	150.0
7200.	150.9	152.1	152.1	152.0	152.0	152.0
7400.	153.0	154.1	154.1	154.0	154.0	154.0
7600.	155.0	156.1	156.1	156.0	156.0	156.0
7800.	157.0	158.1	158.1	158.0	158.0	158.0
8000.	159.0	160.2	160.1	160.0	160.0	160.0
8200.	160.9	161.9	161.9	162.0	162.0	162.0
8400.	162.8	163.7	163.8	163.9	164.0	164.0
8600.	164.9	165.9	165.9	166.0	166.0	166.0
8800.	167.1	168.0	167.9	167.9	168.0	168.0
9000.	168.6	168.9	169.4	169.9	170.0	170.0
9200.	172.0	172.0	172.0	172.0	172.0	172.0
9400.	174.0	174.0	174.0	174.0	174.0	174.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	175.2	80.0	.876	0.000	0.000	25.1
200.	175.8	81.4	.877	0.000	0.000	25.1
400.	176.4	83.1	.877	0.000	0.000	25.1
600.	176.9	85.0	.877	0.000	0.000	25.1
800.	177.5	86.9	.877	0.000	0.000	25.1
1000.	178.1	88.9	.876	0.000	0.000	25.1
1200.	178.7	90.9	.876	0.000	0.000	25.2
1400.	179.3	92.9	.876	0.000	0.000	25.2
1600.	179.8	94.9	.875	0.000	0.000	25.2
1800.	180.4	96.9	.875	0.000	0.000	25.2
2000.	181.0	98.9	.875	0.000	0.000	25.2
2200.	181.6	100.9	.874	0.000	0.000	25.2
2400.	182.1	102.9	.874	0.000	0.000	25.2
2600.	182.7	104.9	.873	0.000	0.000	25.2
2800.	183.3	106.9	.873	0.000	0.000	25.2
3000.	183.9	108.9	.873	0.000	0.000	25.2
3200.	184.4	110.9	.872	0.000	0.000	25.3
3400.	185.0	112.9	.872	0.000	0.000	25.3
3600.	185.6	114.9	.872	0.000	0.000	25.3
3800.	186.1	116.9	.871	0.000	0.000	25.3
4000.	186.7	118.9	.871	0.000	0.000	25.3
4200.	187.3	120.9	.871	0.000	0.000	25.3
4400.	187.8	122.9	.870	0.000	0.000	25.3
4600.	188.4	124.9	.870	0.000	0.000	25.3
4800.	189.0	126.9	.869	0.000	0.000	25.3
5000.	189.5	128.9	.869	0.000	0.000	25.3
5200.	190.1	130.9	.869	0.000	0.000	25.4
5400.	190.7	132.9	.868	0.000	0.000	25.4
5600.	191.2	134.9	.868	0.000	0.000	25.4
5800.	191.8	136.9	.868	0.000	0.000	25.4
6000.	192.3	138.9	.867	0.000	0.000	25.4
6200.	192.9	140.9	.867	0.000	0.000	25.4
6400.	193.5	142.9	.866	0.000	0.000	25.4
6600.	194.0	144.9	.866	0.000	0.000	25.4
6800.	194.6	146.9	.866	0.000	0.000	25.5
7000.	195.1	148.9	.865	0.000	0.000	25.5
7200.	195.7	150.9	.865	0.000	0.000	25.5
7400.	196.2	153.0	.864	0.000	0.000	25.5
7600.	196.8	155.0	.864	0.000	0.000	25.5
7800.	197.3	157.0	.864	0.000	0.000	25.5
8000.	197.9	159.0	.863	0.000	0.000	25.5
8200.	198.4	160.9	.863	0.000	0.000	25.5
8400.	199.0	162.8	.863	0.000	0.000	25.5
8600.	186.7	164.9	.807	0.000	0.000	84.9
8800.	174.2	167.1	.750	0.000	0.000	91.3
9000.	160.5	168.6	.689	0.000	0.000	99.3

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	42.0	80.7	.209	0.000	0.000	.257	39.7	17.0
200.	43.2	82.4	.215	0.000	0.000	.250	40.9	18.5
400.	44.5	84.2	.220	0.000	0.000	.261	39.8	17.7
600.	45.8	86.2	.226	0.000	0.000	.272	38.8	17.0
800.	47.1	88.1	.232	0.000	0.000	.283	37.9	16.4
1000.	48.4	90.1	.237	0.000	0.000	.294	37.0	15.7
1200.	49.7	92.1	.243	0.000	0.000	.306	36.2	15.1
1400.	51.0	94.1	.248	0.000	0.000	.318	35.4	14.6
1600.	52.3	96.1	.254	0.000	0.000	.331	34.6	14.0
1800.	53.7	98.1	.259	0.000	0.000	.343	33.8	13.5
2000.	55.0	100.1	.265	0.000	0.000	.357	33.1	13.0
2200.	56.4	102.1	.271	0.000	0.000	.370	32.4	12.5
2400.	57.8	104.1	.277	0.000	0.000	.385	31.8	12.0
2600.	59.2	106.1	.282	0.000	0.000	.399	31.1	11.6
2800.	60.7	108.1	.288	0.000	0.000	.415	30.5	11.2
3000.	62.2	110.1	.294	0.000	0.000	.431	29.8	10.7
3200.	63.7	112.1	.300	0.000	0.000	.449	29.2	10.3
3400.	65.2	114.1	.307	0.000	0.000	.467	28.6	9.9
3600.	66.8	116.1	.313	0.000	0.000	.486	28.1	9.5
3800.	68.4	118.1	.319	0.000	0.000	.506	27.5	9.2
4000.	70.1	120.1	.326	0.000	0.000	.528	26.9	8.8
4200.	71.8	122.1	.333	0.000	0.000	.550	26.4	8.4
4400.	73.6	124.1	.340	0.000	0.000	.575	25.8	8.1
4600.	75.4	126.1	.347	0.000	0.000	.601	25.3	7.7
4800.	77.3	128.1	.355	0.000	0.000	.630	24.8	7.4
5000.	79.3	130.1	.362	0.000	0.000	.659	24.2	7.0
5200.	81.3	132.1	.370	0.000	0.000	.694	23.7	6.7
5400.	83.4	134.1	.379	0.000	0.000	.728	23.2	6.4
5600.	85.6	136.1	.387	0.000	0.000	.770	22.7	6.0
5800.	87.9	138.1	.397	0.000	0.000	.812	22.1	5.7
6000.	90.3	140.1	.406	0.000	0.000	.864	21.6	5.4
6200.	92.9	142.1	.416	0.000	0.000	.916	21.1	5.1
6400.	95.5	144.1	.427	0.000	0.000	.983	20.6	4.7
6600.	98.4	146.1	.438	0.000	0.000	1.049	20.0	4.4
6800.	101.4	148.1	.450	0.000	0.000	1.141	19.5	4.1
7000.	104.7	150.1	.463	0.000	0.000	1.230	19.0	3.8
7200.	108.2	152.1	.477	0.000	0.000	1.365	18.4	3.4
7400.	112.1	154.1	.492	0.000	0.000	1.493	17.8	3.1
7600.	116.3	156.1	.509	0.000	0.000	1.714	17.2	2.7
7800.	121.2	158.1	.529	0.000	0.000	1.926	16.6	2.4
8000.	126.6	160.2	.551	0.000	0.000	2.377	15.9	1.9
8200.	133.2	161.9	.578	0.000	0.000	2.823	15.2	1.6
8400.	139.3	163.7	.603	0.000	0.000	4.980	14.6	.9
8600.	149.9	165.9	.646	0.000	0.000	1.586	16.6	3.7
8800.	155.1	168.0	.666	0.000	0.000	1.728	16.1	3.4
9000.	160.6	168.9	.689	0.000	0.000	1.908	15.5	3.1

TIME = 10.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 9000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET					
	.1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.1	82.1	82.1	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.8	92.0	92.0	92.0	92.0
1400.	93.6	93.8	94.0	94.0	94.0	94.0
1600.	95.6	95.8	96.0	96.0	96.0	96.0
1800.	97.6	97.8	98.0	98.0	98.0	98.0
2000.	99.6	99.8	100.0	100.0	100.0	100.0
2200.	101.6	101.8	102.0	102.0	102.0	102.0
2400.	103.6	103.8	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.6	107.8	108.0	108.0	108.0	108.0
3000.	109.6	109.8	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.6	113.8	114.0	114.0	114.0	114.0
3600.	115.6	115.8	116.0	116.0	116.0	116.0
3800.	117.6	117.9	118.0	118.0	118.0	118.0
4000.	119.6	119.8	120.0	120.0	120.0	120.0
4200.	121.6	121.8	122.0	122.0	122.0	122.0
4400.	123.6	123.9	124.0	124.0	124.0	124.0
4600.	125.6	125.9	126.0	126.0	126.0	126.0
4800.	127.6	127.9	128.0	128.0	128.0	128.0
5000.	129.6	129.9	130.0	130.0	130.0	130.0
5200.	131.6	131.9	132.0	132.0	132.0	132.0
5400.	133.6	133.9	134.0	134.0	134.0	134.0
5600.	135.6	135.9	136.0	136.0	136.0	136.0
5800.	137.6	137.9	138.0	138.0	138.0	138.0
6000.	139.6	139.9	140.0	140.0	140.0	140.0
6200.	141.6	141.9	142.0	142.0	142.0	142.0
6400.	143.6	143.9	144.0	144.0	144.0	144.0
6600.	145.6	145.9	146.0	146.0	146.0	146.0
6800.	147.6	147.9	148.0	148.0	148.0	148.0
7000.	149.6	149.9	150.0	150.0	150.0	150.0
7200.	151.6	151.9	152.0	152.0	152.0	152.0
7400.	153.6	153.9	154.0	154.0	154.0	154.0
7600.	155.6	155.8	156.0	156.0	156.0	156.0
7800.	157.6	157.8	158.0	158.0	158.0	158.0
8000.	159.6	159.9	160.0	160.0	160.0	160.0
8200.	161.5	161.8	162.0	162.0	162.0	162.0
8400.	163.4	163.7	163.9	164.0	164.0	164.0
8600.	165.5	165.8	166.0	166.0	166.0	166.0
8800.	167.6	167.8	168.0	168.0	168.0	168.0
9000.	169.2	169.6	169.9	170.0	170.0	170.0
9200.	172.0	172.0	172.0	172.0	172.0	172.0
9400.	174.0	174.0	174.0	174.0	174.0	174.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R C P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.0	105.6	.077	0.000	0.000	0.0
2800.	16.1	107.6	.077	0.000	0.000	0.0
3000.	16.3	109.6	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.6	.078	0.000	0.000	0.0
3600.	16.6	115.6	.078	0.000	0.000	0.0
3800.	16.7	117.6	.078	0.000	0.000	0.0
4000.	16.8	119.6	.078	0.000	0.000	0.0
4200.	16.9	121.6	.078	0.000	0.000	0.0
4400.	17.0	123.6	.079	0.000	0.000	0.0
4600.	17.1	125.6	.079	0.000	0.000	0.0
4800.	17.2	127.6	.079	0.000	0.000	0.0
5000.	17.3	129.6	.079	0.000	0.000	0.0
5200.	17.5	131.6	.080	0.000	0.000	0.0
5400.	17.6	133.6	.080	0.000	0.000	0.0
5600.	17.7	135.6	.080	0.000	0.000	0.0
5800.	17.8	137.6	.080	0.000	0.000	0.0
6000.	17.9	139.6	.081	0.000	0.000	0.0
6200.	18.0	141.6	.081	0.000	0.000	0.0
6400.	18.1	143.6	.081	0.000	0.000	0.0
6600.	18.2	145.6	.081	0.000	0.000	0.0
6800.	18.4	147.6	.082	0.000	0.000	0.0
7000.	18.5	149.6	.082	0.000	0.000	0.0
7200.	18.6	151.6	.082	0.000	0.000	0.0
7400.	18.7	153.6	.082	0.000	0.000	0.0
7600.	18.8	155.6	.083	0.000	0.000	0.0
7800.	18.9	157.6	.083	0.000	0.000	0.0
8000.	19.0	159.6	.083	0.000	0.000	0.0
8200.	19.2	161.5	.083	0.000	0.000	0.0
8400.	19.3	163.4	.083	0.000	0.000	0.0
8600.	19.4	165.5	.084	0.000	0.000	0.0
8800.	19.5	167.6	.084	0.000	0.000	0.0
9000.	19.6	169.2	.084	0.000	0.000	0.0

ANNULUS

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.8	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.8	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.8	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.8	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.8	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.8	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.8	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.8	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.8	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.8	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.8	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.9	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.8	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.8	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.9	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.9	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.9	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.9	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.9	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.9	.080	0.000	0.000	0.000	0.0	0.0
5600.	17.7	135.9	.080	0.000	0.000	0.000	0.0	0.0
5800.	17.8	137.9	.080	0.000	0.000	0.000	0.0	0.0
6000.	17.9	139.9	.081	0.000	0.000	0.000	0.0	0.0
6200.	18.0	141.9	.081	0.000	0.000	0.000	0.0	0.0
6400.	18.1	143.9	.081	0.000	0.000	0.000	0.0	0.0
6600.	18.2	145.9	.081	0.000	0.000	0.000	0.0	0.0
6800.	18.4	147.9	.082	0.000	0.000	0.000	0.0	0.0
7000.	18.5	149.9	.082	0.000	0.000	0.000	0.0	0.0
7200.	18.6	151.9	.082	0.000	0.000	0.000	0.0	0.0
7400.	18.7	153.9	.082	0.000	0.000	0.000	0.0	0.0
7600.	18.8	155.8	.082	0.000	0.000	0.000	0.0	0.0
7800.	18.9	157.8	.083	0.000	0.000	0.000	0.0	0.0
8000.	19.0	159.9	.083	0.000	0.000	0.000	0.0	0.0
8200.	19.2	161.8	.083	0.000	0.000	0.000	0.0	0.0
8400.	19.3	163.7	.083	0.000	0.000	0.000	0.0	0.0
8600.	19.4	165.8	.084	0.000	0.000	0.000	0.0	0.0
8800.	19.5	167.8	.084	0.000	0.000	0.000	0.0	0.0
9000.	19.6	169.6	.084	0.000	0.000	0.000	0.0	0.0

TABLE 4.16 Input Data for Sample Problem 8

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SAMPLE PROBLEM 8:  MIST DRILLING
'TUBING',1
1,4.408,5.,9000.,0.
'CASING',1
1,8.921,9.625,100.,100.
'WELLBORE',0.,9000.,9000.,0.,20.
'TEMP',80.,170.,105.,2500.
'FLUIDS',2
1,8.330,1.,0.
2,9.25,10.,3.
'INITIAL',2,2
'CHANGE',7,0,1,80.,1028.,2.
'GAS',40.
'DRILL',1,10.,1800.
'BHA',600.,6.,2.5,8.75,.75,.75,.75
'CHANGE',7,0,1,80.,1230.,4.
'GAS',55.
'DRILL',0,10.,3600.
'CHANGE',8,0,1,80.,2000.,6.
'GAS',115.
'MIST',1.4
'DRILL',0,10.,5400.
'CHANGE',8,0,1,80.,2200.,8.
'GAS',120.
'MIST',1.4
'DRILL',0,10.,7200.
'CHANGE',8,0,1,80.,2400.,10.
'GAS',140.
'MIST',1.4
'DRILL',0,10.,9000.
```

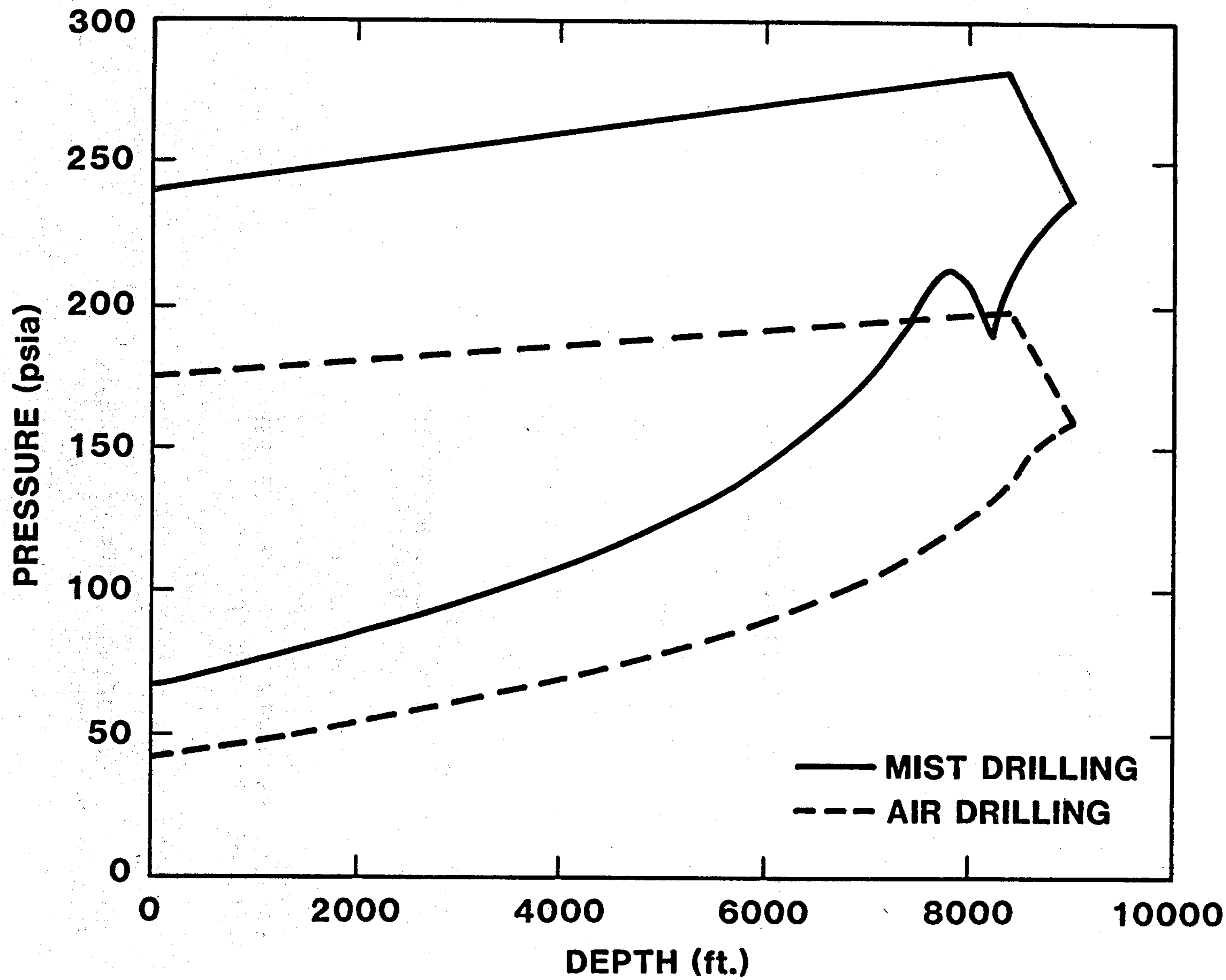

Figure 11. Downhole pressures in the tuing and annulus to 9000 ft for air and mist drilling.

Table 4.17 Output Data for Sample Problem 8.

SAMPLE PROBLEM #8: MIST DRILLING

T U B I N G C O N F I G U R A T I O N

TUBING	ID,IN.	OD,IN.	TOP,FT.	BASE,FT.	CEMENT,FT.
1	4.408	5.000	0.	9000.	0.0

C A S I N G P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	8.921	9.625	100.	100.

W E L L G E O M E T R Y

TOTAL DEPTH= 9000. FT.
BORE DIAMETER= 20.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E F L U I D P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 8.3 LBM/GAL
PLASTIC VISCOSITY= 1. CENTIPOISE
YIELD POINT= 0. LBF/100FT2

FLUID TYPE NO. 2

DENSITY= 9.3 LBM/GAL
PLASTIC VISCOSITY= 10. CENTIPOISE
YIELD POINT= 3. LBF/100FT2

W E L L B O R E I N I T I A L S T A T E

FLUID # 2 IN TUBING & TUBING ANNULUS
FLUID # 2 IN CASING - CASING ANNULI

```
S E T   V A R I A B L E S   AT TIME =      0.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   AIR INJECTED INTO TUBING
        INLET TEMPERATURE=   80. F
        FLOW RATE = 1028. SCF/MIN
        TIME TO CHANGE DATA =      2.000 DAYS
        DEPTH TO CHANGE DATA = 1800. FT
        CIRCULATION TIME PER DAY =  10.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,   I.D.= 2.500 IN,   O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER=  8.750 IN, NOZZLE SIZES=   .750   .750   .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    52.1 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    64.3 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    75.4 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    83.4 PSI



TIME =      1.417 DAYS                              ITERATIONS =  3
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =1028. SCF/MIN    CIRCULATION DEPTH = 1800. FT

              T E M P E R A T U R E   D I S T R I B U T I O N
```

RADIAL POSITIONS, FEET

DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.1	82.1	82.0	82.0
400.	83.2	84.1	84.0	84.0	84.0	84.0
600.	85.1	86.2	86.0	86.0	86.0	86.0
800.	87.2	88.3	88.1	88.0	88.0	88.0
1000.	89.2	90.0	90.0	90.0	90.0	90.0
1200.	91.1	91.7	91.8	92.0	92.0	92.0
1400.	93.2	94.0	94.0	94.0	94.0	94.0
1600.	95.4	96.2	96.0	96.0	96.0	96.0
1800.	96.9	97.2	97.6	98.0	98.0	98.0
2000.	100.0	100.0	100.0	100.0	100.0	100.0
2200.	102.0	102.0	102.0	102.0	102.0	102.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	83.4	80.0	.417	0.000	0.000	29.6
200.	83.5	81.4	.417	0.000	0.000	29.6
400.	83.7	83.2	.416	0.000	0.000	29.7
600.	83.8	85.1	.415	0.000	0.000	29.7
800.	84.0	87.2	.414	0.000	0.000	29.8
1000.	84.1	89.2	.414	0.000	0.000	29.8
1200.	84.3	91.1	.413	0.000	0.000	29.9
1400.	75.6	93.2	.369	0.000	0.000	103.9
1600.	66.3	95.4	.323	0.000	0.000	119.0
1800.	55.2	96.9	.267	0.000	0.000	143.5

ANNULUS

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	29.8	80.6	.149	0.000	0.000	.821	32.2	5.3
200.	31.7	82.3	.158	0.000	0.000	.800	31.9	5.8
400.	33.6	84.1	.166	0.000	0.000	.956	30.2	4.8
600.	35.7	86.2	.176	0.000	0.000	1.208	28.5	3.8
800.	38.3	88.3	.188	0.000	0.000	1.608	26.7	2.9
1000.	41.1	90.0	.201	0.000	0.000	2.964	25.0	1.6
1200.	43.0	91.7	.210	0.000	0.000	7.250	24.0	.6
1400.	48.4	94.0	.235	0.000	0.000	1.385	25.6	4.3
1600.	51.5	96.2	.250	0.000	0.000	1.738	24.1	3.4
1800.	55.2	97.2	.267	0.000	0.000	2.354	22.5	2.5

TIME = 2.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 1800. FT

TEMPERATURE DISTRIBUTION

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.0	82.0	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.7	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.8	90.0	90.0	90.0	90.0
1200.	91.5	91.8	92.0	92.0	92.0	92.0
1400.	93.7	93.9	94.0	94.0	94.0	94.0
1600.	95.8	95.9	96.0	96.0	96.0	96.0
1800.	97.3	97.7	98.0	98.0	98.0	98.0
2000.	100.0	100.0	100.0	100.0	100.0	100.0
2200.	102.0	102.0	102.0	102.0	102.0	102.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.7	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.5	.075	0.000	0.000	0.0
1400.	15.4	93.7	.075	0.000	0.000	0.0
1600.	15.5	95.8	.075	0.000	0.000	0.0
1800.	15.6	97.3	.076	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.8	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.8	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.7	.076	0.000	0.000	0.000	0.0	0.0

1

S E T V A R I A B L E S AT TIME = 2.000 DAYS

FLOWING OPTION = FORWARD CIRCULATION
AIR INJECTED INTO TUBING
INLET TEMPERATURE= 80. F
FLOW RATE = 1230. SCF/MIN
TIME TO CHANGE DATA = 4.000 DAYS
DEPTH TO CHANGE DATA = 3600. FT
CIRCULATION TIME PER DAY = 10.0 HRS

BOTTOM HOLE ASSEMBLY:
DRILL COLLARS:
LENGTH= 600. FT, I.D.= 2.500 IN, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES= .750 .750 .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 65.4 PSI

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 93.9 PSI

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 99.0 PSI

TIME = 3.417 DAYS ITERATIONS = 3

CONDITIONS SINCE LAST TIME STEP:

FLOW RATE =1230. SCF/MIN CIRCULATION DEPTH = 3600. FT

T E M P E R A T U R E D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.0	80.6	80.0	80.0	80.0	80.0
200.	81.4	82.3	82.2	82.1	82.0	82.0
400.	83.1	84.2	84.1	84.0	84.0	84.0
600.	85.0	86.1	86.1	86.0	86.0	86.0
800.	87.0	88.1	88.1	88.0	88.0	88.0
1000.	89.0	90.1	90.1	90.0	90.0	90.0
1200.	91.0	92.1	92.1	92.0	92.0	92.0
1400.	93.0	94.1	94.1	94.0	94.0	94.0
1600.	95.0	96.1	96.1	96.0	96.0	96.0
1800.	97.0	98.1	98.1	98.0	98.0	98.0
2000.	99.0	100.1	100.1	100.0	100.0	100.0
2200.	101.0	102.1	102.0	102.0	102.0	102.0
2400.	103.0	104.1	104.0	104.0	104.0	104.0
2600.	105.0	106.1	106.1	106.0	106.0	106.0
2800.	107.0	108.0	108.0	108.0	108.0	108.0
3000.	109.0	109.8	109.9	110.0	110.0	110.0
3200.	111.1	112.0	112.0	112.0	112.0	112.0
3400.	113.3	114.1	114.0	114.0	114.0	114.0
3600.	114.8	115.2	115.6	116.0	116.0	116.0
3800.	118.0	118.0	118.0	118.0	118.0	118.0
4000.	120.0	120.0	120.0	120.0	120.0	120.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	99.0	80.0	.495	0.000	0.000	29.8
200.	99.1	81.4	.495	0.000	0.000	29.9
400.	99.3	83.1	.494	0.000	0.000	29.9
600.	99.5	85.0	.493	0.000	0.000	30.0
800.	99.6	87.0	.492	0.000	0.000	30.0
1000.	99.8	89.0	.491	0.000	0.000	30.1
1200.	100.0	91.0	.490	0.000	0.000	30.1
1400.	100.1	93.0	.489	0.000	0.000	30.2
1600.	100.3	95.0	.488	0.000	0.000	30.3
1800.	100.4	97.0	.487	0.000	0.000	30.3
2000.	100.6	99.0	.486	0.000	0.000	30.4
2200.	100.7	101.0	.485	0.000	0.000	30.5
2400.	100.9	103.0	.484	0.000	0.000	30.5
2600.	101.0	105.0	.483	0.000	0.000	30.6
2800.	101.2	107.0	.482	0.000	0.000	30.6
3000.	101.3	109.0	.481	0.000	0.000	30.7
3200.	90.7	111.1	.429	0.000	0.000	107.1
3400.	79.2	113.3	.373	0.000	0.000	123.1
3600.	65.3	114.8	.307	0.000	0.000	149.6

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	27.6	80.6	.137	0.000	0.000	.368	39.9	11.9
200.	28.8	82.3	.143	0.000	0.000	.357	40.4	13.0
400.	30.1	84.2	.149	0.000	0.000	.389	38.8	11.9
600.	31.5	86.1	.155	0.000	0.000	.425	37.2	10.9
800.	32.8	88.1	.161	0.000	0.000	.463	35.8	10.0
1000.	34.2	90.1	.168	0.000	0.000	.507	34.5	9.1
1200.	35.7	92.1	.174	0.000	0.000	.556	33.2	8.3
1400.	37.2	94.1	.181	0.000	0.000	.614	31.9	7.5
1600.	38.9	96.1	.188	0.000	0.000	.680	30.7	6.8
1800.	40.6	98.1	.196	0.000	0.000	.764	29.5	6.1
2000.	42.5	100.1	.204	0.000	0.000	.862	28.3	5.4
2200.	44.5	102.1	.213	0.000	0.000	1.000	27.1	4.6
2400.	46.8	104.1	.224	0.000	0.000	1.171	25.9	4.0
2600.	49.4	106.1	.235	0.000	0.000	1.464	24.6	3.2
2800.	52.6	108.0	.249	0.000	0.000	1.881	23.2	2.5
3000.	56.0	109.8	.265	0.000	0.000	3.361	21.8	1.4
3200.	60.0	112.0	.283	0.000	0.000	1.015	25.3	5.8
3400.	62.6	114.1	.294	0.000	0.000	1.132	24.3	5.2
3600.	65.3	115.2	.307	0.000	0.000	1.281	23.3	4.6

TIME = 4.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 3600. FT

T E M P E R A T U R E D I S T R I B U T I O N

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.0	82.0	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.9	92.0	92.0	92.0	92.0
1400.	93.6	93.9	94.0	94.0	94.0	94.0
1600.	95.6	95.9	96.0	96.0	96.0	96.0
1800.	97.6	97.9	98.0	98.0	98.0	98.0
2000.	99.6	99.9	100.0	100.0	100.0	100.0
2200.	101.6	101.9	102.0	102.0	102.0	102.0
2400.	103.6	103.8	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.5	107.8	108.0	108.0	108.0	108.0
3000.	109.5	109.8	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.7	113.9	114.0	114.0	114.0	114.0
3600.	115.3	115.7	116.0	116.0	116.0	116.0
3800.	118.0	118.0	118.0	118.0	118.0	118.0
4000.	120.0	120.0	120.0	120.0	120.0	120.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.1	105.6	.077	0.000	0.000	0.0
2800.	16.2	107.5	.077	0.000	0.000	0.0
3000.	16.3	109.5	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.7	.078	0.000	0.000	0.0
3600.	16.6	115.3	.078	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.9	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.9	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.9	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.9	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.8	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.8	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.8	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.9	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.7	.078	0.000	0.000	0.000	0.0	0.0

```
S E T    V A R I A B L E S    AT TIME =      4.000 DAYS
         FLOWING OPTION = FORWARD CIRCULATION
                    AIR INJECTED INTO TUBING
         MIST DRILLING: WATER ADDED AT    1.4 GAL/MIN
         INLET TEMPERATURE=    80. F
         FLOW RATE = 2000. SCF/MIN
         TIME TO CHANGE DATA =      6.000 DAYS
         DEPTH TO CHANGE DATA = 5400. FT
         CIRCULATION TIME PER DAY =  10.0 HRS

         BOTTOM HOLE ASSEMBLY:
           DRILL COLLARS:
             LENGTH= 600. FT,    I.D.= 2.500 IN,    O.D.= 6.000 IN
           DRILL BIT:
             DIAMETER=  8.750 IN, NOZZLE SIZES=    .750    .750    .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    142.6 PSI


CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    172.4 PSI


GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2100. SCF


TIME =      5.417 DAYS                              ITERATIONS =   3
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =2100. SCF/MIN     CIRCULATION DEPTH = 5400. FT
```

TEMPERATURE DISTRIBUTION

DEPTH, FT	RADIAL POSITIONS, FEET .1	.3	.8	1.5	2.7	50.0
0.	80.0	80.7	80.0	80.0	80.0	80.0
200.	81.4	82.4	82.2	82.1	82.0	82.0
400.	83.1	84.3	84.1	84.0	84.0	84.0
600.	84.9	86.2	86.1	86.0	86.0	86.0
800.	86.9	88.1	88.1	88.0	88.0	88.0
1000.	88.9	90.1	90.1	90.0	90.0	90.0
1200.	90.8	92.1	92.1	92.0	92.0	92.0
1400.	92.8	94.1	94.1	94.0	94.0	94.0
1600.	94.8	96.1	96.1	96.0	96.0	96.0
1800.	96.8	98.1	98.1	98.0	98.0	98.0
2000.	98.8	100.1	100.1	100.0	100.0	100.0
2200.	100.8	102.1	102.1	102.0	102.0	102.0
2400.	102.8	104.1	104.1	104.0	104.0	104.0
2600.	104.8	106.1	106.1	106.0	106.0	106.0
2800.	106.8	108.1	108.1	108.0	108.0	108.0
3000.	108.8	110.1	110.1	110.0	110.0	110.0
3200.	110.8	112.1	112.1	112.0	112.0	112.0
3400.	112.8	114.1	114.1	114.0	114.0	114.0
3600.	114.8	116.1	116.1	116.0	116.0	116.0
3800.	116.8	118.1	118.0	118.0	118.0	118.0
4000.	118.8	120.1	120.0	120.0	120.0	120.0
4200.	120.8	122.1	122.0	122.0	122.0	122.0
4400.	122.8	124.0	124.0	124.0	124.0	124.0
4600.	124.6	125.7	125.8	125.9	126.0	126.0
4800.	126.6	127.7	127.8	127.9	128.0	128.0
5000.	128.8	129.8	129.9	130.0	130.0	130.0
5200.	130.9	131.8	131.9	131.9	132.0	132.0
5400.	132.6	133.1	133.6	133.9	134.0	134.0
5600.	136.0	136.0	136.0	136.0	136.0	136.0
5800.	138.0	138.0	138.0	138.0	138.0	138.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	DENSITY-LBM/CF WATER	DENSITY-LBM/CF VAPOR	VELOCITY FT/SEC
0.	172.4	80.0	.862	.061	.002	29.2
200.	172.8	81.4	.862	.061	.002	29.2
400.	173.3	83.1	.862	.061	.002	29.3
600.	173.7	84.9	.861	.061	.002	29.3
800.	174.2	86.9	.860	.061	.002	29.3
1000.	174.6	88.9	.859	.061	.002	29.4
1200.	175.0	90.8	.858	.060	.002	29.4
1400.	175.4	92.8	.857	.060	.002	29.4
1600.	175.9	94.8	.856	.060	.002	29.5
1800.	176.3	96.8	.855	.060	.003	29.5
2000.	176.7	98.8	.854	.059	.003	29.5
2200.	177.1	100.8	.853	.059	.003	29.6
2400.	177.6	102.8	.852	.059	.003	29.6
2600.	178.0	104.8	.851	.059	.003	29.6
2800.	178.4	106.8	.850	.058	.003	29.7
3000.	178.8	108.8	.849	.058	.004	29.7
3200.	179.2	110.8	.848	.058	.004	29.7
3400.	179.6	112.8	.847	.058	.004	29.8
3600.	180.0	114.8	.846	.057	.004	29.8
3800.	180.4	116.8	.844	.057	.005	29.9
4000.	180.8	118.8	.843	.057	.005	29.9
4200.	181.2	120.8	.842	.056	.005	29.9
4400.	181.6	122.8	.841	.056	.005	30.0
4600.	181.9	124.6	.840	.056	.006	30.0
4800.	182.3	126.6	.839	.055	.006	30.0
5000.	165.0	128.8	.757	.012	.006	103.6
5200.	146.5	130.9	.670	.009	.007	117.1
5400.	124.8	132.6	.569	.007	.007	137.8

ANNULUS

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	54.4	80.7	.271	.053	.002	.445	33.7	9.8
200.	56.2	82.4	.279	.051	.002	.352	34.6	13.2
400.	57.8	84.3	.287	.053	.002	.370	33.7	12.5
600.	59.5	86.2	.294	.054	.002	.386	32.8	12.0
800.	61.3	88.1	.301	.055	.002	.407	32.0	11.4
1000.	63.1	90.1	.309	.057	.002	.424	31.2	10.9
1200.	64.9	92.1	.317	.058	.002	.449	30.5	10.3
1400.	66.8	94.1	.325	.059	.002	.467	29.7	9.9
1600.	68.7	96.1	.333	.061	.003	.497	29.0	9.3
1800.	70.7	98.1	.342	.062	.003	.516	28.2	9.0
2000.	72.8	100.1	.350	.064	.003	.554	27.5	8.4
2200.	74.9	102.1	.359	.065	.003	.573	26.8	8.1
2400.	77.2	104.1	.369	.067	.003	.622	26.2	7.5
2600.	79.5	106.1	.379	.069	.003	.641	25.5	7.2
2800.	81.9	108.1	.389	.070	.004	.706	24.8	6.6
3000.	84.5	110.1	.400	.072	.004	.723	24.1	6.4
3200.	87.2	112.1	.411	.074	.004	.814	23.5	5.7
3400.	90.0	114.1	.423	.076	.004	.824	22.8	5.6
3600.	93.0	116.1	.435	.078	.004	.961	22.2	4.8
3800.	96.3	118.1	.449	.081	.005	.953	21.5	4.9
4000.	99.6	120.1	.463	.083	.005	1.183	20.8	3.9
4200.	103.5	122.1	.479	.086	.005	1.123	20.1	4.1
4400.	107.1	124.0	.494	.089	.005	1.700	19.5	2.7
4600.	108.8	125.7	.501	.090	.006	3.900	19.3	1.2
4800.	114.6	127.7	.526	.094	.006	1.165	18.4	4.0
5000.	118.7	129.8	.542	.076	.006	.903	22.4	6.5
5200.	122.1	131.8	.556	.077	.007	.771	21.8	7.6
5400.	124.9	133.1	.569	.006	.007	.771	21.4	7.6

TIME = 6.000 DAYS ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 5400. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.8	82.0	82.1	82.1	82.0	82.0
400.	83.7	83.9	84.0	84.0	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.5	89.8	90.0	90.0	90.0	90.0
1200.	91.5	91.8	92.0	92.0	92.0	92.0
1400.	93.5	93.8	94.0	94.0	94.0	94.0
1600.	95.5	95.8	96.0	96.0	96.0	96.0
1800.	97.5	97.8	98.0	98.0	98.0	98.0
2000.	99.5	99.8	100.0	100.0	100.0	100.0
2200.	101.5	101.8	102.0	102.0	102.0	102.0
2400.	103.5	103.8	104.0	104.0	104.0	104.0
2600.	105.5	105.8	106.0	106.0	106.0	106.0
2800.	107.5	107.8	108.0	108.0	108.0	108.0
3000.	109.5	109.8	110.0	110.0	110.0	110.0
3200.	111.5	111.8	112.0	112.0	112.0	112.0
3400.	113.5	113.8	114.0	114.0	114.0	114.0
3600.	115.5	115.8	116.0	116.0	116.0	116.0
3800.	117.5	117.8	118.0	118.0	118.0	118.0
4000.	119.5	119.8	120.0	120.0	120.0	120.0
4200.	121.5	121.8	122.0	122.0	122.0	122.0
4400.	123.5	123.8	124.0	124.0	124.0	124.0
4600.	125.4	125.7	126.0	126.0	126.0	126.0
4800.	127.4	127.7	128.0	128.0	128.0	128.0
5000.	129.5	129.8	130.0	130.0	130.0	130.0
5200.	131.5	131.8	132.0	132.0	132.0	132.0
5400.	133.2	133.6	134.0	134.0	134.0	134.0
5600.	136.0	136.0	136.0	136.0	136.0	136.0
5800.	138.0	138.0	138.0	138.0	138.0	138.0

G A S & M I S T D R I L L I N G
F L O W I N G S T R E A M P R O P E R T I E S

T U B I N G

DEPTH	PRESSURE	TEMP	DENSITY-LBM/CF			VELOCITY
FT	PSIA	F	GAS	WATER	VAPOR	FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.8	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.5	.075	0.000	0.000	0.0
1200.	15.3	91.5	.075	0.000	0.000	0.0
1400.	15.4	93.5	.075	0.000	0.000	0.0
1600.	15.5	95.5	.075	0.000	0.000	0.0
1800.	15.6	97.5	.076	0.000	0.000	0.0
2000.	15.7	99.5	.076	0.000	0.000	0.0
2200.	15.8	101.5	.076	0.000	0.000	0.0
2400.	15.9	103.5	.076	0.000	0.000	0.0
2600.	16.0	105.5	.077	0.000	0.000	0.0
2800.	16.2	107.5	.077	0.000	0.000	0.0
3000.	16.3	109.5	.077	0.000	0.000	0.0
3200.	16.4	111.5	.077	0.000	0.000	0.0
3400.	16.5	113.5	.078	0.000	0.000	0.0
3600.	16.6	115.5	.078	0.000	0.000	0.0
3800.	16.7	117.5	.078	0.000	0.000	0.0
4000.	16.8	119.5	.078	0.000	0.000	0.0
4200.	16.9	121.5	.079	0.000	0.000	0.0
4400.	17.0	123.5	.079	0.000	0.000	0.0
4600.	17.1	125.4	.079	0.000	0.000	0.0
4800.	17.2	127.4	.079	0.000	0.000	0.0
5000.	17.4	129.5	.079	0.000	0.000	0.0
5200.	17.5	131.5	.080	0.000	0.000	0.0
5400.	17.6	133.2	.080	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.0	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.8	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.8	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.8	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.8	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.8	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.8	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.8	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.8	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.8	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.8	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.8	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.8	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.8	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.8	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.8	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.8	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.8	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.8	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.7	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.7	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.8	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.8	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.6	.080	0.000	0.000	0.000	0.0	0.0

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S E T   V A R I A B L E S   AT TIME =      6.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   AIR INJECTED INTO TUBING
        MIST DRILLING: WATER ADDED AT   1.4 GAL/MIN
        INLET TEMPERATURE=    80. F
        FLOW RATE = 2200. SCF/MIN
        TIME TO CHANGE DATA =      8.000 DAYS
        DEPTH TO CHANGE DATA = 7200. FT
        CIRCULATION TIME PER DAY =  10.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,    I.D.= 2.500 IN,    O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER=  8.750 IN, NOZZLE SIZES=    .750    .750    .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO    220.0 PSI


GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2310. SCF

GAS FLOW RATE TOO LOW- INCREASED TO:    2426. SCF
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TIME = 7.417 DAYS ITERATIONS = 13

CONDITIONS SINCE LAST TIME STEP:

FLOW RATE =2426. SCF/MIN CIRCULATION DEPTH = 7200. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.8	80.0	80.0	80.0	80.0
200.	81.4	82.5	82.3	82.1	82.1	82.0
400.	83.1	84.3	84.2	84.1	84.0	84.0
600.	85.0	86.2	86.1	86.1	86.0	86.0
800.	86.9	88.2	88.1	88.1	88.0	88.0
1000.	88.8	90.2	90.1	90.0	90.0	90.0
1200.	90.8	92.2	92.1	92.0	92.0	92.0
1400.	92.8	94.2	94.1	94.0	94.0	94.0
1600.	94.8	96.2	96.1	96.0	96.0	96.0
1800.	96.8	98.2	98.1	98.0	98.0	98.0
2000.	98.8	100.2	100.1	100.0	100.0	100.0
2200.	100.8	102.2	102.1	102.0	102.0	102.0
2400.	102.8	104.2	104.1	104.0	104.0	104.0
2600.	104.8	106.2	106.1	106.0	106.0	106.0
2800.	106.8	108.2	108.1	108.0	108.0	108.0
3000.	108.8	110.2	110.1	110.0	110.0	110.0
3200.	110.8	112.2	112.1	112.0	112.0	112.0
3400.	112.8	114.2	114.1	114.0	114.0	114.0
3600.	114.8	116.2	116.1	116.0	116.0	116.0
3800.	116.8	118.2	118.1	118.0	118.0	118.0
4000.	118.8	120.2	120.1	120.0	120.0	120.0
4200.	120.8	122.2	122.1	122.0	122.0	122.0
4400.	122.8	124.2	124.1	124.0	124.0	124.0
4600.	124.8	126.2	126.1	126.0	126.0	126.0
4800.	126.8	128.2	128.1	128.0	128.0	128.0
5000.	128.8	130.2	130.1	130.0	130.0	130.0
5200.	130.8	132.2	132.1	132.0	132.0	132.0
5400.	132.9	134.2	134.1	134.0	134.0	134.0
5600.	134.9	136.2	136.1	136.0	136.0	136.0
5800.	136.9	138.2	138.1	138.0	138.0	138.0
6000.	138.9	140.2	140.0	139.9	140.0	140.0
6200.	140.7	141.6	141.8	141.9	142.0	142.0
6400.	142.8	143.5	143.7	143.9	144.0	144.0
6600.	144.9	145.8	145.9	145.9	146.0	146.0
6800.	146.7	147.7	147.9	148.0	148.0	148.0
7000.	148.7	149.6	149.7	149.9	150.0	150.0
7200.	150.1	150.5	151.3	151.9	152.0	152.0
7400.	154.0	154.0	154.0	154.0	154.0	154.0
7600.	156.0	156.0	156.0	156.0	156.0	156.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	220.0	80.0	1.100	.068	.002	26.5
200.	220.7	81.4	1.101	.068	.002	26.4
400.	221.5	83.1	1.101	.068	.002	26.4
600.	222.2	85.0	1.101	.068	.002	26.4
800.	223.0	86.9	1.101	.068	.002	26.4
1000.	223.7	88.8	1.101	.067	.002	26.5
1200.	224.5	90.8	1.101	.067	.002	26.5
1400.	225.2	92.8	1.100	.067	.002	26.5
1600.	226.0	94.8	1.100	.067	.002	26.5
1800.	226.7	96.8	1.100	.067	.003	26.5
2000.	227.5	98.8	1.099	.067	.003	26.5
2200.	228.2	100.8	1.099	.066	.003	26.5
2400.	229.0	102.8	1.099	.066	.003	26.5
2600.	229.7	104.8	1.098	.066	.003	26.5
2800.	230.4	106.8	1.098	.066	.003	26.5
3000.	231.2	108.8	1.098	.066	.004	26.5
3200.	231.9	110.8	1.097	.065	.004	26.5
3400.	232.7	112.8	1.097	.065	.004	26.5
3600.	233.4	114.8	1.097	.065	.004	26.6
3800.	234.1	116.8	1.096	.065	.005	26.6
4000.	234.9	118.8	1.096	.064	.005	26.6
4200.	235.6	120.8	1.095	.064	.005	26.6
4400.	236.3	122.8	1.095	.064	.005	26.6
4600.	237.1	124.8	1.095	.063	.006	26.6
4800.	237.8	126.8	1.094	.063	.006	26.6
5000.	238.5	128.8	1.094	.063	.006	26.6
5200.	239.3	130.8	1.094	.062	.007	26.6
5400.	240.0	132.9	1.093	.062	.007	26.6
5600.	240.7	134.9	1.093	.062	.007	26.6
5800.	241.5	136.9	1.092	.061	.008	26.7
6000.	242.2	138.9	1.092	.061	.008	26.7
6200.	242.9	140.7	1.092	.061	.008	26.7
6400.	243.6	142.8	1.092	.060	.009	26.7
6600.	244.4	144.9	1.091	.060	.009	26.7
6800.	227.3	146.7	1.012	.011	.010	89.5
7000.	209.7	148.7	.930	.009	.010	97.3
7200.	190.2	150.1	.842	.007	.010	107.6

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	69.4	80.8	.346	.058	.002	.431	30.8	10.2
200.	71.3	82.5	.355	.056	.002	.360	31.7	12.9
400.	73.0	84.3	.362	.057	.002	.372	31.0	12.4
600.	74.8	86.2	.370	.059	.002	.387	30.4	12.0
800.	76.7	88.2	.377	.060	.002	.400	29.7	11.6
1000.	78.6	90.2	.385	.061	.002	.417	29.1	11.1
1200.	80.5	92.2	.393	.062	.002	.431	28.5	10.7
1400.	82.4	94.2	.401	.063	.002	.449	28.0	10.3
1600.	84.5	96.2	.410	.064	.003	.465	27.4	10.0
1800.	86.5	98.2	.418	.066	.003	.486	26.8	9.5
2000.	88.7	100.2	.427	.067	.003	.503	26.3	9.2
2200.	90.8	102.2	.436	.068	.003	.526	25.7	8.8
2400.	93.1	104.2	.445	.070	.003	.545	25.2	8.5
2600.	95.4	106.2	.455	.071	.003	.573	24.7	8.1
2800.	97.8	108.2	.465	.072	.004	.593	24.2	7.8
3000.	100.3	110.2	.475	.074	.004	.626	23.7	7.4
3200.	102.9	112.2	.485	.075	.004	.648	23.1	7.1
3400.	105.5	114.2	.496	.077	.004	.689	22.6	6.7
3600.	108.3	116.2	.507	.079	.004	.713	22.1	6.5
3800.	111.2	118.2	.519	.080	.005	.763	21.6	6.1
4000.	114.2	120.2	.531	.082	.005	.789	21.1	5.9
4200.	117.4	122.2	.544	.084	.005	.853	20.6	5.4
4400.	120.7	124.2	.558	.086	.005	.881	20.1	5.3
4600.	124.2	126.2	.572	.088	.006	.967	19.6	4.8
4800.	127.9	128.2	.587	.090	.006	.996	19.1	4.7
5000.	131.7	130.2	.602	.092	.006	1.117	18.6	4.2
5200.	135.9	132.2	.619	.095	.007	1.143	18.1	4.1
5400.	140.3	134.2	.637	.097	.007	1.325	17.6	3.5
5600.	145.2	136.2	.657	.100	.007	1.339	17.1	3.5
5800.	150.2	138.2	.678	.103	.008	1.646	16.6	2.8
6000.	156.2	140.2	.702	.107	.008	1.616	16.0	2.9
6200.	161.9	141.6	.726	.110	.008	2.331	15.5	2.0
6400.	164.2	143.5	.734	.111	.009	5.206	15.3	.9
6600.	173.7	145.8	.774	.117	.009	1.760	14.5	2.6
6800.	180.6	147.7	.802	.095	.010	1.254	17.5	4.7
7000.	185.9	149.6	.823	.097	.010	1.076	17.1	5.5
7200.	190.3	150.5	.842	.007	.010	1.081	16.7	5.4

TIME =   8.000 DAYS   ITERATIONS = 2
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =   0. SCF/MIN   CIRCULATION DEPTH = 7200. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.9	82.1	82.1	82.1	82.1	82.0
400.	83.7	83.9	84.1	84.1	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.5	91.8	92.0	92.0	92.0	92.0
1400.	93.5	93.9	94.0	94.0	94.0	94.0
1600.	95.5	95.8	96.0	96.0	96.0	96.0
1800.	97.5	97.8	98.0	98.0	98.0	98.0
2000.	99.5	99.8	100.0	100.0	100.0	100.0
2200.	101.5	101.8	102.0	102.0	102.0	102.0
2400.	103.5	103.8	104.0	104.0	104.0	104.0
2600.	105.5	105.8	106.0	106.0	106.0	106.0
2800.	107.5	107.8	108.0	108.0	108.0	108.0
3000.	109.5	109.8	110.0	110.0	110.0	110.0
3200.	111.5	111.8	112.0	112.0	112.0	112.0
3400.	113.5	113.8	114.0	114.0	114.0	114.0
3600.	115.5	115.8	116.0	116.0	116.0	116.0
3800.	117.5	117.8	118.0	118.0	118.0	118.0
4000.	119.5	119.8	120.0	120.0	120.0	120.0
4200.	121.5	121.8	122.0	122.0	122.0	122.0
4400.	123.5	123.8	124.0	124.0	124.0	124.0
4600.	125.5	125.8	126.0	126.0	126.0	126.0
4800.	127.5	127.8	128.0	128.0	128.0	128.0
5000.	129.6	129.8	130.0	130.0	130.0	130.0
5200.	131.6	131.8	132.0	132.0	132.0	132.0
5400.	133.6	133.8	134.0	134.0	134.0	134.0
5600.	135.6	135.8	136.0	136.0	136.0	136.0
5800.	137.6	137.8	138.0	138.0	138.0	138.0
6000.	139.6	139.8	140.0	140.0	140.0	140.0
6200.	141.4	141.7	141.9	142.0	142.0	142.0
6400.	143.4	143.7	143.9	143.9	144.0	144.0
6600.	145.5	145.7	145.9	145.9	146.0	146.0
6800.	147.4	147.7	148.0	148.0	148.0	148.0
7000.	149.4	149.7	149.9	149.9	150.0	150.0
7200.	150.9	151.4	151.9	151.9	152.0	152.0
7400.	154.0	154.0	154.0	154.0	154.0	154.0
7600.	156.0	156.0	156.0	156.0	156.0	156.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.9	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.5	.075	0.000	0.000	0.0
1400.	15.4	93.5	.075	0.000	0.000	0.0
1600.	15.5	95.5	.075	0.000	0.000	0.0
1800.	15.6	97.5	.076	0.000	0.000	0.0
2000.	15.7	99.5	.076	0.000	0.000	0.0
2200.	15.8	101.5	.076	0.000	0.000	0.0
2400.	15.9	103.5	.076	0.000	0.000	0.0
2600.	16.0	105.5	.077	0.000	0.000	0.0
2800.	16.2	107.5	.077	0.000	0.000	0.0
3000.	16.3	109.5	.077	0.000	0.000	0.0
3200.	16.4	111.5	.077	0.000	0.000	0.0
3400.	16.5	113.5	.078	0.000	0.000	0.0
3600.	16.6	115.5	.078	0.000	0.000	0.0
3800.	16.7	117.5	.078	0.000	0.000	0.0
4000.	16.8	119.5	.078	0.000	0.000	0.0
4200.	16.9	121.5	.079	0.000	0.000	0.0
4400.	17.0	123.5	.079	0.000	0.000	0.0
4600.	17.1	125.5	.079	0.000	0.000	0.0
4800.	17.2	127.5	.079	0.000	0.000	0.0
5000.	17.3	129.6	.079	0.000	0.000	0.0
5200.	17.5	131.6	.080	0.000	0.000	0.0
5400.	17.6	133.6	.080	0.000	0.000	0.0
5600.	17.7	135.6	.080	0.000	0.000	0.0
5800.	17.8	137.6	.080	0.000	0.000	0.0
6000.	17.9	139.6	.081	0.000	0.000	0.0
6200.	18.0	141.4	.081	0.000	0.000	0.0
6400.	18.1	143.4	.081	0.000	0.000	0.0
6600.	18.2	145.5	.081	0.000	0.000	0.0
6800.	18.4	147.4	.082	0.000	0.000	0.0
7000.	18.5	149.4	.082	0.000	0.000	0.0
7200.	18.6	150.9	.082	0.000	0.000	0.0

A N N U L U S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	ROCKS	VELOCITY-FT/SEC GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.1	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.8	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.8	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.8	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.8	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.8	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.8	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.8	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.8	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.8	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.8	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.8	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.8	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.8	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.8	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.8	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.8	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.8	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.8	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.8	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.8	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.8	.080	0.000	0.000	0.000	0.0	0.0
5600.	17.7	135.8	.080	0.000	0.000	0.000	0.0	0.0
5800.	17.8	137.8	.080	0.000	0.000	0.000	0.0	0.0
6000.	17.9	139.8	.081	0.000	0.000	0.000	0.0	0.0
6200.	18.0	141.7	.081	0.000	0.000	0.000	0.0	0.0
6400.	18.1	143.7	.081	0.000	0.000	0.000	0.0	0.0
6600.	18.2	145.7	.081	0.000	0.000	0.000	0.0	0.0
6800.	18.4	147.7	.082	0.000	0.000	0.000	0.0	0.0
7000.	18.5	149.7	.082	0.000	0.000	0.000	0.0	0.0
7200.	18.6	151.4	.082	0.000	0.000	0.000	0.0	0.0

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S E T   V A R I A B L E S   AT TIME =      8.000 DAYS
        FLOWING OPTION = FORWARD CIRCULATION
                   AIR INJECTED INTO TUBING
        MIST DRILLING: WATER ADDED AT    1.4 GAL/MIN
        INLET TEMPERATURE=   80. F
        FLOW RATE = 2400. SCF/MIN
        TIME TO CHANGE DATA =     10.000 DAYS
        DEPTH TO CHANGE DATA = 9000. FT
        CIRCULATION TIME PER DAY =  10.0 HRS

        BOTTOM HOLE ASSEMBLY:
          DRILL COLLARS:
            LENGTH= 600. FT,    I.D.= 2.500 IN,    C.D.= 6.000 IN
          DRILL BIT:
            DIAMETER=  8.750 IN, NOZZLE SIZES=   .750    .750    .750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO   240.0 PSI



TIME =      9.417 DAYS                                  ITERATIONS =  7
CONDITIONS SINCE LAST TIME STEP:
    FLOW RATE =2400. SCF/MIN     CIRCULATION DEPTH = 9000. FT
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T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.0	80.8	80.0	80.0	80.0	80.0
200.	81.4	82.5	82.3	82.1	82.1	82.0
400.	83.1	84.3	84.2	84.1	84.0	84.0
600.	85.0	86.2	86.1	86.1	86.0	86.0
800.	86.9	88.2	88.1	88.1	88.0	88.0
1000.	88.9	90.2	90.1	98.0	90.0	90.0
1200.	90.9	92.2	92.1	92.0	92.0	92.0
1400.	92.9	94.2	94.1	94.0	94.0	94.0
1600.	94.9	96.2	95.1	96.0	96.0	96.0
1800.	96.9	98.2	98.1	98.0	98.0	98.0
2000.	98.9	100.2	100.1	100.0	100.0	100.0
2200.	100.9	102.2	102.1	102.0	102.0	102.0
2400.	102.9	104.2	104.1	104.0	104.0	104.0
2600.	104.9	106.2	106.1	106.0	106.0	106.0
2800.	106.9	108.2	108.1	108.0	108.0	108.0
3000.	108.9	110.2	110.1	110.0	110.0	110.0
3200.	110.9	112.2	112.1	112.0	112.0	112.0
3400.	112.9	114.2	114.1	114.0	114.0	114.0
3600.	114.9	116.2	116.1	116.0	116.0	116.0
3800.	116.9	118.2	118.1	118.0	118.0	118.0
4000.	118.9	120.2	120.1	120.0	120.0	120.0
4200.	120.9	122.2	122.1	122.0	122.0	122.0
4400.	122.9	124.2	124.1	124.0	124.0	124.0
4600.	124.9	126.2	126.1	126.0	126.0	126.0
4800.	126.9	128.2	128.1	128.0	128.0	128.0
5000.	128.9	130.2	130.1	130.0	130.0	130.0
5200.	130.9	132.2	132.1	132.0	132.0	132.0
5400.	132.9	134.2	134.1	134.0	134.0	134.0
5600.	134.9	136.2	136.1	136.0	136.0	136.0
5800.	136.9	138.2	138.1	138.0	138.0	138.0
6000.	138.9	140.2	140.1	140.0	140.0	140.0
6200.	140.9	142.2	142.2	142.1	142.0	142.0
6400.	143.0	144.3	144.2	144.1	144.0	144.0
6600.	145.0	146.3	146.2	146.1	146.0	146.0
6800.	147.1	148.4	148.2	148.1	148.0	148.0
7000.	149.2	150.5	150.3	150.1	150.0	150.0
7200.	151.4	152.8	152.5	152.2	152.0	152.0
7400.	153.8	155.4	154.7	154.1	154.0	154.0
7600.	156.8	158.7	157.4	156.1	156.0	156.0
7800.	160.3	162.2	160.0	158.1	158.0	158.0
8000.	161.5	159.4	159.5	159.7	160.0	160.0
8200.	158.2	157.5	159.4	161.5	161.9	162.0
8400.	158.6	161.5	162.7	163.7	164.0	164.0
8600.	163.6	165.1	165.5	165.9	166.0	166.0
8800.	166.6	167.5	167.7	167.9	168.0	168.0
9000.	168.1	168.4	169.2	169.9	170.0	170.0
9200.	172.0	172.0	172.0	172.0	172.0	172.0
9400.	174.0	174.0	174.0	174.0	174.0	174.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	WATER	VAPOR	VELOCITY FT/SEC
0.	240.0	80.0	1.200	.075	.002	24.0
200.	241.0	81.4	1.202	.075	.002	24.0
400.	242.0	83.1	1.203	.075	.002	23.9
600.	243.0	85.0	1.204	.075	.002	23.9
800.	244.0	86.9	1.205	.075	.002	23.9
1000.	245.0	88.9	1.205	.075	.002	23.9
1200.	246.0	90.9	1.206	.075	.002	23.9
1400.	247.0	92.9	1.206	.075	.002	23.9
1600.	248.0	94.9	1.207	.074	.002	23.9
1800.	249.0	96.9	1.207	.074	.003	23.9
2000.	250.0	98.9	1.208	.074	.003	23.9
2200.	251.0	100.9	1.208	.074	.003	23.8
2400.	252.0	102.9	1.209	.074	.003	23.8
2600.	253.0	104.9	1.209	.074	.003	23.8
2800.	254.0	106.9	1.210	.074	.003	23.8
3000.	255.0	108.9	1.210	.074	.004	23.8
3200.	256.0	110.9	1.211	.073	.004	23.8
3400.	257.0	112.9	1.211	.073	.004	23.8
3600.	258.0	114.9	1.212	.073	.004	23.8
3800.	259.0	116.9	1.213	.073	.005	23.8
4000.	260.0	118.9	1.213	.073	.005	23.8
4200.	261.0	120.9	1.214	.072	.005	23.7
4400.	262.0	122.9	1.214	.072	.005	23.7
4600.	263.1	124.9	1.215	.072	.006	23.7
4800.	264.1	126.9	1.215	.072	.006	23.7
5000.	265.1	128.9	1.216	.071	.006	23.7
5200.	266.1	130.9	1.216	.071	.007	23.7
5400.	267.1	132.9	1.217	.071	.007	23.7
5600.	268.1	134.9	1.217	.070	.007	23.7
5800.	269.2	136.9	1.218	.070	.008	23.7
6000.	270.2	138.9	1.218	.070	.008	23.7
6200.	271.2	140.9	1.219	.069	.008	23.6
6400.	272.2	143.0	1.219	.069	.009	23.6
6600.	273.3	145.0	1.220	.069	.009	23.6
6800.	274.3	147.1	1.220	.068	.010	23.6
7000.	275.3	149.2	1.220	.068	.010	23.6
7200.	276.3	151.4	1.220	.067	.011	23.6
7400.	277.4	153.8	1.220	.067	.011	23.6
7600.	278.4	156.8	1.219	.066	.012	23.6
7800.	279.4	160.3	1.216	.064	.013	23.7
8000.	280.4	161.5	1.219	.064	.013	23.6
8200.	281.4	158.2	1.229	.066	.012	23.4
8400.	282.5	158.6	1.233	.066	.013	23.4
8600.	268.2	163.6	1.161	.010	.014	77.1
8800.	253.9	166.6	1.094	.007	.015	81.9
9000.	238.5	168.1	1.025	.006	.016	87.4

A N N U L U S

DEPTH	PRESSURE	TEMP	DENSITY-LBM/CF				VELOCITY-FT/SE	
FT	PSIA	F	GAS	WATER	VAPOR	ROCKS	GAS	ROCKS
0.	67.0	80.8	.334	.056	.002	.392	32.1	11.2
200.	68.8	82.5	.343	.054	.002	.332	33.0	13.9
400.	70.5	84.3	.350	.055	.002	.344	32.3	13.5
600.	72.3	86.2	.357	.056	.002	.357	31.7	13.0
800.	74.0	88.2	.365	.057	.002	.370	31.0	12.5
1000.	75.8	90.2	.372	.058	.002	.383	30.4	12.1
1200.	77.7	92.2	.380	.059	.002	.397	29.8	11.7
1400.	79.6	94.2	.388	.061	.002	.412	29.2	11.3
1600.	81.5	96.2	.395	.062	.003	.427	28.6	10.9
1800.	83.4	98.2	.403	.063	.003	.443	28.0	10.5
2000.	85.4	100.2	.412	.064	.003	.460	27.5	10.1
2200.	87.5	102.2	.420	.065	.003	.478	26.9	9.7
2400.	89.6	104.2	.429	.066	.003	.497	26.4	9.3
2600.	91.8	106.2	.438	.068	.003	.516	25.9	9.0
2800.	94.0	108.2	.447	.069	.004	.538	25.3	8.6
3000.	96.4	110.2	.456	.070	.004	.560	24.8	8.3
3200.	98.7	112.2	.466	.072	.004	.584	24.3	7.9
3400.	101.2	114.2	.476	.073	.004	.610	23.8	7.6
3600.	103.7	116.2	.486	.074	.004	.638	23.3	7.3
3800.	106.4	118.2	.497	.076	.005	.667	22.8	6.9
4000.	109.1	120.2	.508	.077	.005	.700	22.3	6.6
4200.	112.0	122.2	.519	.079	.005	.735	21.8	6.3
4400.	114.9	124.2	.531	.081	.005	.774	21.3	6.0
4600.	118.0	126.2	.544	.082	.006	.816	20.8	5.7
4800.	121.3	128.2	.557	.084	.006	.863	20.3	5.4
5000.	124.7	130.2	.570	.086	.006	.915	19.8	5.1
5200.	128.3	132.2	.585	.088	.007	.974	19.4	4.8
5400.	132.0	134.2	.600	.090	.007	1.040	18.9	4.5
5600.	136.1	136.2	.616	.093	.007	1.117	18.4	4.1
5800.	140.4	138.2	.633	.095	.008	1.204	17.9	3.8
6000.	145.0	140.2	.652	.098	.008	1.310	17.4	3.5
6200.	149.9	142.2	.672	.101	.009	1.433	16.8	3.2
6400.	155.3	144.3	.694	.104	.009	1.591	16.3	2.9
6600.	161.3	146.3	.718	.107	.009	1.782	15.8	2.6
6800.	167.9	148.4	.745	.111	.010	2.050	15.2	2.3
7000.	175.5	150.5	.776	.116	.010	2.399	14.6	1.9
7200.	184.3	152.8	.812	.121	.011	2.980	13.9	1.6
7400.	194.9	155.4	.855	.127	.012	3.886	13.2	1.2
7600.	207.3	158.7	.904	.134	.013	6.179	12.5	.8
7800.	214.4	162.2	.930	.137	.014	13.247	12.2	.3
8000.	208.5	159.4	.909	.135	.013	32.002	12.5	.1
8200.	190.3	157.5	.832	.123	.012	79.084	13.6	.1
8400.	210.7	161.5	.915	.135	.013	3.370	12.4	1.4
8600.	222.9	165.1	.963	.112	.015	2.116	14.5	2.8
8800.	231.5	167.5	.996	.115	.015	1.687	14.1	3.5
9000.	238.6	168.4	1.025	.005	.016	1.710	13.6	3.4

TIME = 10.000 DAYS ITERATIONS = 3
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. SCF/MIN CIRCULATION DEPTH = 9000. FT

T E M P E R A T U R E   D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.3	.8	1.5	2.7	50.0
0.	80.1	80.1	80.0	80.0	80.0	80.0
200.	81.9	82.1	82.1	82.1	82.1	82.0
400.	83.7	83.9	84.1	84.1	84.0	84.0
600.	85.6	85.9	86.0	86.0	86.0	86.0
800.	87.6	87.9	88.0	88.0	88.0	88.0
1000.	89.6	89.9	90.0	90.0	90.0	90.0
1200.	91.6	91.9	92.0	92.0	92.0	92.0
1400.	93.6	93.9	94.0	94.0	94.0	94.0
1600.	95.6	95.9	96.0	96.0	96.0	96.0
1800.	97.6	97.9	98.0	98.0	98.0	98.0
2000.	99.6	99.9	100.0	100.0	100.0	100.0
2200.	101.6	101.9	102.0	102.0	102.0	102.0
2400.	103.6	103.9	104.0	104.0	104.0	104.0
2600.	105.6	105.9	106.0	106.0	106.0	106.0
2800.	107.6	107.9	108.0	108.0	108.0	108.0
3000.	109.6	109.9	110.0	110.0	110.0	110.0
3200.	111.6	111.9	112.0	112.0	112.0	112.0
3400.	113.6	113.9	114.0	114.0	114.0	114.0
3600.	115.6	115.9	116.0	116.0	116.0	116.0
3800.	117.6	117.9	118.0	118.0	118.0	118.0
4000.	119.6	119.9	120.0	120.0	120.0	120.0
4200.	121.6	121.9	122.0	122.0	122.0	122.0
4400.	123.6	123.9	124.0	124.0	124.0	124.0
4600.	125.6	125.9	126.0	126.0	126.0	126.0
4800.	127.6	127.9	128.0	128.0	128.0	128.0
5000.	129.6	129.9	130.0	130.0	130.0	130.0
5200.	131.6	131.9	132.0	132.0	132.0	132.0
5400.	133.6	133.9	134.0	134.0	134.0	134.0
5600.	135.6	135.9	136.0	136.0	136.0	136.0
5800.	137.6	137.9	138.0	138.0	138.0	138.0
6000.	139.6	139.9	140.0	140.0	140.0	140.0
6200.	141.6	141.9	142.0	142.0	142.0	142.0
6400.	143.7	143.9	144.1	144.1	144.0	144.0
6600.	145.7	145.9	146.1	146.1	146.0	146.0
6800.	147.7	147.9	148.0	148.0	148.0	148.0
7000.	149.8	150.0	150.1	150.1	150.0	150.0
7200.	151.9	152.1	152.1	152.1	152.0	152.0
7400.	154.2	154.2	154.0	154.0	154.0	154.0
7600.	156.9	156.6	156.1	156.1	156.0	156.0
7800.	159.8	159.0	158.1	158.1	158.0	158.0
8000.	160.4	160.0	159.8	159.8	159.9	160.0
8200.	159.5	160.5	161.7	161.7	161.9	162.0
8400.	161.4	162.6	163.8	163.8	163.9	164.0
8600.	164.9	165.4	165.9	165.9	166.0	166.0
8800.	167.3	167.7	167.9	167.9	168.0	168.0
9000.	168.9	169.4	169.9	169.9	170.0	170.0
9200.	172.0	172.0	172.0	172.0	172.0	172.0
9400.	174.0	174.0	174.0	174.0	174.0	174.0

GAS & MIST DRILLING
FLOWING STREAM PROPERTIES

TUBING

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/CF GAS	DENSITY-LBM/CF WATER	DENSITY-LBM/CF VAPOR	VELOCITY FT/SEC
0.	14.7	80.1	.073	0.000	0.000	0.0
200.	14.8	81.9	.074	0.000	0.000	0.0
400.	14.9	83.7	.074	0.000	0.000	0.0
600.	15.0	85.6	.074	0.000	0.000	0.0
800.	15.1	87.6	.074	0.000	0.000	0.0
1000.	15.2	89.6	.075	0.000	0.000	0.0
1200.	15.3	91.6	.075	0.000	0.000	0.0
1400.	15.4	93.6	.075	0.000	0.000	0.0
1600.	15.5	95.6	.075	0.000	0.000	0.0
1800.	15.6	97.6	.076	0.000	0.000	0.0
2000.	15.7	99.6	.076	0.000	0.000	0.0
2200.	15.8	101.6	.076	0.000	0.000	0.0
2400.	15.9	103.6	.076	0.000	0.000	0.0
2600.	16.0	105.6	.077	0.000	0.000	0.0
2800.	16.1	107.6	.077	0.000	0.000	0.0
3000.	16.3	109.6	.077	0.000	0.000	0.0
3200.	16.4	111.6	.077	0.000	0.000	0.0
3400.	16.5	113.6	.078	0.000	0.000	0.0
3600.	16.6	115.6	.078	0.000	0.000	0.0
3800.	16.7	117.6	.078	0.000	0.000	0.0
4000.	16.8	119.6	.078	0.000	0.000	0.0
4200.	16.9	121.6	.079	0.000	0.000	0.0
4400.	17.0	123.6	.079	0.000	0.000	0.0
4600.	17.1	125.6	.079	0.000	0.000	0.0
4800.	17.2	127.6	.079	0.000	0.000	0.0
5000.	17.3	129.6	.079	0.000	0.000	0.0
5200.	17.5	131.6	.080	0.000	0.000	0.0
5400.	17.6	133.6	.080	0.000	0.000	0.0
5600.	17.7	135.6	.080	0.000	0.000	0.0
5800.	17.8	137.6	.080	0.000	0.000	0.0
6000.	17.9	139.6	.081	0.000	0.000	0.0
6200.	18.0	141.6	.081	0.000	0.000	0.0
6400.	18.1	143.7	.081	0.000	0.000	0.0
6600.	18.2	145.7	.081	0.000	0.000	0.0
6800.	18.4	147.7	.082	0.000	0.000	0.0
7000.	18.5	149.8	.082	0.000	0.000	0.0
7200.	18.6	151.9	.082	0.000	0.000	0.0
7400.	18.7	154.2	.082	0.000	0.000	0.0
7600.	18.8	156.9	.082	0.000	0.000	0.0
7800.	18.9	159.8	.082	0.000	0.000	0.0
8000.	19.0	160.4	.083	0.000	0.000	0.0
8200.	19.2	159.5	.083	0.000	0.000	0.0
8400.	19.3	161.4	.084	0.000	0.000	0.0
8600.	19.4	164.9	.084	0.000	0.000	0.0
8800.	19.5	167.3	.084	0.000	0.000	0.0
9000.	19.6	168.9	.084	0.000	0.000	0.0

A N N U L U S

DEPTH	PRESSURE	TEMP		DENSITY-LBM/CF			VELOCITY-FT/SEC	
FT	PSIA	F	GAS	WATER	VAPOR	ROCKS	GAS	ROCKS
0.	14.7	80.1	.074	0.000	0.000	0.000	0.0	0.0
200.	14.8	82.1	.074	0.000	0.000	0.000	0.0	0.0
400.	14.9	83.9	.074	0.000	0.000	0.000	0.0	0.0
600.	15.0	85.9	.074	0.000	0.000	0.000	0.0	0.0
800.	15.1	87.9	.074	0.000	0.000	0.000	0.0	0.0
1000.	15.2	89.9	.075	0.000	0.000	0.000	0.0	0.0
1200.	15.3	91.9	.075	0.000	0.000	0.000	0.0	0.0
1400.	15.4	93.9	.075	0.000	0.000	0.000	0.0	0.0
1600.	15.5	95.9	.075	0.000	0.000	0.000	0.0	0.0
1800.	15.6	97.9	.076	0.000	0.000	0.000	0.0	0.0
2000.	15.7	99.9	.076	0.000	0.000	0.000	0.0	0.0
2200.	15.8	101.9	.076	0.000	0.000	0.000	0.0	0.0
2400.	15.9	103.9	.076	0.000	0.000	0.000	0.0	0.0
2600.	16.1	105.9	.077	0.000	0.000	0.000	0.0	0.0
2800.	16.2	107.9	.077	0.000	0.000	0.000	0.0	0.0
3000.	16.3	109.9	.077	0.000	0.000	0.000	0.0	0.0
3200.	16.4	111.9	.077	0.000	0.000	0.000	0.0	0.0
3400.	16.5	113.9	.078	0.000	0.000	0.000	0.0	0.0
3600.	16.6	115.9	.078	0.000	0.000	0.000	0.0	0.0
3800.	16.7	117.9	.078	0.000	0.000	0.000	0.0	0.0
4000.	16.8	119.9	.078	0.000	0.000	0.000	0.0	0.0
4200.	16.9	121.9	.079	0.000	0.000	0.000	0.0	0.0
4400.	17.0	123.9	.079	0.000	0.000	0.000	0.0	0.0
4600.	17.1	125.9	.079	0.000	0.000	0.000	0.0	0.0
4800.	17.2	127.9	.079	0.000	0.000	0.000	0.0	0.0
5000.	17.4	129.9	.079	0.000	0.000	0.000	0.0	0.0
5200.	17.5	131.9	.080	0.000	0.000	0.000	0.0	0.0
5400.	17.6	133.9	.080	0.000	0.000	0.000	0.0	0.0
5600.	17.7	135.9	.080	0.000	0.000	0.000	0.0	0.0
5800.	17.8	137.9	.080	0.000	0.000	0.000	0.0	0.0
6000.	17.9	139.9	.081	0.000	0.000	0.000	0.0	0.0
6200.	18.0	141.9	.081	0.000	0.000	0.000	0.0	0.0
6400.	18.1	143.9	.081	0.000	0.000	0.000	0.0	0.0
6600.	18.2	145.9	.081	0.000	0.000	0.000	0.0	0.0
6800.	18.4	147.9	.082	0.000	0.000	0.000	0.0	0.0
7000.	18.5	150.0	.082	0.000	0.000	0.000	0.0	0.0
7200.	18.6	152.1	.082	0.000	0.000	0.000	0.0	0.0
7400.	18.7	154.2	.082	0.000	0.000	0.000	0.0	0.0
7600.	18.8	156.6	.082	0.000	0.000	0.000	0.0	0.0
7800.	18.9	159.0	.083	0.000	0.000	0.000	0.0	0.0
8000.	19.0	160.0	.083	0.000	0.000	0.000	0.0	0.0
8200.	19.2	160.5	.083	0.000	0.000	0.000	0.0	0.0
8400.	19.3	162.6	.084	0.000	0.000	0.000	0.0	0.0
8600.	19.4	165.4	.084	0.000	0.000	0.000	0.0	0.0
8800.	19.5	167.7	.084	0.000	0.000	0.000	0.0	0.0
9000.	19.6	169.4	.084	0.000	0.000	0.000	0.0	0.0

4.8 SAMPLE PROBLEM 9: Steam Production

Sample problem 9 simulates a well producing two phase steam, with a bottom-hole quality of 0.16 at the relatively high rate of about 290,000 lbm/hr. The results show that the two phase flow is in the slug flow regime. At the surface, the quality of the steam is 0.22.

TABLE 4.18 Input Data for Sample Problem, 9

```
SAMPLE PROBLEM 9:  STEAM PRODUCTION
'TUBING',2
1,7.825,8.625,1459.,1459.
2,6.969,7.625,2400.,2400.
'CASING',1
1,12.347,13.375,50.,50.
'WELLBORE',2400.,2400.,2400.,2400.,31.
'TEMP',70.,460.,70.,10.
'FLUIDS',1
1,8.33,1.,0.0
'INITIAL',1,1
'CHANGE,9,0,1,460.,580.,1.00
'STEAM',1,.16
```

Table 4.19 Output Data for Sample Problem 9.

SAMPLE PROBLEM #9: STEAM PRODUCTION: WELL BR-13

T U B I N G   C O N F I G U R A T I O N

TUBING	ID, IN.	OD, IN.	TOP, FT.	BASE, FT.	CEMENT, FT.
1	7.825	8.625	0.	1459.	1459.0
2	6.969	7.625	1459.	2400.	2400.0

C A S I N G   P R O G R A M

CASING	ID, IN	OD, IN	DEPTH, FT	CEMENT INTERVAL, FT
1	12.347	13.375	50.	50.

W E L L   G E O M E T R Y

TOTAL DEPTH= 2400. FT.
BORE DIAMETER= 31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH

W E L L B O R E   F L U I D   P R O P E R T I E S

FLUID TYPE NO. 1

DENSITY= 8.3 LBM/GAL
PLASTIC VISCOSITY= 1. CENTIPOISE
YIELD POINT= 0. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

FLUID # 1 IN TUBING & TUBING ANNULUS
FLUID # 1 IN CASING - CASING ANNULI

S E T V A R I A B L E S AT TIME = 0.000 DAYS
FLOWING OPTION = TWO-PHASE STEAM PRODUCTION
STEAM QUALITY = .160
INLET TEMPERATURE = 460. F
FLOW RATE = 580. GAL/MIN
TIME TO CHANGE DATA = 1.000 DAYS

TIME = 1.000 DAYS ITERATIONS = 4

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.1	.4	1.3	2.4	3.9	50.0
0.	398.2	70.0	70.0	70.0	70.0	70.0
200.	405.1	335.0	174.8	122.5	103.8	101.0
400.	411.2	347.2	201.0	153.3	136.1	133.6
600.	416.8	359.0	227.1	184.0	168.5	166.3
800.	422.0	370.5	253.1	214.7	200.9	198.9
1000.	426.7	381.7	278.9	245.3	233.3	231.5
1200.	431.2	392.7	304.7	276.0	265.7	264.2
1400.	435.4	401.4	328.5	306.0	298.0	296.8
1600.	439.5	407.3	350.0	335.2	330.2	329.5
1800.	445.2	420.8	377.6	366.5	362.6	362.1
2000.	450.4	434.1	405.1	397.7	395.1	394.7
2200.	455.3	447.2	432.6	428.8	427.5	427.4
2400.	460.0	460.0	460.0	460.0	460.0	460.0
2600.	492.6	492.6	492.6	492.6	492.6	492.6
2800.	525.3	525.3	525.3	525.3	525.3	525.3

S T E A M P R O D U C T I O N

F L O W I N G S T R E A M P R O P E R T I E S

DEPTH FT	PRESSURE PSIA	TEMP F	DENSITY-LBM/FT3 VAPOR	LIQUID	VELOCITY FT/SEC	
0.	242.3	398.2	.512	1.812	103.8	SLUG
200.	262.0	405.1	.550	2.016	94.0	SLUG
400.	280.6	411.2	.586	2.217	86.0	SLUG
600.	298.4	416.8	.619	2.417	79.4	SLUG
800.	315.5	422.0	.652	2.616	73.8	SLUG
1000.	332.0	426.7	.682	2.816	68.9	SLUG
1200.	348.2	431.2	.712	3.018	64.6	SLUG
1400.	364.0	435.4	.741	3.223	60.8	SLUG
1600.	379.5	439.5	.768	3.432	72.4	SLUG
1800.	402.4	445.2	.809	3.765	66.5	SLUG
2000.	424.4	450.4	.846	4.104	61.4	SLUG
2200.	445.9	455.3	.882	4.453	57.0	SLUG
2400.	466.9	460.0	.917	4.813	53.0	

4.9 SAMPLE PROBLEM 10: Steam Injection

Sample problem 10 models a steam injection process. Dry steam (200 lb) is injected at about 25,000 lbm/hr. The mist flow correlations are used in this example.

TABLE 4.20 Input Data for Sample Problem 10

```
SAMPLE PROBLEM 10:  STEAM INJECTION
'TUBING',1
1,7.825,8.625,1459.,1459.
'CASING',1
1,12.347,13.375,50.,50.
'WELLBORE',1459.,1459.,1459.,1459.,31.
'TEMP',100.,410.1,400.,800.
'FLUIDS',1
1,8.33,1.,0.0
'INITIAL',1,1
'CHANGE',10, 0,1,410.1,50.,.5
'STEAM',2,200.
```

Table 4.21 Output Data for Sample Problem 10.

```
SAMPLE PROBLEM #10: STEAM INJECTION



 T U B I N G   C O N F I G U R A T I O N
       TUBING   ID,IN.   OD,IN.   TOP,FT.   BASE,FT.   CEMENT,FT.
         1      7.825    8.625        0.      1459.     1459.0


C A S I N G    P R O G R A M
       CASING        ID, IN     OD, IN       DEPTH, FT   CEMENT INTERVAL, FT
         1           12.347     13.375          50.                    50.

W E L L    G E O M E T R Y

          TOTAL DEPTH=     1459. FT.
          BORE DIAMETER=    31.000 IN.

NOTE: TRUE DEPTH=MEASURED DEPTH


W E L L B O R E   F L U I D   P R O P E R T I E S

         FLUID TYPE NO.     1

         DENSITY=   8.3 LBM/GAL
         PLASTIC VISCOSITY=   1. CENTIPOISE
         YIELD POINT=  0. LBF/100FT2

W E L L B O R E   I N I T I A L   S T A T E

          FLUID # 1 IN TUBING & TUBING ANNULUS
          FLUID # 1 IN CASING - CASING ANNULI
```

S E T V A R I A B L E S AT TIME = 0.000 DAYS
FLOWING OPTION = TWO-PHASE STEAM INJECTION
INLET PRESSURE = 200.0 PSIA
INLET TEMPERATURE = 410. F
FLOW RATE = 50. GAL/MIN
TIME TO CHANGE DATA = .500 DAYS

TIME = .500 DAYS ITERATIONS = 4

T E M P E R A T U R E D I S T R I B U T I O N

	RADIAL POSITIONS, FEET					
DEPTH, FT	.2	.4	1.3	2.4	3.9	50.0
0.	410.1	100.0	100.0	100.0	100.0	100.0
200.	381.4	307.0	228.9	184.6	175.6	175.0
400.	381.0	334.0	284.3	256.1	250.4	250.0
600.	380.5	360.7	339.6	327.6	325.2	325.0
800.	380.1	387.2	394.8	399.1	399.9	400.0
1000.	379.7	388.1	396.9	402.0	403.0	403.1
1200.	379.2	388.9	399.1	404.9	406.0	406.1
1400.	378.8	389.7	401.2	407.8	409.1	409.2
1600.	412.3	412.3	412.3	412.3	412.3	412.3
1800.	415.3	415.3	415.3	415.3	415.3	415.3

S T E A M I N J E C T I O N

F L O W I N G S T R E A M P R O P E R T I E S

DEPTH	PRESSURE	TEMP	DENSITY-LBM/FT3		VELOCITY	
FT	PSIA	F	VAPOR	LIQUID	FT/SEC	
0.	200.0	410.1	.417	0.000	49.9	
200.	199.1	381.4	.438	.006	46.8	MIST
400.	198.1	381.0	.436	.009	46.7	MIST
600.	197.1	380.5	.434	.011	46.7	MIST
800.	196.1	380.1	.432	.011	46.9	MIST
1000.	195.1	379.7	.430	.010	47.2	MIST
1200.	194.1	379.2	.427	.010	47.6	MIST
1400.	193.0	378.8	.425	.009	47.9	MIST

REFERENCES

1. Angel, R.R., "Volume Requirements for Air and Gas Drilling", T. P. 4679 Transactions, Vol. 210, SPE of AIME, (1957), 325-330

2. Gould, Thomas L., "Vertical Two-Phase Steam-Water Flow in Geothermal Wells", J. Pet. Tech., (August, 1974), 833-842

3. Mitchell, R.F., "Advanced Wellbore Thermal Simulator - GEOTEMP2-Research Report", SAND82-7003/1, Sandia National Laboratories. Feb., 1982.

4. Keenan, Joseph H., et al., Steam Tables, Wiley-Interscience, New York, NY (1969), 134-159

5. Wooley, G.R., "Wellbore and Soil Thermal Simulation for Geothermal Wells - Development of Computer Model and Acquisition of Field Temperature Data; Part I Report", SAND79-7119, Sandia National Laboratories, March, 1980

6. Wooley, G.R., "Wellbore and Soil Thermal Simulation for Geothermal Wells - Comparison of GEOTEMP Predictions to Field Data and Evaluation of Flow Variables; Part II Report", SAND79-7116, Sandia National Laboratories, March, 1980

7. Wooley, G.R., "User's Manual for GEOTEMP, A Computer Code for Predicting Downhole Wellbore and Soil Temperatures in Geothermal Wells; Appendix to Part I Report", SAND79-7118, Sandia National Laboratories, March, 1980

8. Orkiszewski, J., "Predicting Two-Phase Pressure Drops in Vertical Pipe", Journal of Petroleum Technology, June, 1968, pp 829-838

9. Chieriei, G.L., et al., "Two-Phase Vertical Flow in Oil Wells - Prediction of Pressure Drop", Journal of Petroleum Technology, August, 1974, pp 927-938

Appendix A. Corrections and Addenda to the Research Report (SAND82-7003/1)

The contractor report published in February, 1982, entitled "Advanced Wellbore Thermal Simulator GEOTEMP2 Research Report," by R. F. Mitchell (4) contains several errors. This appendix will try to point out these errors so that there will be no unexplained inconsistencies among the code listing, Users' Manual and Research Report.

The only major errors in the Research Report are the reported results of the air and mist drilling sample problems. Several changes to the code have been made since the publication of this document. Because of these changes, Figure 11 (the temperature profile in the annulus) is now known to be incorrect. However, the point of this figure is to show that the annulus temperature is near the undisturbed geothermal temperature. The results that GEOTEMP2 now give show that the annulus temperature profile is even closer to the undisturbed profile than is shown in Figure 22 (see sample problem 7 in this user's manual). Also, because of the changes, Figures 10, 13, 24, and 15 cannot be reproduced exactly. It is important to reiterate that GEOTEMP2 does not attempt to find the minimum pressure necessary to maintain flow nor the minimum volumetric flow rate to maintain lifting capacity. Running GEOTEMP2 with randomly guessed values of either quantity and allowing the code to increase the values as necessary will not result in smooth curves as those shown in these four figures. It is still true that GEOTEMP2 is more conservative than the Angel charts (1) because a slip velocity for the cuttings is included, and, therefore, a higher necessary gas flow is predicted. It is also true that adding mist increases the necessary volumetric flow rate and standpipe pressure.

The Orkizewski correlations for bubble velocity reported in the research report are only for liquid Reynolds numbers greater than 6000 (8). In the course of normal geothermal operations, lower Reynolds numbers will not be encountered. For example, a steam production well of relatively low flowrate might have 10,000 lb/hr of steam and water flowing through a six-inch pipe. The liquid Reynolds number in the tubing is defined as:

$$N_{Re_\ell} = \frac{4}{\Pi} \frac{\dot{m}}{D\mu}$$

where m is the total mass flowrate, D is the hydraulic pipe diameter, and is the viscosity of the liquid. At 100°C, liquid water has a viscosity of 0.68 lb/ft/hr, and its viscosity decreases with increasing temperature. Therefore, the fluid flowing in this well would have a liquid Reynolds number of about 40,000. Note that lower Reynolds numbers can be obtained with lower mass flow, larger pipe diameters or higher viscosity materials. This is important to remember if GEOTEMP2 is going to be used to model situations other than typical geothermal wells.

A typographical error in Orkizewski's original paper is reproduced in the research report. Although no formal errata exists for the paper, Chieriei (9) mentions the mistake. Equation (48) in the research report should read:

$$v_b = \frac{1}{2}\left[\alpha + (\alpha^2 + 13.59\mu_w/\rho_w D^{.5})^{.5}\right] \text{ for } 3000 < N_{Re_b} < 8000.$$

The surface tension correlation given in Appendix C of the research report (equation C-20) is incorrect. It should read:

$$\sigma = 7.8609 \times 10^{-2} \exp(-77.225/\Delta\mu),$$

where the surface tension units are in Newtons per meter.

In the derivation of the compressible flow model, some assumptions are not stated explicitly. The integration of Equation (5) for the pressure drop due to gravity yields the expression:

$$w = \rho_1 v_1 g \cos\theta \frac{\Delta z}{\Delta v}$$

where w is the pressure drop, ρ_1, is the fluid density at the cell entrance, v_2 and v_1, are the velocities at entrance and exit of the cell, respectively, Δz is the cell length, and . The term v_2/v_1 is equivalent to $1 + \Delta v/v_1$. Using this latter form and expanding the logarithm gives:

$$\ell n\left(\frac{v_2}{v_1}\right) = \ell n\left(1 + \frac{\Delta v}{v_1}\right) = \frac{\Delta v}{v_1} - \frac{1}{2}\left(\frac{\Delta v}{v_1}\right)^2 + \frac{1}{3}\left(\frac{v}{v_1}\right)^3 - \ldots$$

By neglecting the cubic term the pressure drop expression is simplified to:

$$w = {}_1 g\ z\left(\frac{3}{2} - \frac{v_2}{2v_1}\right)\cos\theta,$$

which is Equation (8) in the Research Report. However, no assumption was stated explicitly concerning this derivation. In expanding the logarithm, the condition, $-1 < \Delta v/v. \leq 1$, needs to be fulfilled. This is true when $v_2 \leq 2v_1$, which is probably observed for all cases within the program. (Only when Δz, i.e. the vertical grid size, is very large, would this condition not be satisfied.)

Finally, this equation for the gravitational pressure drop is combined with the other pressure drop terms to give a quadratic expression for the exit velocity, v_2, whose solution is given by Equation (13) in the Research Report as:

$$v_2 = \frac{-b - (b^2 - 4ac)^{1/2}}{2a}$$

(The terms a, b, and c are defined in the Research Report). Only one root was taken since the second root yields a much higher velocity (producing supersonic flow) which is not physically reasonable.

Appendix B - Description of Subroutines and Functions

This appendix lists the 26 subroutines and 18 function subprograms contained in GEOTEMP2. A brief description is provided of each subroutine and function. More detail concerning the treatment provided in a given subroutine or function may be found in the Part I report on the development of GEOTEMP (5) or in the Research Report for GEOTEMP2 (4).

MAIN

The MAIN subroutine of program GEOTEMP2 calls the subroutines which perform the calculations or other operations. This subroutine has three principal functions: 1) Defining the problem (casing, radial grid, well operation, etc.), the initial conditions (temperatures), and properties of the fluids, soil, and cement; 2) Reading the CHANGE records and directing the program to the appropriate subroutine and 3) iterating over time.

READ

All of the input data described in section 2 is read in this subroutine. These data are then written onto the output file TAPE6.

PROP

The thermal properties of materials used in GEOTEMP2 are defined in PROP. The density, specific heat capacity, and thermal conductivity of steel, cement, soil, and the fluids are defined here. All properties, except those of the fluids are treated as constants. The soil properties may be modified for each vertical layer using the procedure described in the Introduction. The specific heat capacity and thermal conductivity of the fluids are calculated using a correlation based on the fluid density (4).

GRID

Subroutine GRID generates the location of the mathematical nodes and cells used to establish the energy balance equations. Ten radial positions, with an exponential distribution, are calculated using a maximum radius of 50 feet. The cross-sectional areas of each radial cell are calculated for use in the vertical heat conduction calculations. Finally, the vertical distribution of nodes is defined with a constant increment of 200 feet.

COND

This subroutine calculates the thermal conductances in the radial direction between adjacent nodes. Thermal resistances are first calculated using material properties and well geometry. Inside the wellbore, surface convection resistances are added for flowing stream (if applicable) and natural convection. The resistances are converted to a total thermal conductance between nodes.

COEF

Subroutine COEF calculates the coefficients of the terms in the energy balance equations. The coefficients for flowing conditions and shut in are calculated separately for the first three radial nodes of the wellbore.

WELL

The temperature calculations are performed in this subroutine. Wellbore temperatures are computed in the direction of fluid flow. The soil temperatures are then calculated and the new values are checked for convergence.

CONAN

This subroutine calculates the effective thermal conductivity of each of the annular regions in a well.

DWNFLO

This subroutine keeps track of the position of the liquid interfaces which are moving down when multiple fluids are used in the wellbore.

UPFLOW

This subroutine performes the same functions as DWNFLO but now for the case of the liquid interfaces moving upward. Note that GEOTEMP2 does not treat displacement of a gas by liquid or vice versa. When gas or steam systems are used, these subroutines are not called.

FPROP

This subroutine is called from COND to calculate the fluid (i.e. liquid) properties at a given location in the wellbore.

FLOW

The flowing stream and static properties for a gas in the wellbore are determined in this subroutine. In addition, this subroutine determines whether the gas flow has 'choked', i.e. there is insufficient pressure to support the assumed mass flow rate. The code increases the standpipe pressure until the condition for stable flow is satisfied. Finally, in the gas drilling case, the gas flow rate is increased if there is insufficient capacity for lifting the cuttings.

VEXIT

The exit flow properties of a gas in a given pipe element are determined in this subroutine.

ACHNG

This subroutine calculates the change in the gas flow properties (pressure, density, temperature, and velocity) due to an abrupt change in area within the tubing or annulus.

GPROP

This subroutine calculates the following gas properties at a specified depth and temperature in the wellbore:

density, specific heat capacity (at constant pressure and at constant volume), thermal conductivity, viscosity, and velocity.

NOZL

This subroutine is called by FLOW and checks for choked flow in the bit nozzles. It increases the standpipe pressure if the flow is found to be choked.

VSLIP

The initial slip velocity of the cuttings with respect to the flowing gas is calculated here.

VMIXT

This subroutine calculates the exit flow properties for a gas, mist, and cuttings mixture given the inlet conditions.

PSAT

This subroutine, which is called from TUFAS, calculates the saturated vapor pressure for two-phase steam flow at a specified temperature.

DVSAT

This subroutine, called from TUFAS, calculates the saturated vapor density for two-phase steam flow at a specified temperature.

DLSAT

This subroutine, called from TUFAS, calculates the saturated liquid density for two-phase steam flow at a specified temperature.

STEAM

Pressure, internal energy and their first partial derivatives are calculated as functions of density and temperature for both vapor and liquid phases.

ESAT

This subroutine calculates the enthalpy of the saturated vapor/liquid system for two-phase steam flow.

KSAT

The thermal conductivity of the saturated vapor-liquid system for two-phase steam flow is calculated in this subroutine.

TUFAS

This is the principal subroutine which is used to calculate the flowing stream properties for two-phase steam flow.

GMORK

The bubble rise velocity and Orkizewski's gamma function for two-phase slug flow are calculated in this subroutine.

The following are the function subprograms contained in GEOTEMP2.

HTUBE

This function calculates the film coefficient for natural convection in a tube.

VISC

The fluid viscosity is determined by this function.

CA

This function subprogram calculates the average properties for an annulus with a cement/packer-fluid interface.

CONV

This function computes a surface film coefficient for forced convection in an annulus.

CONVN

This function calculates the film coefficient for natural convection within the annulus.

KTUBE

The tubing size at a given depth is found in this function.

FRIC

This function subprogram calculates the Darcy friction factor for gas flow.

GVISC

Gas viscosity at a given temperature is calculated here.

CD

This function calculates the aerodynamic drag coefficient for cuttings.

SVVIS

This function calculates the saturated vapor viscosity for two-phase steam flow.

SLVIS

This function calculates the saturated liquid viscosity for two-phase steam flow.

FR2P

The Darcy friction factor for two-phase flow is determined by this function.

SURTN

The surface tension for water at a specified temperature is calculated here.

DENCR

This function subprogram determines the density for two-phase flow given the temperature, pressure, and initial guess of the density.

RLORK

The liquid fraction for two-phase bubble flow is found here.

HMIX

The two-phase heat transfer film coefficient is calculated by this function.

H2PR

The conductivity between the two-phase steam and the center of the tubing-casing annulus is found.

TSAT

This function subprogram calculates the temperature of the saturated vapor at a specified pressure for two-phase steam flow.

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6241	L. E. Duda (10)
6241	J. R. Kelsey (40)
6242	J. C. Dunn
6250	B. W. Marshall
8024	M. A. Pound

```
      PROGRAM GEOTEMP(INPUT,OUTPUT,TAPE5,TAPE6)
C
C*******  GEOTEMP2  VERSION 2.0    [DECEMBER, 1984]  ************************
C
C
C     THIS PROGRAM COMPUTES THE TEMPERATURES IN AND SURROUNDING A WELL
C      AND IS AN EXTENDED VERSION OF A PREVIOUS CODE NAMED GEOTEMP.
C      IMPROVEMENTS TO THE CODE INCLUDE GAS AND MIST DRILLING
C      AND TWO PHASE STEAM INJECTION AND PRODUCTION.
C
C     THE FOLLOWING REPORTS PROVIDE THE DOCUMENTATION FOR THIS CODE:
C
C          1) L. A. MONDY AND L. E. DUDA, "ADVANCED WELLBORE THERMAL
C             SIMULATOR - GEOTEMP2 - USER MANUAL", SAND84-0857, SANDIA
C             NATIONAL LABORATORIES, NOVEMBER 1984.
C          2) R. F. MITCHELL, "ADVANCED WELLBORE THERMAL SIMULATOR -
C             GEOTEMP2 - RESEARCH REPORT", SAND82-7003/1, SANDIA NATIONAL
C             LABORATORIES, FEBRUARY, 1982.
C          3) G. R. WOOLEY, "WELLBORE AND SOIL THERMAL SIMULATION FOR
C             GEOTHERMAL WELLS - DEVELOPMENT OF COMPUTER MODEL AND
C             ACQUISITION OF FIELD TEMPERATURE DATA; PART I REPORT",
C             SAND79-7119, SANDIA NATIONAL LABORATORIES, MARCH, 1980.
C
C
C      VERSION 2.0 OF THE CODE GEOTEMP2 CORRECTS SEVERAL ERRORS FOUND
C       IN THE ORIGINAL IMPLEMENTATION OF THE CODE. QUESTIONS OR
C       COMMENTS CONCERNING THIS CODE SHOULD BE DIRECTED TO:
C
C                      LEONARD E. DUDA
C                      SANDIA NATIONAL LABORATORIES
C                      (PHONE: (505) 844-2377)
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C   WOULD NOT INFRINGE PRIVATELY OWNED RIGHTS.                               *
C                                                                            *
C*****************************************************************************
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK4/ U(151,20),Q(151,2)
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK12/ VFR2
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK14/ TSUR,BHT,TDEPTH,DEPTHT
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      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK18/ DENG(151,2),PRESS(151,2),VGAS(151,2)
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      COMMON /BLK20/ DCUT(151),VCUT(151),DLIQ(151,2),DVAP(151,2),DRT,
     & VFR3
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
      DIMENSION BITN(3)
      CHARACTER DUMMY*10
      DATA PI/3.1415927/
      DATA TIME/0./,DTMAX/24./
C
C  READ IN VARIABLES
C
      CALL READ
C
C  MATERIAL PROPERTIES
C
      CALL PROP
C
C DEFINE GRID
C
      CALL GRID
C
C  INITIALIZE TEMPERATURES
C
      COSDVN=(TVD-DDVN)/(TD-DDVN)
      IF(ABS(TD-1.-DDVN).LT.1.00.AND.TVD.EQ.DDVN) COSDVN=1.0
      DTDZ1=(TDEPTH-TSUR)/DEPTHT
      DTDZ2=(BHT-TDEPTH)/(TVD-DEPTHT)
      NR1 = NR + 1
      DO 28 K=1,NZP1
      VD=Z(K)
      IF(VD.GT.DDVN)VD=DDVN+(Z(K)-DDVN)*COSDVN
      TT=DTDZ1*VD+TSUR
      IF(VD.GT.DEPTHT)TT=TDEPTH+DTDZ2*(VD-DEPTHT)
      DO 28 I=1,NR1
      TWJ(K,I) = TT
   28 TW(K,I) = TT
C
      DCRIM=DCLRI*24.
      DCROM=DCLRO*24.
      BITRM=BITR*24.
C
C
C  READ AND WRITE NEW FLOWING DATA
C
C     IFLOW = FLOWING STREAM OPTION
C         1 = INJECTION
C         2 = PRODUCTION
C         3 = FORWARD CIRCULATION
C         4 = REVERSE CIRCULATION
C         5 = FORWARD CIRCULATION COMPRESSIBLE
C         6 = DRILLING, LIQUID SYSTEMS
C             (RESET TO IFLOW = 3)
C         7 = DRILLING, GAS SYSTEMS
C             (RESET TO IFLOW = 5)
C         8 = DRILLING, MIST
C             (RESET TO IFLOW = 5)
C         9 = STEAM PRODUCTION
C        10 = STEAM INJECTION
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C     TIN1 = INLET TEMPERATURE OF FLOWING FLUID, F
C     VFRP = VOLUME FLOW RATE OF FLUID, GPM
C     VFRP = GAS FLOW RATE, SCF/MIN  GAS FLOW OPTIONS
C
      VFR3P=0.
      VFR2P=0.
      VFR3=0.
      NFLOW=0
      DAYS=0.0
    6 READ(5,*,END=50,ERR=52)DUMMY,IFLOW,ISEC,IPF,TIN1,VFRP,DAYCH
      I2PH=0
      TCHG = DAYCH*24.
      DDCHG=0.0
      HRC=0.0
C
C CHANGE CARD OPTIONS
C
C GAS FLOW OPTIONS (IFLOW 5,7,8) READ PSTAND
C
      IF((IFLOW-5)*(IFLOW-7)*(IFLOW-8).EQ.0)READ(5,*,END=50,ERR=52)
     & DUMMY,PSTAND
C
C MIST FLOW OPTION (IFLOW 8) READ VFR3P
C
      IF(IFLOW.EQ.8)READ(5,*,END=50,ERR=52)DUMMY,VFR3P
      VFR3=VFR3P*60./7.4805
C
C READ DRILLING PARAMETERS (IFLOW 6,7,8)
C     IBH = 0 NO BOTTOM HOLE ASSY CHANGE
C     IBH = 1 READ BOTTOM HOLE ASSY CARD
C     HRC = HOURS OF CIRCULATION DAILY
C     DDCHG = DEPTH REACHED AT TIME DAYCH
C
      IF((IFLOW-6)*(IFLOW-7)*(IFLOW-8).EQ.0)READ(5,*,END=50,ERR=52)
     & DUMMY,IBH,HRC,DDCHG
C
C READ BOTTOM HOLE ASSY DATA
C  DCLRL = LENGTH OF DRILL COLLAR ASSEMBLY, FT.
C  DCRIM = DRILL COLLAR I.D., IN.
C  DCROM = DRILL COLLAR O.D., IN.
C  BITRM = DRILL BIT DIAMETER, IN.
C  BITN(I) = BIT NOZZLE DIAMETER, IN.
C
      IF(IBH.EQ.1)READ(5,*,END=50,ERR=52)DUMMY,DCLRL,DCROM,DCRIM,BITRM,
     & (BITN(K),K=1,3)
C
C  SECONDARY FLOW
C
C  ISEC = 0  NO SECONDARY FLOW CHANGE
C  ISEC = 1  SECONDARY FLOW CHANGE
C
      IF(ISEC.EQ.1)READ(5,*,END=50,ERR=52)DUMMY,ISF,TIN2,VFR2P
C
C  VOLUME FLOW RATE FT3/HR
C
      VFR2=VFR2P*60./7.4805
C
C  TWO-PHASE STEAM PRODUCTION/INJECTION
C
      IF(IFLOW.LT.9)GO TO 54
```

```
C
C  IFLOW =  9  TWP-PHASE STEAM PRODUCTION
C  IFLOW = 10  TWO-PHASE STEAM INJECTION
C
      READ (5,*)DUMMY,ISTM,XXXX
      IF(ISTM.EQ.1)QUALS=XXXX
      IF(ISTM.EQ.2)PSTEM=XXXX
C
      TINK=(TIN1+459.67)/1.8
      CALL PSAT(PSTST,XX,TINK)
      PSTST=PSTST/6894.757
C
      IF(ISTM.EQ.1)PSTEM=PSTST
      IF(ISTM.EQ.1)GO TO 55
      IF(PSTEM.GT.PSTST)QUALS=0.
      IF(PSTEM.LE.PSTST)QUALS=1.
   55 CONTINUE
      IF(IFLOW.EQ.9)IFLOW=2
      IF(IFLOW.EQ.10)IFLOW=1
      NFLOW=1
      VFR=VFRP*60./7.4805
      I2PH=1
C
      WRITE(6,104)DAYS
      IF(IFLOW.EQ.2)WRITE(6,153)
      IF(IFLOW.EQ.1)WRITE(6,154)
      IF(ISTM.EQ.1)WRITE(6,155)QUALS
      IF(ISTM.EQ.2)WRITE(6,156)PSTEM
      WRITE(6,116)TIN1,VFRP,DAYCH
      CALL TUFAS
      GO TO 11
C
   54 CONTINUE
C
      IF(IFLOW.EQ.6)IFLOW=3
      IF(IFLOW.EQ.7)IFLOW=5
      IF(IFLOW.EQ.8)IFLOW=5
      WRITE (6,104) DAYS
      IF (IFLOW .EQ. 1) WRITE (6,108)
      IF (IFLOW .EQ. 2) WRITE (6,110)
      IF (IFLOW .EQ. 3) WRITE (6,112)
      IF (IFLOW .EQ. 5) WRITE (6,112)
      IF (IFLOW .EQ. 4) WRITE (6,114)
      IF(IFLOW.EQ.5.AND.IPF.EQ.1)WRITE(6,139)
      IF(IFLOW.EQ.5.AND.IPF.EQ.2)WRITE(6,140)
      IF(IFLOW.EQ.5.AND.IPF.EQ.3)WRITE(6,141)
      IF(IFLOW.EQ.5.AND.VFR3.GT.0.01)WRITE(6,149)VFR3P
      IF(NFLOW.EQ.0.AND.IFLOW.LT.5)GO TO 34
      NI(1)=1
      NI(2)=1
      NA(1,1)=IPF
      NA(1,2)=IPF
      TD1=TD
      IF(DDCHG.GT.0.10)TD1=DEPTH
      ZI(1,1)=TD1
      ZI(1,2)=TD1
      NFLOW=1
      IF(IFLOW.GT.4)GO TO 47
      NFLOW=0
   34 CONTINUE
```

```
      IF (IFLOW .LT. 1 .OR. IFLOW .GT. 5) WRITE (6,115)
      IF(IFLOW.EQ.1.OR.IFLOW.EQ.3)WRITE(6,130)IPF
      IF(IFLOW.EQ.2)WRITE(6,132)IPF
      IF(IFLOW.EQ.4)WRITE(6,134)IPF
      IF(NI(1).EQ.1.AND.NI(2).EQ.1)GO TO 45
      DO 46 JNT=1,2
      IF(JNT.EQ.1)WRITE(6,124)
      IF(JNT.EQ.2)WRITE(6,126)
      NIJ=NI(JNT)
      DO 46 INT=1,NIJ
      NN1=NIJ-INT+1
      ZTOP=0.
      IF(INT.GT.1)ZTOP=ZI(NN1+1,JNT)
   46 WRITE(6,128)NA(NN1,JNT),ZTOP,ZI(NN1,JNT)
      GO TO 47
   45 IF(NA(1,1).EQ.NA(1,2))WRITE(6,136)NA(1,1)
      IF(NA(1,1).NE.NA(1,2))WRITE(6,138)NA(1,1),NA(1,2)
   47 CONTINUE
      IF(ISEC.EQ.1)WRITE(6,152)ISF,TIN2,VFR2P
      IF(IFLOW.GT.4)GO TO 35
      WRITE (6,116) TIN1,VFRP,DAYCH
      GO TO 36
   35 VFR=VFRP
      WRITE(6,117)TIN1,VFR,DAYCH
      GO TO 37
C
C  CONVERT UNITS ON FLOW RATE, GAL/MIN TO FT3/HR
C     60 MIN/HR AND 7.4805 GAL/FT3
C
   36 VFR = VFRP*60./7.4805
   37 IF (HRC .GT. 0.) DRT = 24.*(DDCHG - DEPTH)/((TCHG - TIME)*HRC)
      IF(HRC.LE.0.0)DRT=0.0
      VFRC = VFR
      IF(DDCHG.LT.0.1)GO TO 11
      WRITE(6,145)DDCHG,HRC
      WRITE(6,146)DCLRL,DCRIM,DCROM
      WRITE(6,147)BITRM,(BITN(LL),LL=1,3)
      DCLRI=DCRIM/24.
      DCLRO=DCROM/24.
      BITR=BITRM/24.
      BITA=0.0
      DO 9 LL=1,3
    9 BITA=BITA+3.1416*(BITN(LL)/24.)**2
      IF(BITA.LE.0.0)BITA=3.14159*DCLRI**2
      KDR=DEPTH/(Z(2)-Z(1))+1.5
      IF(KDR.LE.1)KDR=2
   11 CONTINUE
C
C  FORM WELLBORE CONDUCTANCES
C
      DELT = 0.01
      DT = DELT*DTMAX
      IF(IFLOW.GT.4)CALL FLOW
      CALL COND
      CALL COEF
C
C  INCREMENT TIME
C
      IDRLL=0
    4 CONTINUE
```

```
      IF (DDCHG .GT. 0.1) GO TO 8
C
C  TIME INCREMENTS - NOT DRILLING
C
      DT=DELT*DTMAX
      GO TO 12
C
C  TIME INCREMENTS - DRILLING
C
    8 CONTINUE
      IF(HRC.GE.0.1)GO TO 10
      HRC=0.0
      VFR=0.
      DRT=0.0
      IDRLL=3
   10 IF(IDRLL.GE.3)GO TO 16
C
C  DRILLING
C
      DT=HRC/3.0
      IF(HRC.LE.2.0)DT=HRC/2.0
      IF(HRC.LE.1.0)DT=HRC
      IF(HRC.LE.2.0)IDRLL=1
      IF(HRC.LE.1.0)IDRLL=2
      VFR=VFRC
      IDRLL=IDRLL+1
      GO TO 12
C
C  SHUT-IN
C
   16 VFR=0.
      IF(IDRLL.EQ.3.AND.IFLOW.GT.4)CALL FLOW
      IF(IDRLL.EQ.3)CALL COND
      DT=8.0-HRC/3.0
      IF(HRC.GT.22.0)DT=12.-HRC/2.0
      IF(HRC.GT.23.0)DT=24.-HRC
      IF(HRC.GT.22.0)IDRLL=4
      IF(HRC.GT.23.0)IDRLL=5
      IDRLL=IDRLL+1
      IF(IDRLL.EQ.6)IDRLL=0
      IF(HRC.GT.23.9)HRC=24.0
      IF(HRC.GT.23.9)GO TO 8
C
C
   12 IF(TIME.GE.TCHG)GO TO 39
      IF(TIME+DT.GT.TCHG)DT=TCHG-TIME
      TIME = TIME + DT
      IF(DT.LT.0.01)DT=0.01
      DAYS = TIME/24.
      DELT=1.25*DELT
      IF (DDCHG .LT. 0.1) GO TO 14
      DRLRT = DRT
      IF (VFR .LT. 0.1) DRLRT = 0.
      DEPTH = DEPTH + DT*DRLRT
      KDRO = KDR
      ZCELL=Z(2)-Z(1)
      KDR=DEPTH/ZCELL+1.5
      IF(KDR.LE.1)KDR=2
      NZ=KDR+1
      NZP1=KDR+2
```

```
      IF (KDR .EQ. KDRO) GO TO 14
      IF(IFLOW.GT.4)CALL FLOW
      CALL COND
      CALL COEF
C
C  COMPUTE WELLBORE TEMPERATURES
C
   14 IF(IFLOW.GT.4)GO TO 40
      IF(VFR.LT.1.0)GO TO 40
      IF(NI(1).EQ.1.AND.NI(2).EQ.1.AND.IPF.EQ.NA(1,1))GO TO 40
C
C   UPDATE WELLBORE FLUID INTERFACES
C
      VF=VFR*DT
      VF2=0.
      IF(ISEC.EQ.1)VF2=VFR2*DT
      IF(IFLOW.EQ.2)GO TO 41
      JFLOW=1
      IF(IFLOW.EQ.4)JFLOW=2
      CALL DWNFLO(VF,IPF,IFLOW,JFLOW)
      IF(IFLOW.EQ.1)GO TO 42
   41 CALL UPFLOW(VF,VF2,IPF,IFLOW)
   42 CALL COND
      WRITE(6,120)DAYS
      DO 44 JNT=1,2
      IF(JNT.EQ.1)WRITE(6,124)
      IF(JNT.EQ.2)WRITE(6,126)
      NIJ=NI(JNT)
      DO 44 INT=1,NIJ
      NN1=NIJ-INT+1
      ZTOP=0.
      IF(INT.GT.1)ZTOP=ZI(NN1+1,JNT)
   44 WRITE(6,128)NA(NN1,JNT),ZTOP,ZI(NN1,JNT)
      GO TO 43
   40 IF(IFLOW.GT.4)CALL FLOW
      CALL COND
      CALL COEF
   43 CALL WELL
      IF ( TIME .LT. (TCHG-1.E-3) .AND. DDCHG .LT. 0.1) GO TO 4
      TLEFT=TCHG-TIME
      IF(IDRLL.EQ.0.AND.TLEFT.LE.23.99)GO TO 51
      IF(IDRLL.EQ.3.AND.TLEFT.LE.23.99)GO TO 51
      GO TO 4
   51 CONTINUE
C
C PRINT OPTION
C
      GPM = VFR*7.4805/60.
      WRITE (6,101) DAYS,NIT
      IF (DDCHG .GT. 0.1.AND.IFLOW.LE.4) WRITE (6,122) GPM,DEPTH
      IF(DDCHG.GT.0.1.AND.IFLOW.GE.5)WRITE(6,123)VFR,DEPTH
      WRITE (6,118) (R(I),I=1,5),R(NR1)
      WRITE (6,106) (Z(K),(TWJ(K,I),I=1,5),TWJ(K,NR1),K=1,NZP1)
      IF(I2PH.EQ.0)GO TO 58
      IF(IFLOW.EQ.2)WRITE(6,157)
      IF(IFLOW.EQ.1)WRITE(6,158)
      WRITE(6,159)
      DO 57 I=1,KDR
   57 WRITE(6,160)Z(I),PRESS(I,1),TWJ(I,1),
     & DVAP(I,1),DLIQ(I,1),VGAS(I,1),(IREGM(I,J),J=1,3)
```

```
   58 CONTINUE
      IF(IFLOW.LT.5)GO TO 39
      WRITE(6,142)
      WRITE(6,143)
      DO 38 I=1,KDR
      WRITE(6,144)Z(I),PRESS(I,1),TWJ(I,1),DENG(I,1),DLIQ(I,1),
     & DVAP(I,1),VGAS(I,1)
   38 CONTINUE
      WRITE(6,150)
      DO 338 I=1,KDR
      WRITE(6,151)Z(I),PRESS(I,2),TWJ(I,2),DENG(I,2),DLIQ(I,2),
     & DVAP(I,2),DCUT(I),VGAS(I,2),VCUT(I)
  338 CONTINUE
   39 CONTINUE
      IF (ABS((TIME - TCHG)/TIME) .LT. 0.001) GO TO 6
      IF(TIME.GE.TCHG)GO TO 6
      GO TO 4
   50 STOP
C
C  INPUT ERROR
C
   52 WRITE(6,148)
      STOP
C
C  FORMAT STATEMENTS
C
  101 FORMAT (///1X,"TIME =",F10.3," DAYS",30X,"ITERATIONS =",I3)
  104 FORMAT ("1"//2X,"S E T   V A R I A B L E S   AT TIME =",
     & F10.3," DAYS")
  106 FORMAT (3X,F8.0,3X,5F9.1,4X,F9.1)
  108 FORMAT (10X,"FLOWING OPTION = INJECTION")
  110 FORMAT (10X,"FLOWING OPTION = PRODUCTION")
  112 FORMAT (10X,"FLOWING OPTION = FORWARD CIRCULATION")
  114 FORMAT (10X,"FLOWING OPTION = REVERSE CIRCULATION")
  115 FORMAT (//10X,"FLOWING OPTION INCORRECTLY DEFINED"//)
  116 FORMAT (10X,"INLET TEMPERATURE =",F6.0," F"/
     & 10X,"FLOW RATE =",F6.0," GAL/MIN"/
     & 10X,"TIME TO CHANGE DATA =",F10.3," DAYS")
  117 FORMAT(10X,"INLET TEMPERATURE=",F6.0," F"/
     & 10X,"FLOW RATE =",F6.0," SCF/MIN"/
     & 10X,"TIME TO CHANGE DATA =",F10.3," DAYS")
  118 FORMAT (/17X,"T E M P E R A T U R E   ",
     & "D I S T R I B U T I O N"//30X,"RADIAL POSITIONS, FEET"/
     & 4X,"DEPTH, FT",1X,5F9.1,4X,F9.1/)
  120 FORMAT(/" FLUIDS IN WELL UPDATED AT TIME=",F10.3," DAYS")
  122 FORMAT (1X,"CONDITIONS SINCE LAST TIME STEP:"/
     & 5X,"FLOW RATE =",F5.0," GAL/MIN",
     & 5X,"CIRCULATION DEPTH =",F6.0," FT")
  123 FORMAT(" CONDITIONS SINCE LAST TIME STEP:"/
     & 5X,"FLOW RATE =",F5.0," SCF/MIN",
     & 5X,"CIRCULATION DEPTH =",F6.0," FT")
  124 FORMAT(18X," FLUIDS IN TUBING")
  126 FORMAT(18X," FLUIDS IN ANNULUS")
  128 FORMAT(20X," FLUID #",I2," FROM ",F7.0," FT.  TO ",F7.0," FT.")
  130 FORMAT(20X," FLUID #",I2," INJECTED INTO TUBING")
  132 FORMAT(20X," FLUID #",I2," PRODUCED")
  134 FORMAT(20X," FLUID #",I2," INJECTED INTO ANNULUS")
  136 FORMAT(20X," FLUID #",I2," IN WELL")
  138 FORMAT(20X," FLUID #",I2," IN TUBING"/
     @20X," FLUID #",I2," IN ANNULUS")
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  139 FORMAT(20X," AIR INJECTED INTO TUBING")
  140 FORMAT(20X," NITROGEN INJECTED INTO TUBING")
  141 FORMAT(20X," FOAM INJECTED INTO TUBING")
  142 FORMAT(//17X,"G A S   &   M I S T   D R I L L I N G"/
     & 10X,"F L O W I N G   S T R E A M   P R O P E R T I E S"//)
  143 FORMAT(27X,"T U B I N G"//2X,"DEPTH   PRESSURE    TEMP",8X,
     & "DENSITY-LBM/CF",7X,"VELOCITY"/3X,"FT",9X,"PSIA",5X,"F",8X,
     & "GAS   WATER   VAPOR",6X,"FT/SEC")
  144 FORMAT(1X,F7.0,3X,F7.1,2X,F6.1,1X,3F8.3,5X,F6.1)
  145 FORMAT (10X,"DEPTH TO CHANGE DATA =",F6.0," FT"/
     & 10X,"CIRCULATION TIME PER DAY =",F6.1," HRS"/)
  146 FORMAT(10X,"BOTTOM HOLE ASSEMBLY:"/12X,"DRILL COLLARS: "/
     & 14X,"LENGTH=",F5.0," FT,   I.D.=",F6.3," IN,   O.D.=",F6.3," IN")
  147 FORMAT( 12X,"DRILL BIT:"/14X,"DIAMETER=",F7.3," IN, NOZZLE",
     & " SIZES=",3F7.3," IN")
  148 FORMAT(//"********** ERROR ***********"//" CHECK CHANGE OPTIONS")
  149 FORMAT(10X,"MIST DRILLING: WATER ADDED AT",F6.1," GAL/MIN")
  150 FORMAT(/27X,"A N N U L U S"//2X,"DEPTH   PRESSURE    TEMP",12X,
     & "DENSITY-LBM/CF",10X,"VELOCITY-FT/SEC"/3X,"FT",9X,"PSIA",5X,"F",
     & 8X,"GAS   WATER   VAPOR   ROCKS",5X,"GAS    ROCKS")
  151 FORMAT(1X,F7.0,3X,F7.1,2X,F6.1,1X,4F8.3,2F8.1)
  152 FORMAT(10X,"SECONDARY FLOW"/20X,"FLUID #",I2/
     & 20X,"INLET TEMPERATURE=",F6.0," F"/20X,"FLOW RATE=",F6.0,
     &" GAL/MIN")
  153 FORMAT(10X,"FLOWING OPTION = TWO-PHASE STEAM PRODUCTION")
  154 FORMAT(10X,"FLOWING OPTION = TWO-PHASE STEAM INJECTION")
  155 FORMAT(10X,"STEAM QUALITY =",F6.3)
  156 FORMAT(10X,"INLET PRESSURE =",F8.1," PSIA")
  157 FORMAT(//17X,"S T E A M   P R O D U C T I O N"//)
  158 FORMAT(//17X,"S T E A M   I N J E C T I O N"//)
  159 FORMAT(8X,"F L O W I N G   S T R E A M   P R O P E R T I E S"//
     & 4X,"  DEPTH   PRESSURE    TEMP     DENSITY-LBM/FT3  VELOCITY"/
     & 4X,"    FT       PSIA       F         VAPOR   LIQUID   FT/SEC ")
  160 FORMAT(4X,F7.0,3X,F7.1,3X,F6.1,3X,F8.3,1X,F8.3,F9.1,7X,3A2)
  200 FORMAT (20X,3I5,3F10.0)
  201 FORMAT(20X,5F10.0)
  202 FORMAT(20X,4F10.0)
  203 FORMAT(A2)
C
      END
      SUBROUTINE READ
C
C  THIS SUBROUTINE READS THE PROBLEM PARAMETERS
C
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK12/ VFR2
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK14/ TSUR,BHT,TDEPTH,DEPTHT
      COMMON /BLK16/ NPF,NTS,KZP
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      CHARACTER DUMMY*10
      DIMENSION TITLE(20)
C
C  READ AND WRITE PROBLEM TITLE
C
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      READ (5,212) TITLE
  212 FORMAT (20A4)
      WRITE (6,124) TITLE
  124 FORMAT ("1"//1X,20A4//)
C
   31 READ(5,*)DUMMY,NTS
C
C  READ TUBING PARAMETERS
C
C     RI(J) = I.D. OF TUBING,IN.
C     RO(J) = O.D. OF TUBING,IN.
C     ZC(J) = BOTTOM OF TUBING INTERVAL,FT.
C     DZ(J) = CEMENT INTERVAL LENGTH,FT.
C
      READ(5,*)(J,RI(J),RO(J),ZC(J),DZ(J),I=1,NTS)
      DO 1 I=1,NTS
      IF(RO(1).GE.RO(I))GO TO 2
      RO(1)=RO(I)
    2 IF(RI(1).LT.RI(I))GO TO 3
      RI(1)=RI(I)
    3 J=I+5
      RO(J)=RO(I)
      RI(J)=RI(I)
      ZC(J)=ZC(I)
    1 DZ(J)=DZ(I)
      WRITE(6,101)
  101 FORMAT(///1X," T U B I N G  C O N F I G U R A T I O N"/
     &8X,"TUBING  ID,IN.  OD,IN.  TOP,FT.  BASE,FT.  CEMENT,FT.")
      DT1=0.
      DO 5 J=1,NTS
      JJ=J+5
      IF(J.GT.1)DT1=ZC(JJ-1)
    5 WRITE(6,103)J,RI(JJ),RO(JJ),DT1,ZC(JJ),DZ(JJ)
  103 FORMAT(9X,I2,2X,2F8.3,F9.0,F10.0,F10.1)
C
C
C  READ CASING PARAMETERS
C     RI(J) = ID OF CASING, IN
C     RO(J) = OD OF CASING, IN
C     ZC(J) = SETTING DEPTH OF CASING, FT
C     DZ(J) = CEMENT INTERVAL LENGTH ON CASING J, FT
C
   32 READ(5,*)DUMMY,NCS
      IF(NCS.EQ.0)GO TO 10
      DO 6 I=1,NCS
      READ(5,*)J,RI1,RO1,ZC1,DZ1
      J=J+1
      RI(J)=RI1
      RO(J)=RO1
      ZC(J)=ZC1
    6 DZ(J)=DZ1
  202 FORMAT (20X,I5,4F10.0)
      WRITE (6,102)
  102 FORMAT (///1X,"C A S I N G   P R O G R A M"/
     & 8X,"CASING",6X,"ID, IN",4X,"OD, IN",
     & 6X,"DEPTH, FT",2X,"CEMENT INTERVAL, FT")
      DO 66 I=1,NCS
      J=I+1
   66 WRITE(6,104)I,RI(J),RO(J),ZC(J),DZ(J)
   10 CONTINUE
```

```
  104 FORMAT (1X,I10,5X,2F10.3,2X,F10.0,7X,F10.0)
C
C   READ BOREHOLE GEOMETRY
C
C   DEPTH = INITIAL DEPTH, FT.
C   TD = TOTAL MEASURED DEPTH, FT.
C   TVD = TRUE VERTICAL DEPTH, FT.
C   DDVN = DEPTH OF DEVIATION, FT.
C   R(3) = BOREHOLE DIAMETER, IN.
C
   33 READ(5,*)DUMMY,DEPTH,TD,TVD,DDVN,R(3)
  210 FORMAT(20X,5F10.0)
      WRITE(6,222)
  222 FORMAT(//" W E L L    G E O M E T R Y"/)
      WRITE(6,224)TD,R(3)
  224 FORMAT(10X," TOTAL DEPTH=",F10.0," FT."/
     @10X," BORE DIAMETER=",F10.3," IN.")
      IF(TD.GT.TVD)WRITE(6,226)DDVN,TVD
  226 FORMAT(10X," NOTE: DEVIATED WELL"/
     @10X," DEPTH OF DEVIATION=",F10.0," FT."/
     @10X," TRUE VERTICAL DEPTH=",F10.0," FT.")
C
C   COMPLETE CASING DESCRIPTION
C
   38 IF(R(3).LE.RO(NCS+1))R(3)=RO(NCS+1)+FLOAT(5-NCS)
      IF(NCS.EQ.4)GO TO 22
      DO 8 II=NCS,3
      I=II+1
      J=II+2
      RO(J)=RO(I)+1.1
      RI(J)=RO(I)+.9
      ZC(J)=1.0
    8 DZ(J)=0.0
   22 CONTINUE
C
C  READ INITIAL TEMPERATURES
C
   34 READ (5,*)DUMMY,TSUR,BHT,TDEPTH,DEPTHT
  214 FORMAT (20X,4F10.0)
      IF(TVD.EQ.TD)WRITE(6,208)
      IF(ABS(TD-DDVN).LT.1.)TD=TD+1.
      IF(ABS(DEPTHT*(TVD-DEPTHT)).LT.1.)DEPTHT=DEPTHT+1.
      IF(TVD.LE.TD)GO TO 11
      TVD=TD-1.
      WRITE(6,209)
  208 FORMAT(//" NOTE: TRUE DEPTH=MEASURED DEPTH")
  209 FORMAT(//" NOTE: TMD INPUT SMALLER THAN TVD, SET TVD=TMD")
   11 CONTINUE
C
C   READ FLUID PROPERTIES
C
C   DENFP(I) = DENSITY OF FLUID I,LBM/GAL
C   PVFP(I) = PLASTIC VISCOSITY OF FLUID I, CENTIPOISE
C   YPFP(I) = YIELD POINT OF FLUID I, LBF/100FT2
C
   35 READ(5,*)DUMMY,NPF
      WRITE(6,107)
  107 FORMAT(///1X,"W E L L B O R E   F L U I D  P R O P E R T ",
     @"I E S")
      DO 9 I=1,NPF
```

```
      READ(5,*)J,DENFP(J),PVFP(J),YPFP(J)
  216 FORMAT(20X,I5,3F10.0,6A4)
      WRITE(6,116)J
  116 FORMAT(/10X,"FLUID TYPE NO.",I5/)
      WRITE(6,117)DENFP(J)
  117 FORMAT(10X,"DENSITY=",F6.1," LBM/GAL")
      WRITE(6,118)PVFP(J)
  118 FORMAT(10X,"PLASTIC VISCOSITY=",F5.0," CENTIPOISE")
      WRITE(6,119)YPFP(J)
  119 FORMAT(10X,"YIELD POINT=",F4.0," LBF/100FT2")
    9 CONTINUE
C
C INITIALIZE FLUID PROPERTIES
C   IPF=PRIMARY FLUID #
C   ISF=SECONDARY FLUID #
C   IAF=ANNULAR FLUID #
C   TIN2=INLET TEMP FOR SECONDARY FLUID, F.
C   VFR2=VOLUME FLOW RATE OF SECONDARY FLUID, GPM
C
   36 READ(5,*)DUMMY,IPF,IAF
      ISF=1
      VFR2=0.
      TIN2=70.
  204 FORMAT(20X,3I5,2F10.0)
      WRITE(6,218)
  218 FORMAT(//1X,"W E L L B O R E   I N I T I A L   S T A T E"/)
      WRITE(6,219)IPF,IAF
  219 FORMAT(10X," FLUID #",I2," IN TUBING & TUBING ANNULUS"/
     @10X," FLUID #",I2," IN CASING - CASING ANNULI")
      DO 12 I=1,NPF
      IF((DENFP(I)-21.)*(8.32-DENFP(I)).LT.0.)WRITE(6,106)I,DENFP(I)
  106 FORMAT (/1X,10("*"),2X,"CAUTION FLUID",I3,"  DENSITY =",
     & F6.1," LBM/GAL",2X,10("*")/)
   12 CONTINUE
C
C      INITIALIZE INTERFACE PARAMETERS
C
      TD1=TD
      ZI(1,1)=TD1
      ZI(1,2)=TD1
      NA(1,1)=IPF
      NA(1,2)=IPF
      NI(1)=1
      NI(2)=1
C
   37 RETURN
      END
      SUBROUTINE PROP
C
C  THIS SUBROUTINE DEFINES PROPERTIES OF THE FOLLOWING MATERIALS:
C      STEEL,CEMENT,WELLBORE FLUIDS,AND SOIL
C
      COMMON /BLK9/  DENS(150),SHS(150),CONS(150)
      COMMON /BLK10/ DENST,SHST,CONST,DENC,SHC,CONC
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK12/ VFR2
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK16/ NPF,NTS,KZP
C
```

```
C  SOIL PROPERTIES
C
C     DENS = DENSITY OF SOIL, LBM/FT3
C     SHS = SPECIFIC HEAT CAPACITY OF SOIL, BTU/LBM-F
C     CONS = THERMAL CONDUCTIVITY OF SOIL, BTU/HR-FT-F
C
      DATA DENS/150*140./,SHS/150*0.30/,CONS/150*2.0/
C
C  STEEL AND CEMENT PROPERTIES
C
C     DENST = DENSITY OF STEEL, LBM/FT3
C     SHST = SPECIFIC HEAT CAPACITY OF STEEL, BTU/LBM-F
C     CONST = THERMAL CONDUCTIVITY OF STEEL, BTU/HR-FT-F
C     DENC = DENSITY OF CEMENT, LBM/FT3
C     SHC = SPECIFIC HEAT CAPACITY OF CEMENT, BTU/LBM-F
C     CONC = THERMAL CONDUCTIVITY OF CEMENT, BTU/HR-FT-F
C
      DATA DENST/490./,SHST/0.11/,CONST/26.2/
      DENC=104.
      SHC=0.20
      CONC=0.50
C
C  FLUID PROPERTIES
C
C     DENFP(I) = DENSITY OF FLUID I , LBM/GAL TO LBM/FT3
C     SHFP(I) = SPECIFIC HEAT CAPACITY OF FLUID I , BTU/LBM-F
C     CONFP(I) = THERMAL CONDUCTIVITY OF FLUID I , BTU/HR-FT-F
C
      DO 1 I=1,NPF
      IF (DENFP(I) .GT. 8.32) GO TO 2
      WRITE (6,102) I,DENFP(I)
  102 FORMAT (/2X,10("*")/5X,"FLUID TYPE=",I2," DENSITY =",
     & F8.3," LBM/GAL"/9X,"COMPARED TO 8.33 FOR WATER"/2X,10("*")/)
    2 IF (DENFP(I) .GT. 10.3) GO TO 4
      SF = 0.0798*(DENFP(I) - 8.33)
      IF(SF.LT.0.0)SF=0.0
      GO TO 6
    4 SF = 0.0318*(DENFP(I) - 10.3) + 0.162
    6 DENFP(I)= DENFP(I)*7.4805
      SHFP(I) = 1. - 0.777*SF
      CONFP(I) = 0.399 + 9.6*SF
    1 CONTINUE
      RETURN
      END
      SUBROUTINE GRID
C
C THIS SUBROUTINE FORMS THE R-Z GRID
C
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK16/ NPF,NTS,KZP
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      DATA NR/10/,RMAX/50.0/,DDEPTH/200./
C
C CHANGE DIAMETERS TO RADII, CHANGE INCHES TO FEET
C
      K=NTS+5
      DO 2 I=1,K
```

```
      RI(I) = RI(I)/24.
    2 RO(I) = RO(I)/24.
C
C  INITIALIZE DRILLING DATA
C
      DCLRL=-200.
      DCLRI=RI(K)
      DCLRO=RO(K)
      BITA=PI*DCLRI**2
      BITR=RI(2)
C
C  SOIL RADII
C
      R(1) = RI(1)/2.
      R(2) = (RI(2) + RO(1))/2.
      R(3) = R(3)/24.
      DR(3) = R(3) - R(2)
      CR = 0.1
      DCR = 1.0
      NR1 = NR + 1
      NIT = 0
    6 CR = CR + DCR
      NIT = NIT + 1
      DO 8 I=4,NR1
    8 DR(I) = DR(I-1)*CR
      DO 10 I=4,NR1
   10 R(I) = R(I-1) + (DR(I) + DR(I-1))/2.
      IF (RMAX .GT. R(NR1)) GO TO 6
      CR = CR - DCR
      DCR = DCR/10.
      IF (ABS(R(NR1) - RMAX)/RMAX .LT. 1.E-3) GO TO 12
      IF (NIT .LT. 50) GO TO 6
      WRITE (6,102)
  102 FORMAT (/2X,10("*"),2X,"RADIAL COORDINATES NOT CONVERGED",2X,
     & 10("*")/)
   12 CONTINUE
C
C  COMPUTE AREAS
C
      DO 14 I=1,NR
      R1 = (R(I) + R(I+1))/2.
      RR = 0.
      IF (I .GT. 1) RR = R(I-1)
      R2 = (RR + R(I))/2.
   14 AR(I) = PI*(R1*R1 - R2*R2)
      DO 15 I=1,NTS
      ATA(I,1)=PI*RI(I+5)**2
   15 ATA(I,2)=PI*(RI(2)**2-RO(I+5)**2)
C
C  DEFINE VERTICAL SECTIONS
C
      KDR = 1.5 + (TD + 1.)/DDEPTH
      NZ = KDR + 1
      NZP1 = NZ + 1
      DO 4 K=1,NZP1
    4 Z(K) = (K-1)*DDEPTH
      RETURN
      END
      SUBROUTINE COND
C
```

```
C  THIS SUBROUTINE DEFINES THE CONDUCTANCES BETWEEN CELLS.
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK4/ U(151,20),Q(151,2)
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK9/  DENS(150),SHS(150),CONS(150)
      COMMON /BLK10/ DENST,SHST,CONST,DENC,SHC,CONC
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK5/ CAN(5)
      COMMON /BLK16/ NPF,NTS,KZP
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
      DIMENSION RTI(10,2)
C
C  RESISTANCE TERMS
C
      DO 1 I=1,NTS
      RTI(I,1) = ALOG(RO(I+5)/RI(I+5))/CONST
    1 RTI(I,2) = ALOG( R(2)/RO(I+5))
      RT3=ALOG(RI(2)/R(2))
      RT4 = ALOG(RO(2)/RI(2))/CONST
      RT5 = ALOG(RI(3)/RO(2))
      RT6 = ALOG(RO(3)/RI(3))/CONST
      RT7 = ALOG(RI(4)/RO(3))
      RT8 = ALOG(RO(4)/RI(4))/CONST
      RT9 = ALOG(RI(5)/RO(4))
      RT10 = ALOG(RO(5)/RI(5))/CONST
      RT11 = ALOG(R(3)/RO(5))
      RT12 = ALOG(R(3)/RI(5))
      RT13 = ALOG(R(3)/RI(4))
      RT14 = ALOG(R(3)/RI(3))
C
C  COMPUTE WELLBORE CONDUCTANCES
C
      DO 22 K=1,KDR
      ZKP = Z(KDR)
      IF (K .LT. KDR) ZKP = (Z(K) + Z(K+1))/2.
      ZKM = Z(1)
      IF (K .GT. 1) ZKM = (Z(K) + Z(K-1))/2.
C
C  DETERMINE CASING STRINGS THROUGH CELL AT Z(K)
C
      J=5
   26 IF (ZKP .LT. ZC(J)+0.1) GO TO 28
      J=J-1
      IF(J.EQ.1)GO TO 28
      GO TO 26
   28 II = 0
C
C  AVERAGE TUBING GEOMETRY
C
      KZP=KTUBE(ZKP)-5
      RT1=RTI(KZP,1)
      RT2=RTI(KZP,2)
      RIK=RI(KZP+5)
      ROK=RO(KZP+5)
```

```
      KZM=KTUBE(ZKM)-5
      IF(KZP.EQ.KZM)GO TO 2
      ZMM=ZC(KZM+5)
      PF1=(ZKP-ZMM)/(ZKP-ZKM)
      PF2=(ZMM-ZKM)/(ZKP-ZKM)
      RT1=RT1*PF1+PF2*RTI(KZM,1)
      RT2=RT2*PF1+PF2*RTI(KZM,2)
      RIK=PF1*RIK+PF2*RI(KZM+5)
      ROK=PF1*ROK+PF2*RO(KZM+5)
    2 CONTINUE
      TMT=TWJ(K,1)
      TMA=TWJ(K,2)
      TMM=TMA*(R(1)-RIK)/(R(1)-R(2))+TMT*(RIK-R(2))/(R(1)-R(2))
C
C  SUM RESISTANCES
C
   36 R12 = RT1
      R23=1.E-20
      GO TO (10,12,14,16,18),J
   10 CALL CONAN(2,K,ZKP,ZKM)
      IF (DEPTH .GT. ZC(1)) R23 = RT14/CONS(K)
      GO TO 20
   12 CALL CONAN(2,K,ZKP,ZKM)
      IF (DEPTH .GT. ZC(3)) R23 = RT14/CONS(K)
      GO TO 20
   14 CALL CONAN(3,K,ZKP,ZKM)
      IF (DEPTH .GT. ZC(4)) R23 = RT13/CONS(K)
      IF (DEPTH .GT. ZC(3)) R23 = R23 + RT7/CAN(3) + RT6
      GO TO 20
   16 CALL CONAN(4,K,ZKP,ZKM)
      IF (DEPTH .GT. ZC(5)) R23 = RT12/CONS(K)
      IF (DEPTH .GT. ZC(4)) R23 = R23 + RT9/CAN(4) + RT8
      IF (DEPTH .GT. ZC(3)) R23 = R23 + RT7/CAN(3) + RT6
      GO TO 20
   18 CALL CONAN(5,K,ZKP,ZKM)
      R23 = 1.E-20
      IF (DEPTH .GT. ZC(5)) R23 = RT11/CAN(5) + RT10
      IF (DEPTH .GT. ZC(4)) R23 = R23 + RT9/CAN(4) + RT8
      IF (DEPTH .GT. ZC(3)) R23 = R23 + RT7/CAN(3) + RT6
   20 IF (DEPTH .GT. ZC(2)-1.) R23 = R23 + RT5/CAN(2) + RT4
C
      IF(IFLOW.GT.4)GO TO 200
      IF(VFR.LT.1.0)GO TO 100
      IF(I2PH.GT.0)GO TO 310
C
C  TUBING CIRCULATION-LIQUIDS
C
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,ZKP,ZKM,1)
      VIS=VISC(TMT,0.,0.,RIK,VFR,PVF,YPF)
      H1=CONV(VFR,VIS,DENF,SHF,CONF,0.,RIK)
      IF(IFLOW.LE.2)GO TO 300
C
C  ANNULUS CIRCULATION-LIQUIDS
C
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,ZKP,ZKM,2)
      VIS=VISC(TMA,0.,ROK,RI(2),VFR,PVF,YPF)
      H2=CONV(VFR,VIS,DENF,SHF,CONF,ROK,RI(2))
      GO TO 41
C
C  SHUT-IN TUBING-LIQUIDS
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```
C
  100 CALL FPROP(DENF,PVF,YPF,SHF,CONF,ZKP,ZKM,1)
      VIS=VISC(TMT,TMM,0.,RIK,DENF,PVF,YPF)
      DZL=ZKP-ZKM
C     H1=HTUBE(TMT,TMM,DZL,DENF,VIS,CONF,SHF,0)
      H1=HTUBE(TMT,TMM,0.,RIK,DENF,VIS,CONF,SHF,0)
      IF(IFLOW.LE.2)GO TO 300
C
C  SHUT-IN ANNULUS-LIQUIDS
C
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,ZKP,ZKM,2)
      VIS=VISC(TMA,TMM,ROK,R(2),DENF,PVF,YPF)
      CNA=CONVN(VIS,DENF,SHF,CONF,ROK,R(2),TMA,TMM)
      GO TO 42
C
C  ANNULUS PRODUCTION-INJECTION CASES
C
  300 CNA=CAN(1)
      GO TO 42
C
C  COMPRESSIBLE FLOW-TUBING
C
  200 CALL GPROP(DENT,SHT,SHTCV,CONT,VIST,VFT,K,1)
      CALL GPROP(DENA,SHA,SHACV,CONA,VISA,VFA,K,2)
      VFT=VFT*PI*RIK**2*3600.0
      VFA=VFA*PI*(RI(2)**2-ROK**2)*3600.0
      IF(VFT.LT.1.0)GO TO 210
      H1=CONV(VFT,VIST,DENT,SHT,CONT,0.,RIK)
C
C  COMPRESSIBLE FLOW-ANNULUS
C
      H2=CONV(VFA,VISA,DENA,SHA,CONA,ROK,RI(2))
      GO TO 41
C
C  COMPRESSIBLE CONVECTION
C
  210 DZL=ZKP-ZKM
C
C  TUBING CONVECTION
C
C     H1=HTUBE(TMT,TMM,DZL,DENT,VIST,CONT,SHT,1)
      H1=HTUBE(TMT,TMM,0.,RIK,DENT,VIST,CONT,SHT,1)
C
C  ANNULUS CONVECTION
C
      CNA=CONVN(VISA,DENA,SHA,CONA,ROK,R(2),TMA,TMM)
      GO TO 42
C
C  TWO-PHASE CONVECTION
C
  310 CALL GPROP(DENT,SHT,SHTCV,CONT,VIST,VFT,K,1)
      VFT=VFT*PI*RIK**2*3600.
      H1=CONV(VFT,VIST,DENT,SHT,CONT,0.,RIK)
      GO TO 300
C
   41 U(K,1)=2.0*PI/(1./(H1*RIK)+RT1+1./(H2*ROK))
      U(K,2)=2.0*PI/(R23+1./(H2*ROK))
      GO TO 22
   42 U(K,1)=2.0*PI/(1./(H1*RIK)+RT1+RT2/CNA)
      U(K,2)=2.0*PI/(R23+RT2/CNA)
```

```
   22 CONTINUE
C
C  SOIL CONDUCTANCES
C
      R1 = 2.*PI/ALOG(R(2)/R(1))
      R2 = 2.*PI/ALOG(R(3)/R(2))
      K1 = KDR + 1
      DO 30 K=K1,NZP1
      U(K,1) = R1*CONS(K)
   30 U(K,2) = R2*CONS(K)
      DO 8 I=3,NR
      RR = 2.*PI/ALOG(R(I+1)/R(I))
      DO 8 K=1,NZP1
    8 U(K,I) = RR*CONS(K)
      RETURN
      END
      FUNCTION HTUBE(TF,TC,RI,RO,DEN,VIS,CON,SH,IND)
      G=4.17E8
C     FUNCTION HTUBE(TF,TC,ZL,DEN,VIS,CON,SH,IND)
      BETA=0.0005
      IF(IND.EQ.1)BETA=1./(459.67+TF)
C   CHANGED SO THAT NUSSELT NUMBER H BASED ON RADIUS
      ZL= RO-RI
      GR=G*BETA*DEN**2*ZL**3*ABS(TF-TC)/VIS**2
      PR=VIS*SH/CON
      GRPR=GR*PR
C     IF(GRPR.GT.1.E9)H=0.129*GRPR**.3333
C     IF(GRPR.GT.1.E4.AND.GRPR.LE.1.E9)H=0.59*GRPR**.25
C     IF(GRPR.GE.0.1.AND.GRPR.LE.1.E4)H=.678*(0.952+PR)**(-.25)*
C    & SQRT(PR)*GR**.25
      H=0.59*GRPR**.25
      IF(GRPR.LT.0.1)H=1.0
      HTUBE=H*CON/ZL
      RETURN
      END
      SUBROUTINE COEF
C
C THIS SUBROUTINE COMPUTES THE COEFFICIENTS.
C
      COMMON /BLK2/ A(151,20),B(151,20),C(151,20),D(151,20),E(151,20),
     & QDOT(151,3)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK4/ U(151,20),Q(151,2)
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK7/ F(151,3),G(151,3)
      COMMON /BLK9/  DENS(150),SHS(150),CONS(150)
      COMMON /BLK10/ DENST,SHST,CONST,DENC,SHC,CONC
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK12/ VFR2
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK18/ DENG(151,2),PRESS(151,2),VGAS(151,2)
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      COMMON /BLK20/ DCUT(151),VCUT(151),DLIQ(151,2),DVAP(151,2),DRT,
     & VFR3
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
C
      DENF=DENFP(IPF)
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      SHF=SHFP(IPF)
      SHFCV=SHF
      VFRV=VFR
      IF(IFLOW.LE.4.AND.I2PH.EQ.0)GO TO 9
C     IF(IFLOW.LE.4)GO TO 9
      CALL GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,1,1)
      VFRV=VEL*ATA(1,1)*3600.
    9 CONTINUE
      FRMAS=DENF*VFRV
      FR1 = 2.*VFRV*DENF*SHF
      FR2 = 2.*VFR2*DENFP(ISF)*SHFP(ISF)
      FR3 = FR1 + FR2
      FFR = 0.
C
C  WELLBORE COEFFICIENTS
C
      DO 3 I=1,3
      IF(I.LE.2)AF=ATA(1,I)
      IF(I.EQ.3)AF=PI*(RI(3)**2-RO(2)**2)
      AP=PI*(RO(I)**2-RI(I)**2)
      IF(I.EQ.1)AP=PI*(RO(6)**2-RI(6)**2)
      IF(IFLOW.GT.4.AND.I.LT.3)GO TO 13
      IF(I2PH.GT.0.AND.I.EQ.1)GO TO 13
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,10.,0.,I)
      SHFCV=SHF
      GO TO 14
   13 CALL GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,1,I)
   14 CONTINUE
      HH=(DENF*SHFCV*AF+DENST*SHST*AP)/DT
      IFL = 0
      IF (I .EQ. 2 .AND. IFLOW .LE. 2) IFL = 1
      IF (FR1 .GT. 1. .AND. I .NE. 3 .AND. IFL .EQ. 0) GO TO 20
C
C  NO FLOW CONDITIONS
C
      UKIM1 = 0.
      KK = 2
      IF (I .LE. 2) KK = 1
      DO 22 K=KK,KDR
      IF(I.GT.2)GO TO 30
      Z1=Z(K)
      I1=KTUBE(Z1)
      AP=PI*(RO(I1)**2-RI(I1)**2)
      IF(IFLOW.GT.4.AND.I.LT.3)GO TO 15
      IF(I2PH.GT.0.AND.I.EQ.1)GO TO 15
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,Z1+10.,Z1-10.,I)
      SHFCV=SHF
      GO TO 16
   15 CALL GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,K,I)
   16 CONTINUE
      HH=(DENF*SHFCV*ATA(I1-5,I)+DENST*SHST*AP)/DT
   30 IF (I .NE. 1) UKIM1 = U(K,I-1)
      H = U(K,I) + UKIM1 + HH
      C(K,I) = UKIM1/H
      D(K,I) = U(K,I)/H
      QDOT(K,I)=0.0
   22 E(K,I) = HH/H
      GO TO 3
C
C  FLOWING CONDITIONS
```

```
C
   20 IF(I.EQ.2)GO TO 4
      FFR=FR1
      IF(IFLOW.EQ.2)FFR=-FR1
      IF(IFLOW.EQ.4)FFR=-FR1-FR2
      UKIM1=0.
      UK1IM1=0.
      GO TO 12
    4 FFR=FR1
      IF(IFLOW.EQ.3)FFR=-FR1-FR2
      IF(IFLOW.EQ.5)FFR=-FR1-FR2
      IF(KDR.EQ.(NZ-1))GO TO 12
      JJ=0
      IF(DEPTH.GT.ZC(5))JJ=5
      IF(DEPTH.GT.ZC(4))JJ=4
      IF(DEPTH.GT.ZC(3))JJ=3
      RR=R(3)
      IF(JJ.NE.0)RR=RI(JJ)
      AF=PI*(RR**2-RO(6)**2)
      AP=0.
      IF(JJ.NE.0)AP=PI*(RO(JJ)**2-RI(JJ)**2)
      HH=(DENF*SHF*AF+DENST*SHST*AP)/DT
   12 DO 2 K=2,KDR
      Z1=Z(K)
      I1=KTUBE(Z1)
      AP=PI*(RO(I1)**2-RI(I1)**2)
      DV2=0.0
      DHVAP=0.0
      IF(IFLOW.GT.4.AND.I.LT.3)GO TO 17
      IF(I2PH.GT.0.AND.I.EQ.1)GO TO 17
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,Z1+10.,Z1-10.,I)
      SHFCV=SHF
      GO TO 18
   17 CALL GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,K,I)
      CALL GPROP(DKM1,SKM1,SKM1CV,CKM1,VSKM1,VKM1,K-1,I)
      IF(I2PH.GT.0)GO TO 18
      G1KM1=DENG(K-1,I)*VGAS(K-1,I)*3600.
      G1K=DENG(K,I)*VGAS(K,I)*3600.
      ARK=FRMAS/G1K
      ARKM1=FRMAS/G1KM1
      DV2=FRMAS*(VKM1*VKM1-VEL*VEL)/(Z(K)-Z(K-1))
      DV2=DV2*3.9942E-5
      DMSL=DLIQ(K-1,I)*VGAS(K-1,I)*ARKM1-DLIQ(K,I)*VGAS(K,I)*ARK
      DHVAP=2000.*DMSL/(Z(K)-Z(K-1))
      IF(I.EQ.2)DV2=-DV2
      IF(I.EQ.2)DHVAP=-DHVAP
   18 CONTINUE
      HH=(DENF*SHFCV*ATA(I1-5,I)+DENST*SHST*AP)/DT
      HHKM1=HH
      IF(IFLOW.GT.4)HHKM1=(DKM1*SHFCV*ATA(I1-5,I)+DENST*SHST*AP)/DT
      FR1=2.*FRMAS*SHF
      FFR=FR1
      IF(I.EQ.1.AND.IFLOW.EQ.2)FFR=-FR1
      IF(I.EQ.1.AND.IFLOW.EQ.4)FFR=-FR1-FR2
      IF(I.EQ.2.AND.IFLOW.EQ.3)FFR=-FR1-FR2
      IF(I.EQ.2.AND.IFLOW.EQ.5)FFR=-FR1-FR2
      FR = FFR/(Z(K) - Z(K-1))
      IF (I .EQ. 1) GO TO 6
      UKIM1 = U(K,I-1)
      UK1IM1 = U(K-1,I-1)
```

```
    6 H = FR + U(K,I) + UKIM1 + HH
      A(K,I) = (FR - U(K-1,I) - UK1IM1 - HHKM1)/H
      C(K,I) = UKIM1/H
      D(K,I) = U(K,I)/H
      E(K,I) =  HH/H
      F(K,I) = UK1IM1/H
      QDOT(K,I)=(DV2+DHVAP)/H
    2 G(K,I) = U(K-1,I)/H
    3 CONTINUE
C
C  SOIL COEFFICIENTS
C
      DO 8 I=1,NR
      AREA = AR(I)
      UKIM1 = 0.
      KK = 2
      IF (I .LT. 4) KK = KDR + 1
      DO 8 K=KK,NZ
      HH = DENS(K)*SHS(K)*AREA/DT
      DDZ = Z(K+1) - Z(K)
      CON1 = AREA*(CONS(K-1) + CONS(K))/(4.*(Z(K) - Z(K-1))**2)
      CON2 = AREA*(CONS(K) + CONS(K+1))/(4.*DDZ*DDZ)
      IF (I .GT. 1) UKIM1 = U(K,I-1)
      H = CON1 + CON2 + UKIM1 + U(K,I) + HH
      A(K,I) = CON1/H
      B(K,I) = CON2/H
      C(K,I) = UKIM1/H
      D(K,I) = U(K,I)/H
    8 E(K,I) = HH/H
C
      RETURN
      END
      SUBROUTINE WELL
C
C THIS SUBROUTINE COMPUTES THE TEMPERATURES IN THE WELLBORE
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK2/ A(151,20),B(151,20),C(151,20),D(151,20),E(151,20),
     & QDOT(151,3)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK4/ U(151,20),Q(151,2)
      COMMON /BLK7/ F(151,3),G(151,3)
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
C
C INITIALIZE
C
      NIT = 0
      DO 10 I=1,NR
      DO 10 K=1,NZP1
   10 TW(K,I) = TWJ(K,I)
C
C ITERATE
C
    8 NIT = NIT + 1
```

```
C
C COMPUTE NEW TEMPERATURES
C
      BIG = 0.
      DO 20 I=1,3
C
C  CHECK FOR FLOWING STREAM
C
      Z1=Z(KDR)
      IF(IFLOW.GT.4.AND.I.LE.2)GO TO 33
      IF(I2PH.GT.0.AND.I.EQ.1)GO TO 33
      CALL FPROP(DENF,PVF,YPF,SHF,CONF,Z1+10.,Z1-10.,I)
      VFRV=VFR
      GO TO 34
   33 CALL GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,KDR,I)
      KB=KTUBE(Z(KDR))-5
      VFRV=VEL*ATA(KB,I)*3600.
   34 CONTINUE
      FR1=2.*VFRV*DENF*SHF
      FR3=FR1+FR2
      IFL = 0
      IF (I .EQ. 2 .AND. IFLOW .LE. 2) IFL = 1
      IF(VFR.LT.1.0)GO TO 24
      IF(I.EQ.3)GO TO 24
      IF(IFL.EQ.1)GO TO 24
      GO TO 26
   24 CONTINUE
C
C  NO FLOW CONDITIONS
C
      KK = 2
      IF (IFLOW .LE. 2 .AND. I .EQ. 1) KK = 1
      IF (IFLOW .GE. 3 .AND. I .LE. 2) KK = 1
      DO 28 K=KK,KDR
      TKIM1 = 0.
      IF (I .GT. 1) TKIM1 = TWJ(K,I-1)
      TOLD = TWJ(K,I)
      IF(I.GT.1)GO TO 25
      IF(I2PH.GT.0.AND.ISKIP(K,1).EQ.1)GO TO 27
   25 TWJ(K,I) = C(K,I)*TKIM1 + D(K,I)*TWJ(K,I+1) + E(K,I)*TW(K,I)
   27 DIFF = ABS(TOLD - TWJ(K,I))
   28 IF (DIFF .GT. BIG) BIG = DIFF
      GO TO 20
C
C  FLOWING STREAM CALCULATIONS
C
   26 JFLOW = 0
      IF (I .EQ. 2) GO TO 2
      IF (IFLOW .EQ. 2 .OR. IFLOW .EQ. 4) JFLOW = 1
      GO TO 4
    2 IF (IFLOW .EQ. 3) JFLOW = 1
      IF(IFLOW.EQ.5)JFLOW=1
    4 CONTINUE
      IF (JFLOW .EQ. 0) GO TO 6
C
C  COMPUTE UP FROM BOTTOM
C
      IF (I .EQ. 2) GO TO 30
      TWJ(KDR,1) = TIN1
      IF (IFLOW .EQ. 4) TWJ(KDR,1) = (TWJ(KDR,2)*FR1 + TIN2*FR2)/FR3
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```
      GO TO 32
   30 TWJ(KDR,2) = (TWJ(KDR,1)*FR1 + TIN2*FR2)/FR3
      IF(IFLOW.LE.4)GO TO 32
      CALL GPROP(DEN1,SHF1,SHFCV,CONF1,VIS1,VEL1,KDR,1)
      CALL GPROP(DEN2,SHF2,SHFCV,CONF2,VIS2,VEL2,KDR,2)
      TGAS=(TWJ(KDR,1)*SHF1-(VEL2**2-VEL1**2)*1.9971E-5)/SHF1
      TROCK=TWJ(KDR+1,1)
      TWJ(KDR,2)=(TGAS-TROCK)*DEN1*SHF1/DEN2/SHF2+TROCK
   32 CONTINUE
      DO 14 M=2,KDR
      K = KDR - M + 2
      TOLD=TWJ(K-1,I)
      IF(I2PH.GT.0.AND.ISKIP(K-1,1).EQ.1)GO TO 64
      TKIM1 = 0.
      TT = G(K,I)*TWJ(K-1,I+1)
      IF (I .EQ. 1) GO TO 5
      TKIM1 = TWJ(K,I-1)*C(K,I)
      TT = TT + F(K,I)*TWJ(K-1,I-1)
    5 TOLD = TWJ(K-1,I)
      IF (I .EQ. 1) GO TO 60
      TDIF = TWJ(K,I) - TKIM1
      IF (ABS(TDIF/TKIM1) .LT. 0.001) TDIF = 0.
      TDIFF = TDIF - D(K,I)*TWJ(K,I+1)
      GO TO 62
   60 TDIF = TWJ(K,I) - D(K,I)*TWJ(K,I+1)
      IF (ABS(TDIF/TWJ(K,I)) .LT. 0.001) TDIF = 0.
      TDIFF = TDIF - TKIM1
   62 AT = TDIFF - E(K,I)*(TW(K-1,I) + TW(K,I)) - TT
      AT=AT-QDOT(K,I)
      TWJ(K-1,I) = AT/A(K,I)
   64 DIFF = ABS(TOLD - TWJ(K-1,I))
   14 IF (DIFF .GT. BIG) BIG = DIFF
      GO TO 20
C
C  COMPUTE DOWN FROM TOP
C
    6 IF (I .EQ. 1) TWJ(1,1) = TIN1
      IF (I .EQ. 2) TWJ(1,2) = TIN1
      DO 12 K=2,KDR
      TOLD=TWJ(K,I)
      IF(IFLOW.GT.1)GO TO 68
      IF(I2PH.GT.0.AND.ISKIP(K,1).EQ.1)GO TO 66
   68 CONTINUE
      TKIM1 = 0.
      TT = G(K,I)*TWJ(K-1,I+1)
      IF (I .EQ. 1) GO TO 22
      TKIM1 = TWJ(K,I-1)*C(K,I)
      TT = TT + F(K,I)*TWJ(K-1,I-1)
   22 TOLD = TWJ(K,I)
      TWJ(K,I) = A(K,I)*TWJ(K-1,I)
     & + TKIM1 + D(K,I)*TWJ(K,I+1)
     & + E(K,I)*(TW(K-1,I) + TW(K,I)) + TT + QDOT(K,I)
   66 DIFF = ABS(TOLD - TWJ(K,I))
   12 IF (DIFF .GT. BIG) BIG = DIFF
   20 CONTINUE
C
C  SOIL CALCULATION
C
      DO 3 I=1,NR
      KK = 2
```

```
      IF (I .LT. 4) KK = KDR + 1
      DO 3 K=KK,NZ
      TT = 0.
      IF (I .GT. 1) TT = C(K,I)*TWJ(K,I-1)
      TOLD = TWJ(K,I)
      TWJ(K,I) = A(K,I)*TWJ(K-1,I) + B(K,I)*TWJ(K+1,I)
     & + TT + D(K,I)*TWJ(K,I+1) + E(K,I)*TW(K,I)
      DIFF = ABS(TOLD - TWJ(K,I))
    3 IF (DIFF .GT. BIG) BIG = DIFF
C
C CHECK FOR CONVERGENCE
C
      IF (NIT .LT. 50) GO TO 16
      WRITE (6,100) NIT,BIG
  100 FORMAT (/2X,10("*"),2X," TEMPERATURES NOT CONVERGED ",
     & 2X,10("*")/20X,"NIT =",I3,5X,"BIG =",E12.4/)
      GO TO 18
   16 IF (BIG .LE. 0.1) GO TO 18
C     IF(I2PH.GT.0)CALL TUFAS
      IF(IFLOW.LT.5)GO TO 8
      CALL FLOW
      CALL COEF
      GO TO 8
   18 CONTINUE
C
C UPDATE TWO-PHASE FLOW
C
      IF(I2PH.GT.0)CALL TUFAS
C
      RETURN
      END
      FUNCTION VISC(TEM1,TEM2,R1,R2,FRD,PV,YP)
C
C  THIS FUNCTION COMPUTES THE VISCOSITY OF A FLUID.
C     TEM1 = FLUID TEMPERATURE, OR TEMPERATURE AT R1
C     TEM2 = 0, OR TEMPERATURE AT R2
C     R1 = INSIDE RADIUS OF ANNULUS, FT. R1 = 0 FOR INSIDE A PIPE.
C     R2 = OUTSIDE RADIUS OF ANNULUS, FT.
C     PV = PLASTIC VISCOSITY, CENTIPOISE.
C     YP = YIELD POINT, LBF/100FT2.
C     FRD = FLOW RATE, FT3/HR, OR DENSITY, LBM/FT3
C     THE FIRST OPTIONS ARE FOR FORCED CONVECTION,
C     AND THE SECOND OPTIONS ARE FOR NATURAL CONVECTION.
C     GRAV = GRAVITY ACCELERATION, FT/HR2
C     BETA = VOLUMETEIC COEFFICIENT OF THERMAL EXPANSION, 1/F
C     VISW = VISCOSITY OF WATER FROM 30 F TO 300 F, LBM/FT-HR
C
      DIMENSION VISW(28)
      DATA GRAV/4.17E+8/,BETA/0.0001/
C
C  POWER LAW EXPONENT AND COEFFICIENT
C
      R600 = YP + 2.*PV
      R300 = YP + PV
      R6DR3=R600/R300
      IF(R1.GE.R2)WRITE(6,100)R1,R2
  100 FORMAT("***VISC ERROR***"/" R1=",E15.8,".GT. R2=",E15.8)
      IF(R6DR3.LE.0.0)WRITE(6,200)PV,YP
  200 FORMAT("***VISC ERROR***"/" PV=",E15.8," YP=",E15.8)
      EXP = 3.322*ALOG10(R6DR3)
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      COEF = 5.109*R300/(510.9**EXP)
      A = (3.*EXP + 1.)/(EXP*R2)
      IF (R1 .GT. 0.01) A = 2.*(2.*EXP + 1.)/(EXP*(R2 - R1))
C
C  NATURAL CONVECTION
C
      IF (TEM2 .LT. 0.1) GO TO 12
C
C  APPROXIMATE FLUID VELOCITY TIMES VISCOSITY, LBM/HR2
C     VTV = 8550. CORRESPONDS TO WATER AT 1 FT/SEC
C
C     VTV = GRAV*FRD*BETA*ABS(TEM2 - TEM1)*(R2 - R1)**2
      VTV = 8550.
C
C  SHEAR RATE TIMES VISCOSITY, POISE/SEC
C
      SRTV = 1.148E-6*A*VTV
C
C  VISCOSITY OF FLUID AT 70 F
C     NOTE (241.92 LBM/FT-HR)/POISE
C
      VISC = COEF*(SRTV**(EXP - 1.))
      VISC = 241.92*(VISC**(1./EXP))
      GO TO 10
C
C  FORCED CONVECTION
C
   12 CONTINUE
C
C  FLUID VELOCITY, FT/HR
C
      AREA = 3.1415927*(R2*R2 - R1*R1)
      VEL = FRD/AREA
C
C  SHEAR RATE
C
      SR = VEL*A/3600.
C
C  VISCOSITY OF FLUID AT 70 F
C     NOTE (241.92 LBM/FT-HR)/POISE
C
      VISC = COEF*(SR**(EXP - 1.))
      VISC = 241.92*VISC
C
C  WATER VISCOSITY AT TEMPERATURE TEM
C
   10 TEM = TEM1
      IF (TEM2 .GT. 0.1) TEM = (TEM1 + TEM2)/2.
      TEMC=(TEM-32.0)/1.8
      VISWTR=.24192*241.4*10.**(247.6/(TEMC+133.15))
      IF(TEMC.GT.300.)VISWTR=.24192*(2843.02-6.4759*TEMC)
      IF(TEMC.GT.375.)VISWTR=.24192*(.407*TEMC+262.28)
      VISWTR=VISWTR/1000.
      VISW70=2.3528
C
C  VISCOSITY OF FLUID AT TEMPERATURE TEM.
C
      VISC=VISC*VISWTR/VISW70
      IF(VISC.LE.0.0)WRITE(6,300)VISC
  300 FORMAT("***VISC ERROR***"/" VISC=",E15.8)
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      RETURN
      END
      FUNCTION CA(CAU,CAL,ZC,DZ,ZKP,ZKM)
C
C  THIS FUNCTION CHECKS FOR THE TYPE MATERIAL IN AN ANNULUS AND
C     AVERAGES THE CONDUCTIVITY FOR A CELL IF AN INTERFACE IS FOUND.
C
      IF ((ZC - DZ) .LT. ZKP) GO TO 2
      CA = CAU
      RETURN
    2 IF ((ZC - DZ) .GT. ZKM) GO TO 4
      CA = CAL
      RETURN
    4 CC = CAU*(ZC - DZ - ZKM) + CAL*(ZKP - ZC + DZ)
      CA = CC/(ZKP - ZKM)
      RETURN
      END
      FUNCTION CONVN(VIS,DEN,SH,CON,RI,RO,TI,TO)
C
C  THIS FUNCTION COMPUTES AN OVERALL CONDUCTIVITY OF A NATURALLY
C     CONVECTING FLUID INCLUDING EFFECTIVE CONDUCTIVITY OF FLUID
C     AND SURFACE CONVECTION COEFFICIENT.
C
      DATA GRAV/4.17E+8/,BETA/0.0005/
C  GRAV = ACCELERATION OF GRAVITY, FT3/HR
C  BETA = VOLUME COEFFICIENT OF THERMAL EXPANSION
C
      BETA=.0005
      IF(DEN.LT.5.0)BETA=1./(459.67+TI/2.0+TO/2.0)
C
C  PRANDTL NUMBER
C
      PR = SH*VIS/CON
C
      IF(PR.LE.0.0)WRITE(6,100)SH,VIS,CON
  100 FORMAT("***CONVN ERROR***"/" SH=",E15.8," VIS=",E15.8,
     & " CON=",E15.8)
C
C  GRASHOF NUMBER
C
      GR = ABS(TO - TI)*GRAV*BETA*DEN*DEN
      GR = GR*((RO - RI)**3)/(VIS*VIS)
      IF(GR.LT.1.E-10)GR=1.E-10
C
C  EFFECTIVE FLUID CONDUCTIVITY
C
      CONEFF = 0.049*CON*((GR*PR)**0.333)*(PR**0.074)
      IF (CONEFF .LT. CON) CONEFF = CON
      CONVN=CONEFF
      RETURN
      END
      FUNCTION CONV(VFR,VIS,DEN,SH,CON,RI,RO)
C
C  THIS FUNCTION COMPUTES A SURFACE COEFFICIENT FOR FORCED CONVECTION
C
C     VFR = VOLUME FLOW RATE, FT3/HR
C     VIS = FLUID VISCOSITY, LBM/FT-HR
C     DEN = DENSITY, LBM/FT3
C     SH = SPECIFIC HEAT CAPACITY, BTU/LBM-F
C     CON = THERMAL CONDUCTIVITY, BTU/HR-FT-F
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```
C     RI, RO = INNER AND OUTER RADII OF ANNULUS, FT
C     CONV = SURFACE CONVECTION COEFFICIENT, BTU/HR-FT2-F
C
C  PRANDTL NUMBER
C
      PR = SH*VIS/CON
C
      IF(PR.LT.0.0)WRITE(6,100)SH,VIS,CON
  100 FORMAT("***CONV ERROR***"/" SH=",E15.8," VIS=",E15.8,
     & " CON=",E15.8)
C
C  REYNOLDS NUMBER
C
      AREA = 3.1415927*(RO*RO - RI*RI)
      VEL = VFR/AREA
      RE = 2.*(RO - RI)*DEN*VEL/VIS
      IF(RE.LE.0.0)WRITE(6,200)RO,RI,DEN,VEL,VIS
  200 FORMAT("***CONV ERROR***"/" RO=",F8.3," RI=",F8.3," DEN=",F8.2,
     & " VEL=",F8.0," VIS=",E15.8)
C
C  LOW PRANDTL NUMBER CONVECTION COEFFICIENT
C
      IF (PR .GT. 50.) GO TO 2
      CONV = CON*0.023*(RE**0.8)*(PR**0.35)/(2.*(RO - RI))
      RETURN
C
C  HIGH PRANDTL NUMBER CONVECTION COEFFICIENT
C
    2 F = 64./RE
      IF (RE .LT. 2000.) GO TO 6
      IF (RE .GT. 4000.) GO TO 4
      F = 0.0077349
      F = (64. + F*(RE - 2000.))/2000.
      GO TO 6
    4 F = 0.013
      IF (RE .LT. 349120.) F = 0.316/(RE**0.25)
    6 H = 1.2 + 11.8*(PR - 1)*SQRT(F/8.)/(PR**0.333)
      H = F*RE*PR/(8.*H)
      CONV = CON*H/(2.*(RO - RI))
      RETURN
      END
      SUBROUTINE CONAN(J,K,ZKP,ZKM)
C
C  THIS SUBROUTINE COMPUTES THE CONDUCTIVITY OF ALL THE ANNULI
C     NEEDED TO DETERMINE AN OVERALL CONDUCTANCE AT DEPTH LEVEL K.
C
      COMMON /BLK5/ CAN(5)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK1/ T(151,20),TWJ(151,21)
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK10/ DENST,SHST,CONST,DENC,SHC,CONC
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK16/ NPF,NTS,KZP
C
C  FACTORS FOR LINEAR INTERPOLATION OF TEMPERATURES FROM T(K,2) TO T(K,3
C
      TA = T(K,2)
      TB = (T(K,3) - T(K,2))/(R(3) - R(2))
C
```

```
C  LOOP ON THE NUMBER OF ANNULI NEEDED, J, AT LEVEL K.
C
      DO 2 I=1,J
C
C  INTERIOR AND EXTERIOR ANNULI TEMPERATURES.
C
      ROC=RO(I)
      IF(I.EQ.1)ROC=RO(KZP+5)
      TI = TA + TB*(ROC - R(2))
      IF (I .EQ. 1) TI = (T(K,1) + T(K,2))/2.
      TO = T(K,3)
      IF (I .LT. 5) TO = TA + TB*(RI(I+1) - R(2))
C
C  VISCOSITY OF ANNULUS FLUID
C
      RR = R(3)
      IF (I .LT. 5) RR = RI(I+1)
      VIS = VISC(TI,TO,ROC,RR,DENFP(IAF),PVFP(IAF),YPFP(IAF))
C
C  CONDUCTIVITY OF ANNULUS FLUID AND OF CELL AT LEVEL K
C
      CAU=CONVN(VIS,DENFP(IAF),SHFP(IAF),CONFP(IAF),ROC,RR,TI,TO)
      ZCM=ZC(I)
      DZM=DZ(I)
      IF(I.GT.1)GO TO 3
      ZCM=ZC(KZP+5)
      DZM=DZ(KZP+5)
    3 CONTINUE
    2 CAN(I) = CA(CAU,CONC,ZCM,DZM,ZKP,ZKM)
      RETURN
      END
      FUNCTION KTUBE(Z1)
C
C  DETERMINES TUBING INTERVAL GIVEN DEPTH Z1
C
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK16/ NPF,NTS,KZP
      K=6
    2 IF(ZC(K).GE.Z1)GO TO 3
      K=K+1
      IF(K.LT.NTS+5)GO TO 2
      K=NTS+5
    3 KTUBE=K
      RETURN
      END
      SUBROUTINE DWNFLO(VF,IPF,IFLOW,J)
C
C   VF =  VOLUME OF FLUID INJECTED
C   Z(I,J) = DEPTH OF INTERFACE I
C   NA(I,J) = FLUID TYPE ABOVE INTERFACE I
C   NI(J) =  NUMBER OF INTERFACES
C   IPF =  FLUID TYPE INJECTED
C
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK16/ NPF,NTS,KZP
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
C
```

```
C
      NOF=0
      TD1=TD
      IF(DDCHG.GE..01)TD1=DEPTH
      IF(DDCHG.LT.0.1)GO TO 15
      NIJ=NI(J)
      NUNF=0
      NTD1=0
      DO 16 I=1,NIJ
      DTST=ZI(I,J)-TD1
      IF(DTST.GT.1.)NUNF=NUNF+1
   16 IF(DTST**2.LE.1.)NTD1=I
      IF(NUNF.EQ.0.AND.NTD1.EQ.0)GO TO 18
      IF(NTD1.EQ.0)NTD1=NUNF
      ZI(NTD1,J)=TD1
      DO 17 I=NTD1,NIJ
      NN=I+1-NTD1
      ZI(NN,J)=ZI(I,J)
   17 NA(NN,J)=NA(I,J)
      NI(J)=NI(J)-NTD1+1
      GO TO 15
   18 ZI(1,J)=TD1
   15 CONTINUE
      NN=NI(J)
      IF(IPF.EQ.NA(NN,J))GO TO 10
C
C    NEW INTERFACE GENERATED
C
      NN=NN+1
      NI(J)=NI(J)+1
      NA(NN,J)=IPF
      ZI(NN,J)=0.
C
C    CIRCULATE INTERFACES DOWN
C
   10 CONTINUE
      NIJ=NI(J)
      DO 20 I=1,NIJ
      VF1=VF
    2 K=KTUBE(ZI(I,J))
      A=ATA(K-5,J)
      ZTRY=VF1/A
      IF(ZTRY.GT.(ZC(K)-ZI(I,J)))GO TO 4
    3 ZI(I,J)=ZI(I,J)+ZTRY
      GO TO 5
    4 IF(K.GE.NTS+5)GO TO 3
      VF1=VF1-A*(ZC(K)-ZI(I,J))
      ZI(I,J)=ZC(K)+.1
      GO TO 2
    5 IF(ZI(I,J).GT.TD1)NOF=NOF+1
   20 CONTINUE
C
C   GENERATE INTERFACE AT BOTTOMHOLE
C
      IF(NOF.EQ.NI(J))GO TO 31
      IF(TD1-ZI(NOF+1,J).GT.1.0)GO TO 33
      ZI(NOF+1,J)=TD1
      GO TO 34
   33 NIJ=NI(J)
      JJ=NI(J)-NOF
```

```
      IF(JJ.LE.0)GO TO 31
      DO 30 I=1,JJ
      II=NIJ-I+2
      ZI(II,J)=ZI(II-1,J)
   30 NA(II,J)=NA(II-1,J)
   31 JJ=NOF+1
      NA(JJ,J)=NA(JJ-1,J)
      ZI(JJ,J)=TD1
      NI(J)=NI(J)+1
   34 IF(IFLOW.GT.1)GO TO 40
C
C   RENUMBER INTERFACES FOR INJECTION CASE IFLOW = 1
C
      NIJ=NI(J)-NOF
      DO 32 I=1,NIJ
      ZI(I,J)=ZI(I+NOF,J)
   32 NA(I,J)=NA(I+NOF,J)
      NI(J)=NI(J)-NOF
   40 RETURN
      END
      SUBROUTINE UPFLOW(VF,VF2,IPF,IFLOW)
C
C  VF    =  VOLUME PRODUCED
C  VOF   =  VOLUME CIRCULATED BY SUB DWNFLO
C
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK16/ NPF,NTS,KZP
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
C
      J=1
      VF1=VF+VF2
      RCP=VF/VF1
      TD1=TD
      IF(DDCHG.GT..01)TD1=DEPTH
      K=KTUBE(TD1)-5
      NCO=0
C
C  RENUMBER INTERFACES IF DEPTH CHANGES
C
      IF(IFLOW.EQ.3)J=2
      J1=J+1
      IF(J1.GT.2)J1=1
      IF((ZI(1,J)-TD1)**2.LT.1.0)GO TO 5
      NIJ=NI(J)
      NUNF=0
      NTD1=0
      DO 6 I=1,NIJ
      DTST=ZI(I,J)-TD1
      IF(DTST.GT.1.0)NUNF=NUNF+1
    6 IF(DTST**2.LE.1.0)NTD1=I
      IF(NUNF.EQ.0.AND.NTD1.EQ.0)GO TO 8
      IF(NTD1.EQ.0)NTD1=NUNF
      ZI(NTD1,J)=TD1
      DO 7 I=NTD1,NIJ
      NN=I+1-NTD1
      ZI(NN,J)=ZI(I,J)
    7 NA(NN,J)=NA(I,J)
```

```
      NI(J)=NI(J)-NTD1+1
      GO TO 5
    8 IF(NA(1,J).EQ.NA(1,J1))GO TO 16
      NI(J)=NI(J)+1
      NIJ=NI(J)
      DO 9 I=2,NIJ
      NN=NIJ-I+2
      ZI(NN,J)=ZI(NN-1,J)
    9 NA(NN,J)=NA(NN-1,J)
      NA(1,J)=NA(1,J1)
   16 ZI(1,J)=TD1
    5 CONTINUE
      IF(IFLOW.LT.3)GO TO 10
C
C  ADD INTERFACES CIRCULATED BY DWNFLO
      RCP=RCP*ATA(K,J)/ATA(K,J1)
      NOF1=NOF
      IF(NA(1,1).EQ.NA(1,2))NOF1=NOF1-1
      IF(NOF1.LE.0)GO TO 13
      NI(J)=NI(J)+NOF1
      NIJ=NI(J)
      DO 1 I=1,NOF1
      NN=NIJ-I+1
      NA(NN,J)=NA(NN-NOF1,J)
    1 ZI(NN,J)=ZI(NN-NOF1,J)
   13 DI=TD1
      DO 12 I=1,NOF
      NN=NOF+1-I
      NA(NN,J)=NA(I,J1)
      DI=DI+(ZI(I,J1)-ZI(I+1,J1))/RCP
   12 ZI(NN,J)=DI
C
C   RENUMBER INTERFACES FOR INJECTION SIDE
C
      NIJ=NI(J1)-NOF
      DO 14 I=1,NIJ
      ZI(I,J1)=ZI(I+NOF,J1)
   14 NA(I,J1)=NA(I+NOF,J1)
      NI(J1)=NI(J1)-NOF
      GO TO 20
C
C   PRODUCTION
C
   10 IF(IPF.EQ.NA(1,J))GO TO 15
      NI(J)=NI(J)+1
      N=NI(J)-1
      DO 11 I=1,N
      II=N+2-I
      NA(II,J)=NA(II-1,J)
   11 ZI(II,J)=ZI(II-1,J)
      ZI(1,J)=ZI(2,J)+VF1/ATA(K,J)
      NA(1,J)=IPF
      GO TO 20
   15 ZI(1,J)=ZI(1,J)+VF1/ATA(K,J)
C
C  CIRCULATE INTERFACES
C
   20 CONTINUE
      NIJ=NI(J)
      DO 30 I=1,NIJ
```

```
      VF3=VF1
      K=KTUBE(ZI(I,J))-5
    4 A=ATA(K,J)
      ZTRY=VF3/A
      IF(K.LE.1)GO TO 2
      IF(ZTRY.GT.ZI(I,J)-ZC(K+4))GO TO 3
    2 ZI(I,J)=ZI(I,J)-ZTRY
      IF(ZI(I,J).LT.0.)NCO=NCO+1
      GO TO 30
    3 VF3=VF3-A*(ZI(I,J)-ZC(K+4))
      ZI(I,J)=ZC(K+4)
      K=K-1
      GO TO 4
   30 CONTINUE
      NI(J)=NI(J)-NCO
      RETURN
      END
      SUBROUTINE FPROP(DEN,PV,YP,SH,CON,ZKP,ZKM,J)
C
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      NIJ=1
      IF(J.LT.3)GO TO 4
      I=IAF
      GO TO 5
    4 NIJ=NI(J)
    2 IF(ZKP.LE.ZI(NIJ,J))GO TO 1
      NIJ=NIJ-1
      IF(NIJ.LE.0)NIJ=1
      IF(NIJ.EQ.1)GO TO 1
      GO TO 2
    1 I=NA(NIJ,J)
    5 DEN=DENFP(I)
      PV=PVFP(I)
      YP=YPFP(I)
      SH=SHFP(I)
      CON=CONFP(I)
      IF(NIJ.EQ.1.OR.J.GT.2)GO TO 3
      IF(ZKM.LE.ZI(NIJ,J))GO TO 3
      IF((ZKM-ZI(NIJ,J))**2.LT.1.0)GO TO 3
      ZINT=ZI(NIJ-1,J)
      INT=NA(NIJ-1,J)
      D1=(ZKP-ZINT)/(ZKP-ZKM)
      D2=(ZINT-ZKM)/(ZKP-ZKM)
      DEN=DEN*D1+DENFP(INT)*D2
      PV=PV*D1+PVFP(INT)*D2
      YP=YP*D1+YPFP(INT)*D2
      SH=SH*D1+SHFP(INT)*D2
      CON=CON*D1+CONFP(INT)*D2
    3 RETURN
      END
      SUBROUTINE FLOW
C
C  COMPUTES FLOWING STREAM PROPERTIES
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK11/ VFR,DDCHG,COSDVN
```

```
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK18/ DENG(151,2),PRESS(151,2),VGAS(151,2)
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      COMMON /BLK20/ DCUT(151),VCUT(151),DLIQ(151,2),DVAP(151,2),DRT,
     & VFR3
      COMMON /S1/ D2,V2,DPD,PHI
      COMMON /S2/ DIAS,DENS,DELTA
      COMMON /S3/ G3,G4,D3,D4
      DATA DFTR/16.0184625/
      DATA PFTR/6894.757/
      DATA VFTR/.3048/
      DATA DELTA/1.5/
      DATA DIAS/0.01/
      DATA DENS/2000./
      DATA DLH2O/1000./
C
C  INITIALIZE PARAMETERS
C
      IGAS=NA(1,1)
      IF((IGAS-1)*(IGAS-2).NE.0)GO TO 9
      GO TO (1,2),IGAS
    1 RG=287.06
      DSCF=1.2229
      GO TO 10
    2 RG=296.08
      DSCF=1.1828
      GO TO 10
    9 WRITE(6,1000)IGAS
 1000 FORMAT(//" ************ ERROR *************"//" GAS #",I2,
     & " UNDEFINED"/)
      STOP
C
   10 VFRG=VFR
   12 A1=ATA(1,1)*VFTR**2
      IF(DCLRL.GE.Z(KDR))A1=3.14159*DCLRI**2*VFTR**2
      VFRM=VFRG*VFTR**3/60.
      G=VFRM*DSCF/A1
      G3=VFR3*DLH2O*VFTR**3/3600./A1
      T1=(TWJ(1,1)+459.67)/1.8
      P1=PSTAND*PFTR
      D1=P1/RG/T1
      V1=G/D1
C
      GG=9.80665
      DL=(Z(2)-Z(1))*VFTR
      DHYD=2.*SQRT(A1/3.14159)
      ZDCL=(Z(KDR)-DCLRL)*VFTR
C
      PRESS(1,1)=P1/PFTR
      DENG(1,1)=D1/DFTR
      VGAS(1,1)=V1/VFTR
C
      I=1
C     WRITE(6,2200)I,PRESS(I,1),DENG(I,1),VGAS(I,1),TWJ(I,1)
C2200 FORMAT(1X,I4," P=",E11.4," D=",E11.4," V=",E11.4," T=",E11.4)
C
C
C  SELECT STATIC OR FLOWING GAS
C
```

```
      IF(VFRG.LT.1.0)GO TO 40
      D3=G3/V1
      CALL DVSAT(D4,DX4,T1)
      IF(D4.GT.D3)D4=D3
      G4=D4*V1
      DLIQ(1,1)=(D3-D4)/DFTR
      DVAP(1,1)=D4/DFTR
C
C  DETERMINE FLOWING PROPERTIES IN TUBING
C
      I=1
   14 I=I+1
      T2=(TWJ(I,1)+459.67)/1.8
      GCOS=GG
      IF(Z(I).GT.DDVN)GCOS=GG*COSDVN
      DL1=DL
C
C  CHECK FOR AREA CHANGES
C
      ZT=Z(I-1)*VFTR
      ZB=Z(I)*VFTR
C
C  DRILL COLLAR TO TUBING AREA CHANGE
C
      IF(ZT.GT.ZDCL)GO TO 15
      IF(ZB.GT.ZDCL)GO TO 16
C
C  TUBING AREA CHANGE
C
      K1=KTUBE(Z(I-1))
      K2=KTUBE(Z(I))
      IF(K1.EQ.K2)GO TO 15
      A2=ATA(K2-5,1)*VFTR**2
      DHYD2=2.*SQRT(A2/3.14159)
      DL1=ZC(K1)*VFTR-ZT
      GO TO 17
   16 A2=3.14159*(DCLRI*VFTR)**2
      DHYD2=2.*DCLRI*VFTR
      DL1=ZDCL-ZT
   17 TM=T1+(T2-T1)*DL1/DL
      RE=DHYD*D1*V1/GVISC(T1,IGAS)
      FPD=FRIC(RE,DHYD,1)/DHYD*D1*V1*DL1/4.
      GPD=GCOS*DL1*(D1+D3)
      CALL VEXIT(P1,D1,V1,T1,TM,FPD,GPD,IGAS)
      IF(IGAS.GE.100)GO TO 29
      CALL ACHNG(P1,D1,T1,V1,A1,A2,IGAS)
      IF(IGAS.GE.100)GO TO 29
      DHYD=DHYD2
      DL1=DL-DL1
   15 RE=DHYD*D1*V1/GVISC(T1,IGAS)
      FPD=FRIC(RE,DHYD,1)/DHYD*D1*V1*DL1/4.
      GPD=GCOS*DL1*(D1+D3)
      CALL VEXIT(P1,D1,V1,T1,T2,FPD,GPD,IGAS)
      IF(IGAS.GE.100)GO TO 29
C
      PRESS(I,1)=P1/PFTR
      DENG(I,1)=D1/DFTR
      VGAS(I,1)=V1/VFTR
C
      CALL DVSAT(D4,DX4,T1)
```

```
      IF(D4.GT.D3)D4=D3
      DLIQ(I,1)=(D3-D4)/DFTR
      DVAP(I,1)=D4/DFTR
C
C     WRITE(6,2200)I,PRESS(I,1),DENG(I,1),VGAS(I,1),TWJ(I,1)
      IF(I.EQ.KDR)GO TO 20
      GO TO 14
C
C  CHECK BIT NOZZLES FOR CHOKED FLOW
C
   20 A2=BITA*VFTR**2
      CALL NOZL(P1,T1,D1,V1,A1,A2,IGAS)
      IF(IGAS.GE.100)GO TO 29
C
C  AREA CHANGE: TUBING TO ANNULUS
C
      IK=2
      RI1=DCLRO*VFTR
      IF(Z(I).LE.ZDCL)RI1=RO(KTUBE(Z(I)))*VFTR
      RO1=BITR*VFTR
      IF(Z(I).GT.ZC(2))GO TO 19
      IK=1
      RO1=RI(2)*VFTR
   19 A2=3.14159*(RO1**2-RI1**2)
      DHYD=2.*(RO1-RI1)
      CALL ACHNG(P1,D1,T1,V1,A1,A2,IGAS)
      IF(IGAS.GE.100)GO TO 29
      T1=(TWJ(I,2)+459.67)/1.8
      RI2=RI1
      RO2=RO1
C
      PRESS(I,2)=RG*T1*D1/PFTR
      DENG(I,2)=D1/DFTR
      VGAS(I,2)=V1/VFTR
C
      CALL DVSAT(D4,DX4,T1)
      IF(D4.GT.D3)D4=D3
      DLIQ(I,2)=(D3-D4)/DFTR
      DVAP(I,2)=D4/DFTR
C
      DCUT(I)=0.
      VCUT(I)=0.
C     WRITE(6,2200)I,PRESS(I,2),DENG(I,2),VGAS(I,2),TWJ(I,2)
C
C  DETERMINE INNER CASING
C
      ICASE=1
   21 ICASE=ICASE+1
      ZCS=ZC(ICASE)*VFTR
      RCS=RI(ICASE)*VFTR
      IF(Z(KDR).GE.ZC(ICASE))GO TO 22
      IF(ICASE.EQ.5)GO TO 22
      GO TO 21
C
C  DETERMINE SOLIDS MASS FLOW RATE IF DRILLING
C
   22 ISOL=0
      G2=DRT*DENS*3.14159*BITR**2*VFTR**3/A1/3600.
      IF(DRT.LT.0.01)GO TO 28
      ISOL=1
```

```
      CALL VSLIP(D1,T1,V1,G2,GCOS,IGAS)
      PRESS(I,2)=RG*D1*T1/PFTR
      DENG(I,2)=D1/DFTR
      VGAS(I,2)=V1/VFTR
C
      CALL DVSAT(D4,DX4,T1)
      IF(D4.GT.D3)D4=D3
      DLIQ(I,2)=(D3-D4)/DFTR
      DVAP(I,2)=D4/DFTR
      DCUT(I)=D2/DFTR
      VCUT(I)=V2/VFTR
C
C  FLOWING PROPERTIES IN ANNULUS
C
   28 I=I-1
      T2=(TWJ(I,2)+459.67)/1.8
      GCOS=-GG
      IF(Z(I).GT.DDVN)GCOS=-GG*COSDVN
C
      ZT=Z(I)*VFTR
      ZB=Z(I+1)*VFTR
      K1=KTUBE(Z(I))
      K2=KTUBE(Z(I+1))
      ZTA=ZC(K1)*VFTR
C
   23 ZM=ZT
      IAR=0
      IF(ZM.GT.ZDCL.OR.ZB.LE.ZDCL)GO TO 24
C
C  AREA CHANGE: DRILL COLLAR TO PIPE
C
      RI2=RO(K2)*VFTR
      ZM=ZDCL
      IAR=1
      GO TO 25
C
   24 IF(ZM.GT.ZTA.OR.ZB.LE.ZTA)GO TO 25
C
C  AREA CHANGE:TUBING SIZE
C
      RI2=RO(K1)*VFTR
      ZM=ZTA
      IAR=1
C
   25 IF(ZM.GT.ZCS.OR.ZB.LE.ZCS)GO TO 26
C
C  AREA CHANGE: OPEN HOLE TO CASING
C
      IAR=2
      RO2=RCS
      ZM=ZCS
C
   26 DL1=ZB-ZM
      TM=T1+(T2-T1)*DL1/DL
      VIS1=GVISC(T1,IGAS)
      RE=DHYD*D1*V1/VIS1
      FPD=FRIC(RE,DHYD,IK)/DHYD*D1*V1*DL1/4.
      GPD=GCOS*DL1*(D1+D3)
      IF(ISOL.EQ.1)DPD=.5*CD(D1,DENS,VIS1,DIAS,1)*DELTA*D1*PHI
     & *DL1/DIAS
```

```
      IF(ISOL.EQ.0)CALL VEXIT(P1,D1,V1,T1,TM,FPD,GPD,IGAS)
      IF(ISOL.EQ.1)CALL VMIXT(P1,D1,V1,T1,TM,FPD,GPD,IGAS)
      IF(IGAS.GE.200)GO TO 30
      IF(IGAS.GE.100)GO TO 29
      IF(IAR.EQ.0)GO TO 27
      A2=3.14159*(RO2**2-RI2**2)
      DHYD=2.*(RO2-RI2)
      G2=G2*A1/A2
C     D2=D2*A1/A2
      CALL ACHNG(P1,D1,T1,V1,A1,A2,IGAS)
      IF(ISOL.EQ.1)CALL VSLIP(D1,T1,V1,G2,GCOS,IGAS)
      IF(IGAS.GE.100)GO TO 29
      ZB=ZM
      IF(IAR.EQ.2)IK=1
      GO TO 23
C
   27 CONTINUE
      PRESS(I,2)=P1/PFTR
      DENG(I,2)=D1/DFTR
      VGAS(I,2)=V1/VFTR
C
      CALL DVSAT(D4,DX4,T1)
      IF(D4.GT.D3)D4=D3
      DLIQ(I,2)=(D3-D4)/DFTR
      DVAP(I,2)=D4/DFTR
      DCUT(I)=0.
      VCUT(I)=0.
      IF(ISOL.EQ.1)DCUT(I)=D2/DFTR
      IF(ISOL.EQ.1)VCUT(I)=V2/VFTR
C
C     WRITE(6,2200)I,PRESS(I,2),DENG(I,2),VGAS(I,2),TWJ(I,2)
C
      IF(I.EQ.1)RETURN
      GO TO 28
C
C  CHOKED FLOW
C
   29 PINC=P1/PFTR
      IF(PINC.LE.5.0)PINC=5.0
      IF(PINC.GT.100.0)PINC=100.0
      PSTAND=PSTAND+PINC
      IGAS=NA(1,1)
      WRITE(6,1001)PSTAND
 1001 FORMAT(/" CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO",F8.1,
     & " PSI"/)
      GO TO 12
C
C  INSUFFICIENT LIFTING CAPACITY
C
   30 VFR=VFR*1.05
      IGAS=NA(1,1)
      WRITE(6,1002)VFR
 1002 FORMAT(/" GAS FLOW RATE TOO LOW- INCREASED TO:",F8.0," SCF")
      GO TO 10
C
C  STATIC COLUMN
C
   40 P1=14.7*PFTR
      T1=(TWJ(1,2)+459.67)/1.8
      D1=P1/RG/T1
```

```
C
      DENG(1,2)=D1/DFTR
      PRESS(1,2)=P1/PFTR
      VGAS(1,2)=0.0
      DLIQ(1,2)=0.0
      DVAP(1,2)=0.0
C
      DO 41 I=2,KDR
      GCOS=GG
      IF(Z(I).GT.DDVN)GCOS=GG*COSDVN
      P1=P1+D1*DL*GCOS
      T1=(TWJ(I,2)+459.67)/1.8
      D1=P1/RG/T1
C
      DENG(I,2)=D1/DFTR
      PRESS(I,2)=P1/PFTR
      VGAS(I,2)=0.0
      DLIQ(I,2)=0.0
      DVAP(I,2)=0.0
   41 CONTINUE
C
      DENG(KDR,1)=DENG(KDR,2)
      PRESS(KDR,1)=PRESS(KDR,2)
      VGAS(KDR,1)=0.0
      DLIQ(KDR,1)=0.0
      DVAP(KDR,1)=0.0
      DCUT(KDR)=0.0
      VCUT(KDR)=0.0
C
      DO 42 II=2,KDR
      I=KDR-II+1
      GCOS=GG
      IF(Z(I+1).GT.DDVN)GCOS=GG*COSDVN
      P1=P1-D1*DL*GCOS
      T1=(TWJ(I,1)+459.67)/1.8
      D1=P1/RG/T1
C
      DENG(I,1)=D1/DFTR
      PRESS(I,1)=P1/PFTR
      VGAS(I,1)=0.0
      DLIQ(I,1)=0.0
      DVAP(I,1)=0.0
      DCUT(I)=0.
      VCUT(I)=0.
C
   42 CONTINUE
      RETURN
      END
      FUNCTION FRIC(RE,DHYD,IK)
C
C COMPUTES DARCY FRICTION FACTOR
C
      RR=.0000457/DHYD
      IF(IK.EQ.2)RR=.00305/DHYD
      A=.026*RR**.225+0.133*RR
      B=22.*RR**0.44
      C=-1.62*RR**0.134
      FRIC=A+B*RE**C
      FRIC=4.*FRIC
      FRICL=64./RE
```

```
      IF(FRICL.GT.FRIC)FRIC=FRICL
      RETURN
      END
      FUNCTION GVISC(T,IGAS)
C
C  COMPUTES VISCOSITIES OF GASES
C
      IF(IGAS.EQ.3)GO TO 3
      IF(IGAS.EQ.2)GO TO 1
      D=.552795+2.810892E2/T-135083.40/T/T+39353086./T**3
     & -41.419387E8/T**4
      GO TO 2
    1 D=.579561+2.847486E2/T-13.232490E4/T/T+37.106107E6/T**3
     & -37.549675E8/T**4
    2 GVISC=SQRT(T)/D*1.E-6
      RETURN
    3 GVISC=10.
      RETURN
      END
      SUBROUTINE VEXIT(P1,D1,V1,T1,T2,FPD,GPD,IGAS)
C
C  DETERMINES EXIT FLOW PROPERTIES FOR PIPE ELEMENT
C
      COMMON /S3/ G3,G4,D3,D4
C
      G1=D1*V1
      G=G1+G3
      R=P1/D1/T1
      A=G+FPD+GPD/V1/2.
      B=-P1-G*V1+FPD*V1-1.5*GPD
      C=R*T2*G1
C
      D=B*B-4.*A*C
      IF(D.LE.0.)GO TO 1
      V1=(-B-SQRT(D))/A/2.
      D1=G1/V1
      D3=G3/V1
      P1=R*D1*T2
      T1=T2
      RETURN
    1 IGAS=IGAS+100
      X=C/P1
      Y=B+P1
      B=-2.*Y-4.*A*X
      C=Y*Y
      P2=(-B+SQRT(B*B-4.*C))/2.
      P1=P2-P1
      IF(P1.LE.35000.)P1=35000.
      RETURN
      END
      SUBROUTINE ACHNG(P1,D1,T1,V1,A1,A2,IGAS)
C
C  COMPUTES CHANGE IN FLOWING PROPERTIES
C    DUE TO ABRUPT AREA CHANGE
C
      COMMON /S3/ G3,G4,D3,D4
      CP=1004.0
      IF(IGAS.EQ.2)CP=1038.3
      CW=0.0
      IF(D3.GT.1.E-6)CALL DLSAT(D3A,XX1,T1)
```

```
      IF(D3.GT.1.E-6)CALL STEAM(XX1,XX2,XX3,XX4,XX5,CW,D3A,T1)
      R=P1/D1/T1
C
      DM1=D1*V1*A1
      DM3=G3*A1
      DMT=DM1+DM3
C
      CPA=(DM1*CP+DM3*CW)/DMT
C
      A=DMT-.5*DM1*R/CPA
      B=-P1*A2-DMT*V1
      C=R*DM1*(T1+V1**2*.5/CPA)
      DD=B*B-4.*A*C
      IF(DD.LE.0.0)GO TO 1
      V1A=(-B-SQRT(DD))/A/2.
      T1=T1+.5/CPA*(V1**2-V1A**2)
      D1=DM1/A2/V1A
      D3=DM3/A2/V1A
      P1=R*D1*T1
      V1=V1A
      A1=A2
      RETURN
    1 IGAS=IGAS+100
      G=DM1/A2
      B=2.*G*V1-4.*G*G/D1
      C=(G*V1)**2
      P2=(-B+SQRT(B*B-4.*C))/2.
      P1=P2-P1
      IF(P1.LE.35000.)P1=35000.
      RETURN
      END
      SUBROUTINE GPROP(DENF,SHF,SHFCV,CONF,VIS,VEL,K,ITA)
C
C  THIS SUBROUTINE RETURNS THE FOLLOWING GAS PROPERTIES
C
C     DENF = DENSITY, LBM/CF
C     SHF = SPECIFIC HEAT CAPACITY, CP , BTU/LBM-F
C     SHFCV = SPECIFIC HEAT CAPACITY, CV , BTU/LBM-F
C     CONF = THERMAL CONDUCTIVITY, BTU/HR-FT-F
C     VIS = VISCOSITY, LBM/FT-HR
C     VEL = VELOCITY, FT/SEC
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK18/ DENG(151,2),PRESS(151,2),VGAS(151,2)
      COMMON /BLK20/ DCUT(151),VCUT(151),DLIQ(151,2),DVAP(151,2),DRT,
     & VFR3
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
C
      KP1=K+1
      IF(KP1.GT.KDR)KP1=KDR
      IF(I2PH.GT.0)GO TO 2
      IGAS=NA(1,1)
      DENF=(DENG(K,ITA)+DENG(KP1,ITA))/2.
      SHF=.2398
      IF(IGAS.EQ.2)SHF=.2480
      SHFCV=SHF/1.4
      TCELL=TWJ(K,ITA)+TWJ(KP1,ITA)
      TKEL=(TCELL/2.+459.67)/1.8
```

```
      VIS=GVISC(TKEL,IGAS)*.671971*3600.
      VEL=(VGAS(K,ITA)+VGAS(KP1,ITA))/2.
C
C  DETERMINE AVERAGE PROPERTIES FOR GAS-SOLIDS MIXTURE
C
C     IF(ITA.EQ.1)GO TO 1
      IF(VEL.LE.0.1)GO TO 1
      CS=0.30
      D2=(DCUT(K)+DCUT(KP1))/2.
      V2=(VCUT(K)+VCUT(KP1))/2.
      D1=DENF+D2
      G1=DENF*VEL+D2*V2
      SHFCV=(SHFCV*DENF+CS*D2)/D1
      SHF=(SHF*DENF*VEL+CS*D2*V2)/G1
      VEL=(DENF*VEL+D2*V2)/D1
      DENF=D1
    1 CONTINUE
      PR=.7368
      VIS1=VIS
      IF(IGAS.EQ.3)VIS1=GVISC(TKEL,1)*.671971*3600.
      CONF=SHF*VIS1/PR
      RETURN
C
C  TWO-PHASE STEAM PROPERTIES
C
    2 D1=(DVAP(K,1)+DVAP(KP1,1))/2.
      D2=(DLIQ(K,1)+DLIQ(KP1,1))/2.
      DENF=D1+D2
      D1M=D1*16.0184625
      D2M=D2*16.0184625
      T1=(TWJ(K,1)+TWJ(KP1,1))/2.
      T1K=(T1+459.67)/1.8
      DE1=0.0
      DE2=0.0
      IF(D1M.GT.1.E-12.AND.D2M.GT.1.E-12)GO TO 3
      IF(D1M.GT.1.E-12)CALL STEAM(X1,X2,X3,X4,X5,DE1,D1M,T1K)
      IF(D2M.GT.1.E-12)CALL STEAM(X1,X2,X3,X4,X4,DE2,D2M,T1K)
      GO TO 4
    3 CALL DVSAT(D1S,DD1S,T1K)
      CALL DLSAT(D2S,DD2S,T1K)
      CALL ESAT(X1,X2,DE1,DE2,D1S,D2S,DD1S,DD2S,T1K)
    4 CONTINUE
      SHFCV=(D1*DE1+D2*DE2)/DENF*2.38845E-4
      SHF=(D1*DE1*1.329+D2*DE2)/DENF*2.38845E-4
      VIS=(SLVIS(T1K)*D2+SVVIS(T1K)*D1)/DENF*.671971*3600.
      PR=.7368
      CONF=SHF*VIS/PR
      VEL=(VGAS(K,1)+VGAS(KP1,1))/2.
      RETURN
      END
      SUBROUTINE NOZL(P,T,D,V,A1,A2,IGAS)
C
C  THIS SUBROUTINE CHECKS FOR CHOKED FLOW IN THE BIT NOZZLES
C    IF FLOW IS NOT CHOKED-RETURN TO FLOW
C    IF FLOW IS CHOKED-IGAS INCREASED BY 100 AND P SET
C    TO ESTIMATED STANDPIPE PRESSURE INCREASE REQUIRED
C
      CP=1004.0
      IF(IGAS.EQ.2)CP=1038.3
      GO=D*V
```

```
      G=G0*A1/A2
      Z=P/D/T
      A=.5/CP-1./Z
      B=D*T/G+V/Z
      C=T+.5*V*V/CP
      DD=B*B+4.*A*C
      IF(DD.GE.0.0)RETURN
      P1=SQRT(-4.*A*C)*Z*G-V*G
      P=P1-P
      IF(P.LT.35000.)P=35000.
      IGAS=IGAS+100
      RETURN
      END
      FUNCTION CD(DEN1,DEN2,VIS1,D2,IND)
C
C  THIS FUNCTION COMPUTES THE DRAG COEFFICIENT FOR SOLID
C   PARTICLES MOVING IN A FLOWING STREAM BASED ON
C   SWANSON'S CORRELATION.
C
C    DEN1=DENSITY OF THE FLUID
C    DEN2=DENSITY OF THE SOLID PARTICLE
C    VIS1=VISCOSITY OF THE FLUID
C    D2=THE AVERAGE PARTICLE DIAMETER
C    IND=INDICATOR OF PARTICLE TYPE
C      1 IRREGULAR QUARTZ
C      2 CUBICAL GALENA
C      3 SPHERICAL
C      4 IRREGULAR KCL
C      5 IRREGULAR SPHALERITE
C
      DIMENSION A(5),B(5)
      DATA A/1.277,1.082,.942,1.870,1.022/
      DATA B/2.80,3.11,3.27,2.56,2.18/
      DATA G/9.80665/
      VN=4./3.*G*D2*(DEN2-DEN1)/DEN1
      VN=SQRT(VN)
      CD1=A(IND)*(1.+6.93*B(IND)*VIS1/D2/DEN1/VN)
      CD=CD1**2
      RETURN
      END
      SUBROUTINE VSLIP(DEN1,T,V1,G2,GG,IGAS)
C
C  INITIAL SLIP VELOCITY
C
      COMMON /S1/ D2,V2,DPD,PHI
      COMMON /S2/ D,DENS,DELTA
C
      GCOS=ABS(GG)
      G1=DEN1*V1
      VN=SQRT(4.*GCOS*D*(DENS-DEN1)/DEN1/3.)
      VIS1=GVISC(T,IGAS)
      CD1=CD(DEN1,DENS,VIS1,D,1)
      VS=VN*SQRT(1./CD1)
      A=VS
      B=G2/DENS+G1/DEN1-VS
      C=G2/DENS
      PHI=(SQRT(B*B+4.*A*C)-B)/2./A
      V1=G1/(1.-PHI)/DEN1
      V2=V1-VS
      D1=G1/V1
```

```
      D2=G2/V2
      RETURN
      END
      SUBROUTINE VMIXT(P1,D1,V1,T1,T2,FPD,GPD,IGAS)
C
      COMMON /S1/ D2,V2,DPD,PHI
      COMMON /S2/ DIAS,DENS,DELTA
      COMMON /S3/ G3,G4,D3,D4
C
      R=P1/T1/D1
      G1=D1*V1
      G=G1+G3
      G2=D2*V2
      D3=G3/V1
      DENM=D1+D2+D3
      GPD=GPD/D1
      FPD=FPD/D1
C
      W10=GPD*DENM
      W11=-.5*W10/V1
      W12=-.5*W10/V2
      F10=-FPD/G
      F11=F10*G
      F12=F10*G2
      F10=2.*F10*(G*V1+G2*V2)
C
      W20=GPD*PHI*(DENS-D1)
      W22=-.5*W20/V2
      PH0=DPD
      PH1=.5*PH0*(V1*V1-V2*V2)
      PH2=-PH1/V2
      PH1=PH1/V1
      PH0=PH0*(V1-V2)*(V1-V2)
C
      DV2D=G2-W22-PH2
      DV20=(W20+PH0)/DV2D
      DV2V1=PH1/DV2D
C
      D1V1=G-W11-F11+(G2-W12-F12)*DV2V1
      D10=P1+W10+F10-(G2-W12-F12)*DV20
C
      V1P=V1*(1.-PHI)+V1/V2*PHI*DV20
      DV1P=1.0-PHI+V1/V2*PHI*DV2V1
C
      A=D1V1*DV1P
      B=D1V1*V1P-D10*DV1P
      C=G1*R*T2-D10*V1P
      DTEST=B*B-4.*A*C
      IF(DTEST.LE.0.0)GO TO 100
      DV1=(-B-SQRT(DTEST))/2./A
      V1=V1+DV1
      IF(V1.LE.0.0)GO TO 200
      DV2=DV2V1*DV1+DV20
      V2=V2+DV2
      IF(V2.LE.0.0)GO TO 200
      D1=G1/V1
      D2=G2/V2
      D3=G3/V1
      PHI=D2/DENS
      T1=T2
```

```
      P1=R*D1*T1
C
      RETURN
  100 IGAS=IGAS+100
      P1=DTEST/(B*DV1P-2.*A*V1P)
      IF(P1.LE.35000.)P1=35000.
      RETURN
  200 IGAS=IGAS+200
      RETURN
      END
      SUBROUTINE PSAT(P,DP,T)
C
      DIMENSION F(8)
      DATA F/-741.9242,-29.72100,-11.55286,-0.8685635,.1094098,
     @ .439993,.2520658,.05218684/
      DATA TC,PC/647.3,22120.0E3/
C
      T1=3.382-0.01*T
      TR=TC/T
      F1=F(1)+F(2)*T1
      F2=F(2)
      DO 1 I=3,8
      F1=F1+F(I)*T1**(I-1)
    1 F2=F2+FLOAT(I-1)*F(I)*T1**(I-2)
      P=PC*EXP(.01*(TR-1.0)*F1)
      DP=-.01*(TR/T*F1+.01*(TR-1.0)*F2)*P
      RETURN
      END
      SUBROUTINE DVSAT(D,DD,TDUM)
C
      T=TDUM
      IF(T.GE.647.0)GO TO 1
      IF(T.LT.273.15)T=273.16
      TR=(T-273.15)/374.12
      IF(TR.GT.1.0)TR=1.0
      R1=460.330
      R2=107.779
      X=2.6-.6*TR
      TRX=TR**X
      IF(TRX.GT.1.0)TRX=.99999
      R=SQRT(1.0-TRX)*(R1-R2)+R2
      CALL PSAT(P,DP,T)
      D=P/R/T
      DR=.5*(R1-R2)/SQRT(1.-TRX)*TRX*(X/TR-.6*ALOG(TR))/374.12
      DD=D*(DP/P+DR/R-1./T)
      RETURN
    1 DD=0.0
      D=317.
      RETURN
      END
      SUBROUTINE DLSAT(D,DD,T)
C
      DATA T1,T2/273.15,647.29/
      DATA D1,D2/1000.0,317.00903/
      DATA X1,X2/1.6160,.40873/
C
      IF(T.GE.647.0)GO TO 1
      TR=(T-T1)/(T2-T1)
      IF(TR.LE.0.0)TR=.00001
      X=X1*EXP(X2*TR**5)
```

```
      TRX=TR**X
      SQX=SQRT(1.-TRX)
      D=D2+(D1-D2)*SQX
      DD=.5*(D2-D1)/(T2-T1)/SQX*X*TRX*(ALOG(TR)*X2*5.*TR**4+1./TR)
      RETURN
    1 D=317.0
      DD=0.0
      RETURN
      END
      SUBROUTINE STEAM(P,DPD,DPT,U,DUD,DUT,DSI,T)
C
      DIMENSION A(7,10),C(8),AJ(7),DAJ(7),D2AJ(7)
C
      DATA A/29.492937,-5.1985860,6.8335354,-0.1564104,-6.3972405,
     @ -3.9661401,-0.69048554,
     @ -132.13917,7.7779182,-26.149751,-0.72546108,26.409282,
     @ 15.453061,2.7407416,
     @ 274.64632,-33.301902,65.326396,-9.2734289,-47.740374,
     @ -29.142470,-5.1028070,
     @ -360.93828,-16.254622,-26.181978,4.3125840,56.323130,
     @ 29.568796,3.9636085,
     @ 342.18431,-177.31074,0.0,0.0,0.0,0.0,0.0,
     @ -244.50042,127.48742,0.0,0.0,0.0,0.0,0.0,
     @ 155.18535,137.46153,0.0,0.0,0.0,0.0,0.0,
     @ 5.9728487,155.97836,0.0,0.0,0.0,0.0,0.0,
     @ -410.30848,337.31180,-137.46618,6.7874983,136.87317,
     @ 79.847970,13.041256,
     @ -416.05860,-209.88866,-733.96848,10.401717,645.81880,
     @ 399.17570,71.531353/
      DATA C/1857.065,3229.12,-419.465,36.6649,-20.5516,4.85233,
     @ 46.000,-1011.249/
C
      DATA TAC,E/1.544912,4.800/
      DATA R/.46151/
C
      TA=1000./T
      D=DSI/1000.
      X=EXP(-E*D)
C
      DM=D-0.634
      AJ(1)=A(1,1)+A(1,2)*DM
      DAJ(1)=A(1,2)
      D2AJ(1)=0.0
      DO 10 I=3,8
      AJ(1)=AJ(1)+A(1,I)*DM**(I-1)
      D2AJ(1)=D2AJ(1)+FLOAT((I-1)*(I-2))*DM**(I-3)
   10 DAJ(1)=DAJ(1)+A(1,I)*FLOAT(I-1)*DM**(I-2)
      FX=X*(A(1,9)+A(1,10)*D)
      AJ(1)=AJ(1)+FX
      DAJ(1)=DAJ(1)+X*A(1,10)-E*FX
      D2AJ(1)=D2AJ(1)+E*E*FX-2.*E*X*A(1,10)
C
      DM=D-1.0
      DO 11 J=2,7
      AJ(J)=A(J,1)+A(J,2)*DM
      DAJ(J)=A(J,2)
      D2AJ(J)=0.0
      DO 12 I=3,8
      AJ(J)=AJ(J)+A(J,I)*DM**(I-1)
      D2AJ(J)=D2AJ(J)+FLOAT((I-1)*(I-2))*DM**(I-3)
```

```
   12 DAJ(J)=DAJ(J)+A(J,I)*FLOAT(I-1)*DM**(I-2)
      FX=X*(A(J,9)+A(J,10)*D)
      AJ(J)=AJ(J)+FX
      D2AJ(J)=D2AJ(J)+E*E*FX-2.*E*X*A(J,10)
   11 DAJ(J)=DAJ(J)+X*A(J,10)-E*FX
C
      TMC=TA-TAC
      TM=TA-2.5
      Q=AJ(1)
      D2QDD=D2AJ(1)
      DQD=DAJ(1)
      DO 14 J=2,7
      Q=Q+TMC*AJ(J)*TM**(J-2)
      D2QDD=D2QDD+TMC*D2AJ(J)*TMC**(J-2)
   14 DQD=DQD+TMC*DAJ(J)*TM**(J-2)
C
      DQT=0.0
      D2QDT=0.0
      DO 15 J=2,7
      D2QDT=D2QDT+DAJ(J)*TM**(J-3)*(TM+TMC*FLOAT(J-2))
   15 DQT=DQT+AJ(J)*TM**(J-3)*(TM+TMC*FLOAT(J-2))
C
      D2QTT=2.*AJ(3)+(2.*TM+2.*TMC)*AJ(4)
      DO 16 J=5,7
   16 D2QTT=D2QTT+(2.*TM**(J-3)+TMC*TM**(J-4)*FLOAT((J-2)*(J-3)))*AJ(J)
C
      DPSI=C(1)+C(7)*(ALOG(T)-1.0)-C(8)/TA
      D2PSI=-C(7)*TA+C(8)
      DO 4 I=3,6
      D2PSI=D2PSI+C(I)*FLOAT((2-I)*(1-I))*TA**(2-I)
    4 DPSI=DPSI+C(I)*FLOAT(2-I)*TA**(1-I)
      D2PSI=-D2PSI/1000.
C
      P=D*R*T*(1.0+D*Q+D*D*DQD)*1.E6
      DPD=(R*T+D*R*T*(2.*Q+4.*D*DQD+D*D*D2QDD))*1000.0
      DPT=D*R+D*D*R*(Q-TA*DQT+D*DQD-D*TA*D2QDT)*1.E6
      U=(R*T*D*TA*DQT+DPSI)*1000.
      DUT=(-R*D*TA*TA*D2QTT+D2PSI)*1000.0
      DUD=(R*DQT+R*D*D2QDT)*1000.0
      RETURN
      END
      FUNCTION SVVIS(T)
C
C  SVVIS = SATURATED VAPOR VISCOSITY  PA-S
C  T = TEMP KELVIN
C  TC = TEMP CELSIUS
C  D = DENSITY GM/CC
C
      TC=T-273.15
      V1=.407*TC+80.4
      IF(TC.GT.300.)GO TO 1
      CALL DVSAT(D,DD,T)
      D=D/1000.
      V2=-D*(1858.0-5.9*TC)
      SVVIS=(V1+V2)*1.E-7
      RETURN
    1 CALL DVSAT(D1,DD,573.15)
      CALL DVSAT(D2,DD,648.15)
      D2=D2/1000.
      VV=-D1*88./1000.
```

```
      VC=353.*D2+676.5*D2*D2+107.1*D2**3
      SVVIS=(V1+VV+(VC-VV)*(TC-300.)/75.)*1.E-7
      RETURN
      END
      FUNCTION SLVIS(T)
C
C  SLVIS = SAT LIQ VISCOSITY PA-S
C  T = TEMP KELVIN
C  D = DENS KG/M3
C
      TK=T
      IF(T.GT.573.15)TK=573.15
      SLVIS=241.4*10**(247.8/(T-140.))*1.E-7
      IF(T.LE.573.15)RETURN
      CALL DLSAT(D3,DD,573.15)
      CALL DLSAT(DL,DD,T)
      CALL DVSAT(DV,DD,T)
      SLVIS=SVVIS(T)*(D3-DL)/(D3-DV)+SLVIS*(DL-DV)/(D3-DV)
      RETURN
      END
      SUBROUTINE ESAT(E1,E2,DE1,DE2,D1,D2,DD1,DD2,T)
      CALL STEAM(P,DPD,DPT,E1,DED,DET,D1,T)
      E1=E1+P/D1
      DP=0.0
      IF(T.LE.647.2)CALL PSAT(P,DP,T)
      DE1=DED*DD1+DET+DP/D1-P*DD1/D1**2
      CALL STEAM(P,DPD,DPT,E2,DED,DET,D2,T)
      DP=0.0
      IF(T.LE.647.2)CALL PSAT(P,DP,T)
      E2=E2+P/D2
      DE2=DED*DD2+DET+DP/D2-P*DD2/D2**2
      RETURN
      END
      SUBROUTINE KSAT(CON,T,IND)
C
C  IND = 1  VAPOR
C  IND = 2  LIQUID
C  CON WATT/M-K
C  T  KELVIN
C
      IF(IND.EQ.1)GO TO 10
      IF(IND.EQ.2)GO TO 20
      WRITE(6,100)
  100 FORMAT("KSAT ERROR IND OUT OF RANGE")
      STOP
   10 CONTINUE
      TC=T-273.15
      CON1=17.6+5.87E-2*TC+1.04E-4*TC*TC-4.51E-8*TC**3
      IF(T.LE.647.2)CALL DVSAT(D,DD,T)
      IF(T.GT.647.3)D=317.0
      D=D/1000.
      IF(T.GT.647.2)GO TO 30
      CALL PSAT(PS,DP,T)
      IF(PS.GT.5.E7)GO TO 30
      IF(TC.LE.0.0)TC=0.01
      CON=(CON1+(103.51+0.4198*TC-2.771E-5*TC*TC)*D+
     & 2.1482E14*D*D/TC**4.2)/1000.
      RETURN
   20 CONTINUE
      TA=T/273.15
```

```
      CON=-922.47+2839.5*TA-1800.7*TA*TA+525.77*TA**3-73.440*TA**4
      CON=CON/1000.
      RETURN
   30 CON=39.44895+750.64429*D-564.34229*D*D+786.34375*D**3
      CON=CON/1000.
      RETURN
      END
      SUBROUTINE TUFAS
C
C  COMPUTES FLOWING STREAM PROPERTIES
C  FOR TWO-PHASE FLOW
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZC(15),TVD,DDVN
      COMMON /BLK6/ IFLOW,PI,DT,TIN1,TIN2,FR1,FR2,FR3,NIT
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK11/ VFR,DDCHG,COSDVN
      COMMON /BLK15/ ATA(10,2)
      COMMON /BLK17/ ZI(10,2),NA(10,2),NI(2),NOF
      COMMON /BLK18/ DENG(151,2),PRESS(151,2),VGAS(151,2)
      COMMON /BLK19/ DEPTH,BITR,BITA,DCLRL,DCLRI,DCLRO,PSTAND
      COMMON /BLK20/ DCUT(151),VCUT(151),DLIQ(151,2),DVAP(151,2),DRT,
     & VFR3
      COMMON /BLK21/ IREGM(151,3),QUALS,PSTEM,I2PH,ISKIP(151,2)
      COMMON /S3/ G3,G4,D3,D4
      DIMENSION IFRNM(3,6)
      DATA IFRNM/"LI","QU","ID","BU","BB","LE","SL","UG","  ",
     & "TR","AN","S.","MI","ST","  ","VA","PO","R "/
      DATA DFTR/16.0184625/
      DATA PFTR/6894.757/
      DATA VFTR/.3048/
C
C  INITIALIZE
C
C
      G3=0.0
      G4=0.0
      D3=0.0
      D4=0.0
      TSCF=288.15
      CALL DLSAT(DLSCF,DD,TSCF)
      FLM=VFR/60.*4.719474E-4*DLSCF
C
      KAR=1
      IF(IFLOW.EQ.2)KAR=KDR
      KT=KTUBE(Z(KAR))-5
      AREA=ATA(KT,1)*VFTR*VFTR
C
      G1=FLM*QUALS/AREA
      G2=FLM*(1.-QUALS)/AREA
C
      P1=PSTEM*PFTR
      T1=(TIN1+459.67)/1.8
      IF(T1.GT.647.2)GO TO 2
      CALL PSAT(PS1,DP,T1)
      IF(P1.GT.PS1*1.0001)GO TO 1
      IF(P1.LT.PS1*.9999)GO TO 2
C
C  TWO-PHASE FLOW
C
```

```
      CALL DLSAT(D2,DD,T1)
      CALL DVSAT(D1,DD,T1)
      VNS=G1/D1+G2/D2
C
      GO TO 3
C
C  LIQUID FLOW
C
    1 CONTINUE
      CALL DLSAT(D2,DD,T1)
      D2=DENCR(P1,T1,D2)
      G2=G1+G2
      G1=0.0
      D1=0.0
      VNS=G2/D2
      GO TO 3
C
C  VAPOR FLOW
C
    2 CONTINUE
      D1=1.0
      IF(T1.LE.647.2)CALL DVSAT(D1,DD,T1)
      D1=DENCR(P1,T1,D1)
      G1=G1+G2
      G2=0.0
      D2=0.0
      VNS=G1/D1
C
    3 CONTINUE
      IF(VFR.LT.1.0)GO TO 80
      IND=0
      PRESS(KAR,1)=P1/PFTR
      DLIQ(KAR,1)=G2/VNS/DFTR
      DVAP(KAR,1)=G1/VNS/DFTR
      VGAS(KAR,1)=VNS/VFTR
      DO 4 I=1,3
    4 IREGM(KAR,I)=0
      ISKIP(KAR,1)=0
C
      KN=KAR
C
C  TEST FOR TWO-PHASE FLOW
C
   10 CONTINUE
      K=KN
      IND=0
      KN=K-1
      IF(IFLOW.EQ.1)KN=K+1
      IF(KN.EQ.0)RETURN
      IF(KN.GT.KDR)RETURN
      GG=9.80665
      DZ=(Z(K)-Z(KN))*VFTR
      IF(DZ.LT.0.0)GG=-GG
      DZ=ABS(DZ)
C
C  CHECK FOR AREA CHANGES
C
      KT1=KTUBE(Z(K))-5
      KT2=KTUBE(Z(KN))-5
      IF(KT1.EQ.KT2)GO TO 12
```

```
      RA=ATA(KT1,1)/ATA(KT2,1)
      G1=G1*RA
      G2=G2*RA
   12 CONTINUE
      AREA=ATA(KT2,1)*VFTR*VFTR
      DHYD=2.*SQRT(AREA/PI)
C
      T1=(TWJ(K,1)+459.67)/1.8
      P1=PRESS(K,1)*PFTR
      NCYC=4
      ICYC=1
      DZ=DZ/FLOAT(NCYC)
   90 CONTINUE
      IF(T1.GT.647.2)GO TO 52
      CALL PSAT(PS1,DPDT,T1)
      GT=G1+G2
      IF(G2.LT.GT*1.E-12.AND.P1.LT.1.001*PS1)GO TO 50
      IF(IFLOW.EQ.1)GO TO 72
      IF(P1.GT.PS1*1.001.AND.G1/GT.LE.1.E-12)GO TO 40
      GO TO 74
   72 IF(G1.LE.GT*1.E-12.AND.P1.GT.0.999*PS1)GO TO 40
   74 CONTINUE
      IF(P1.LT.PS1*.999.AND.G2.GT.0.0)GO TO 13
      IF(P1.GT.PS1*1.0001.AND.G1.GT.0.0)GO TO 14
      GO TO 16
   13 T1=TSAT(P1)
      PS1=P1
      GO TO 16
   14 IF(P1.LT.2.212E7)T1=TSAT(P1)
      IF(P1.GE.2.212E7)GO TO 42
      PS1=P1
   16 CONTINUE
      IF(P1.GT.PS1*1.0001)GO TO 40
      IF(P1.LT.PS1*.9999)GO TO 50
C
C  TWO PHASE FLOW
C
C
C  INITIAL VELOCITIES
C
   17 CALL DVSAT(D1,DD1,T1)
      CALL DLSAT(D2,DD2,T1)
      V1=G1/D1
      V2=G2/D2
      VNS=V1+V2
C
      CALL ESAT(E1,E2,DE1,DE2,D1,D2,DD1,DD2,T1)
C
C  TEST FOR FLOW REGIME
C
      ITRAN=0
      GT=G1+G2
      IF(G1/GT.LE.1.E-12)GO TO 20
      IF(G2/GT.LE.1.E-6)GO TO 26
      IF(V1.LE.1.E-12)GO TO 20
      SRTN=SURTN(T1)
      IF(SRTN.LE.1.E-6)SRTN=1.E-6
      VTG=V1*SQRT(SQRT(D2/ABS(GG)/SRTN))
      ELB=1.071-0.2218*VNS**2/DHYD/.3048
      ELS=50.+36.*VTG*V2/V1
```

```
      ELM=75.+84.*(VTG*V2/V1)**.75
      IF(ELB.LT.0.13)ELB=0.13
      IF(V1.LE.VNS*ELB)GO TO 20
      IF(V1.GT.VNS*ELB.AND.ELS.GT.VTG)GO TO 22
      IF(ELM.GT.VTG.AND.VTG.GT.ELS)ITRAN=1
      IF(ITRAN.EQ.1)GO TO 22
      GO TO 26
C
C  BALANCE OF MOMENTUM
C
C  BUBBLE FLOW
C
   20 RE=D2*DHYD*V2/SLVIS(T1)
      FRAC=FR2P(RE,WN,SN,DHYD,2)
      RL=RLORK(V1,V2)
      DPFR=.5*FRAC/DHYD*D2*(V2/RL)**2*DZ
      DPGR=GG*(RL*(D2-D1)+D1)*DZ
      IFRG=2
      GO TO 30
C
C  SLUG FLOW
C
   22 GT=G1+G2
      RE=D2*DHYD*VNS/SLVIS(T1)
      FRAC=FR2P(RE,WN,SN,DHYD,2)
      CALL GMORK(T1,DHYD,D2,GT,VNS,GAM,VR)
      DPFR=.5*FRAC/DHYD*D2*VNS**2*((V2+VR)/(VNS+VR)+GAM)*DZ
      DPGR=GG*((GT+D2*VR)/(VNS+VR)+D2*GAM)*DZ
      IF(ITRAN.EQ.1)GO TO 24
      IFRG=3
      GO TO 30
C
C  TRANSITION FLOW
C
   24 PSF=(ELM-VTG)/(ELM-ELS)
      PMF=(VTG-ELS)/(ELM-ELS)
      VOLFG=1./(1.+V2/V1)
      RE=D1*DHYD*V1/SVVIS(T1)
      SRTN=SURTN(T1)
      IF(SRTN.LE.1.E-6)SRTN=1.E-6
      WN=(V1*SLVIS(T1)/SRTN)**2*D2/D1
      SN=SRTN/(D1*V1**2*DHYD)
      FRAC=FR2P(RE,WN,SN,DHYD,3)
      DPFR=PSF*DPFR+PMF*.5*FRAC/DHYD*D1*V1**2*DZ
      DPGR=PSF*DPGR+PMF*(VOLFG*D1+(1.-VOLFG)*D2)*GG*DZ
      IFRG=4
      GO TO 30
C
C  MIST FLOW
C
   26 VOLFG=1./(1.+V2/V1)
      RE=D1*DHYD*V1/SVVIS(T1)
      SRTN=SURTN(T1)
      IF(SRTN.LE.1.E-6)SRTN=1.E-6
      WN=(V1*SLVIS(T1)/SRTN)**2*D2/D1
      SN=SRTN/(D1*V1*V1*DHYD)
      FRAC=FR2P(RE,WN,SN,DHYD,3)
      DPFR=.5*FRAC/DHYD*D1*V1**2*DZ
      DPGR=(VOLFG*D1+(1.-VOLFG)*D2)*DZ*GG
      IFRG=5
```

```
C
   30 P1A=P1-DPFR-DPGR
      IF(P1A.LE.0.0)GO TO 34
      P1=P1A
      IF(P1.GT.2.212E7)T2=647.2
      IF(P1.LE.2.212E7)T2=TSAT(P1)
      DTEM=T2-T1
C
C  BALANCE OF ENERGY
C
      PRMX=V2/(V1+V2)
      H2PH=HMIX(G1,G2,D1,D2,T1,PRMX,DHYD)
      H2PH=H2PR(H2PH,DHYD,KT2,K,KN)
      TANN=(TWJ(K,2)+TWJ(KN,2))/2.
      IF(K.EQ.1.OR.KN.EQ.1)TANN=2.*TWJ(2,2)-TWJ(3,2)
      TANN=(TANN+459.67)/1.8
      QFLUX=4.*H2PH*DZ*(T1+DTEM/2.-TANN)/DHYD
      DG2=-G2
      IF(ABS(E2-E1).LT.0.0001)GO TO 32
      DG2=(DTEM*(G1*DE1+G2*DE2)+GT*GG*DZ+QFLUX)/(E1-E2)
C
   32 PF=1.0
      IF(G1-DG2.LE.0.0)PF=G1/DG2
      IF(G2+DG2.LE.0.0)PF=-G2/DG2
C
      T1=T1+DTEM
      G1=G1-DG2*PF
      G2=G2+DG2*PF
C
      CALL DVSAT(D1,DD1,T1)
      CALL DLSAT(D2,DD2,T1)
      V1=G1/D1
      V2=G2/D2
      VNS=V1+V2
C
      IF(G1.LT.0.0)G1=0.0
      IF(G2.LT.0.0)G2=0.0
C
      TOLD=TWJ(KN,1)
      TNEW=T1*1.8-459.67
      TOLD=TNEW
      TWJ(KN,1)=.8*TNEW+.2*TOLD
      IND=1
      GO TO 60
C
C FLASHING FLOW
C
   34 IF(P1-DPFR.LE.0.0)GO TO 70
      DPGR=D1*GG*DZ
      P1=P1-DPGR-DPFR
      IF(P1.LE.0.0)GO TO 70
      DTEM=(-G2*(E1-E2)+QFLUX)/(G1*DE1+G2*DE2)
      T1=T1+DTEM
      TS=TSAT(P1)
      IF(T1.LT.TS)T1=TS
      IFRG=5
      G1=G1+G2
      G2=0.0
      D1=DENCR(P1,T1,D1)
      D2=0.0
```

```
      VNS=G1/D1
      GO TO 60
C
C  LIQUID FLOW
C
   40 D2=DLIQ(K,1)*DFTR
   42 D1=0.0
      IFRG=1
      G2=G1+G2
      G1=0.0
      VNS=G2/D2
      RE=G2*DHYD/SLVIS(T1)
      FRAC=FR2P(RE,0.0,0.0,DHYD,2)
      DPFR=.5*FRAC*G2*VNS*DZ/DHYD
      DPGR=GG*D2*DZ
      P1A=P1-DPFR-DPGR
      IF(P1A.GT.0.0)GO TO 43
      CALL DVSAT(D1,DD1,T1)
      CALL DLSAT(D2,DD2,T1)
      CALL ESAT(E1,E2,DE1,DE2,D1,D2,DD1,DD2,T1)
      GO TO 34
   43 T2=(TWJ(KN,1)+459.67)/1.8
      IF(T2.GT.647.2)GO TO 44
      CALL PSAT(PS2,DPS2,T2)
      IF(P1A.LT.PS2)GO TO 44
      T1=T2
      P1=P1A
      CALL DLSAT(D2S,DD,T1)
      IF(D2.LT.D2S)D2=D2S
      D2=DENCR(P1,T1,D2)
      VNS=G2/D2
      GO TO 60
   44 P1B=PS1*(P1A-P1)-P1*(PS2-PS1)
      P1B=P1B/(P1A-P1+PS1-PS2)
      DZ=DZ*(P1A-P1B)/(P1A-P1)
      P1=P1B
      T1=TSAT(P1)
      PS1=P1
      GO TO 17
C
C  VAPOR FLOW
C
   50 D1=DVAP(K,1)*DFTR
      GO TO 54
   52 D2=0.0
      G1=G1+G2
      G2=0.0
      IF(D1.LE.0.0)D1=P1/461.50/T1
      D1=DENCR(P1,T1,D1)
   54 VNS=G1/D1
      IFRG=6
      RE=G1*DHYD/SVVIS(T1)
      FRAC=FR2P(RE,0.0,0.0,DHYD,2)/DHYD
      DPFR=.5*FRAC*G1*VNS
      DPGR=GG*D1*DZ
      P1A=P1
      P1=P1-DPFR-DPGR
      IF(P1.LE.0.0)GO TO 70
      T1=(TWJ(KN,1)+459.67)/1.8
      D1=DENCR(P1,T1,D1)
```

```
      VNS=G1/D1
      IF(T1.GT.647.2)GO TO 60
      CALL PSAT(PS2,DPS2,T1)
      IF(P1.LE.PS2)GO TO 60
      T1=TSAT(P1A)
      PS1=P1A
      GO TO 17
C
C STORE CALCULATED VARIABLES
C
   60 ICYC=ICYC+1
      IF(ICYC.LE.NCYC)GO TO 90
      DLIQ(KN,1)=G2/VNS/DFTR
      DVAP(KN,1)=G1/VNS/DFTR
      DO 61 LL=1,3
   61 IREGM(KN,LL)=IFRNM(LL,IFRG)
      VGAS(KN,1)=VNS/VFTR
      PRESS(KN,1)=P1/PFTR
      ISKIP(KN,1)=1
      IF(IFRG.EQ.1)ISKIP(KN,1)=0
      IF(IFRG.EQ.6)ISKIP(KN,1)=0
C
      GO TO 10
C
C  ERROR HANDLING
C
   70 P1=P1/PFTR
      DPFR=DPFR/PFTR
      DPGR=DPGR/PFTR
      TF=T1*1.8-459.67
      WRITE(6,100)K,KN,(IFRNM(KK,IFRG),KK=1,3),P1,TF,DPFR,DPGR
  100 FORMAT(/" TWO-PHASE PRESSURE LESS THAN ZERO"/
     & " FROM K=",I3," TO K=",I3," FLOW TYPE= ",3A2/
     & " INITIAL PRESSURE=",F6.2," PSIA   TEMPERATURE=",F6.1," F"/
     & " FRICTIONAL PRESSURE DROP=",F8.2," PSIA"/
     & " GRAVITATIONAL PRESSURE DROP=",F8.2," PSIA")
      STOP
C
C  SHUT-IN TWO PHASE
C
   80 PRESS(KAR,1)=P1/PFTR
      DLIQ(KAR,1)=D2*(1.-QUALS)/DFTR
      DVAP(KAR,1)=D1*QUALS/DFTR
      VGAS(KAR,1)=0.0
      IF(KAR.EQ.KDR)GO TO 85
C
C  INJECTION - SURFACE PRESS DEFINED
C
      DD=D1+D2
      DO 82 I=2,KDR
      DZ=(Z(I)-Z(I-1))*VFTR
      P1=P1+9.80665*DD*DZ
      T1=(TWJ(I,1)+459.67)/1.8
      DD=DENCR(P1,T1,DD)
      IF(T1.GT.647.2)GO TO 83
      CALL PSAT(PS1,DP,T1)
      IF(P1.LE.PS1)GO TO 83
      DLIQ(I,1)=DD/DFTR
      DVAP(I,1)=0.0
      IFRG=1
```

```
      GO TO 84
   83 DVAP(I,1)=DD/DFTR
      DLIQ(I,1)=0.0
      IFRG=6
   84 PRESS(I,1)=P1/PFTR
      VGAS(I,1)=0.0
      DO 82 K=1,3
   82 IREGM(I,K)=IFRNM(K,IFRG)
      RETURN
C
C  PRODUCTION - BOTTOM HOLE PRESSURE DEFINED
C
   85 DD=D1+D2
      ISPR=0
      DO 86 II=2,KDR
      I=KDR-II+1
      ISKIP(I,1)=0
      DZ=(Z(I+1)-Z(I))*VFTR
      DPGR=9.80665*DD*DZ
      T1=(TWJ(I,1)+459.67)/1.8
      PS1=1.E12
      IF(T1.GT.647.2)GO TO 89
      CALL PSAT(PS1,DP,T1)
      IF(P1.GT.PS1.AND.P1-DPGR.GT.PS1)GO TO 89
      DPGR=P1-PS1
      ISPR=1
      CALL DVSAT(DD,DPD,T1)
   89 P1=P1-DPGR
      DD=DENCR(P1,T1,DD)
      IF(ISPR.EQ.1)GO TO 87
      IF(P1.LE.PS1)GO TO 87
      DLIQ(I,1)=DD/DFTR
      DVAP(I,1)=0.0
      IFRG=1
      GO TO 88
   87 DVAP(I,1)=DD/DFTR
      DLIQ(I,1)=0.0
      TWJ(I,1)=TSAT(P1)*1.8-459.67
      ISKIP(I,1)=1
      IFRG=6
   88 PRESS(I,1)=P1/PFTR
      VGAS(I,1)=0.0
      DO 86 K=1,3
   86 IREGM(I,K)=IFRNM(K,IFRG)
      RETURN
      END
      FUNCTION FR2P(RE,WN,SN,DHYD,IK)
C
C  DARCY FRICTION FACTOR FOR TWO PHASE FLOW
C
C  IK = 1  COMMERCIAL STEEL
      RR=.0000457/DHYD
C
C  IK = 2  GALVANIZED IRON
      IF(IK.EQ.2)RR=.000152/DHYD
C
C  IK = 3  DUNN AND ROS MIST FLOW E/D
      IF(IK.NE.3)GO TO 1
      IF(WN.GT.0.005)RR=174.8*SN*WN**0.302
      IF(WN.LE.0.005)RR=34.*SN
```

```
      IF(RR.GT.0.5)RR=0.5
      IF(RR.LT.1.E-3)RR=1.E-3
    1 CONTINUE
      A=.026*RR**.225+0.133*RR
      B=22.*RR**0.44
      C=-1.62*RR**0.134
      FRIC=A+B*RE**C
      FR2P=4.*FRIC
      FRICL=64./RE
      IF(FRICL.GT.FR2P)FR2P=FRICL
      RETURN
      END
      SUBROUTINE GMORK(T,DHYM,D2M,GTM,VNSM,GAM,VR)
C
C  THIS SUBROUTINE CALCULATES ORKIZEWSKI'S GAMMA FUNCTION
C  AND BUBBLE RISE VELOCITY VR
C
C  T = TEMP KELVIN
C  DHYM = HYDRAULIC DIAMETER M
C  D2M = LIQUID DENSITY KG/M3
C  GTM = TOTAL MASS FLUX DENSITY KG/M2-S
C  VNSM = NO SLIP VELOCITY M/S
C
C CALCULATE ENGLISH UNIT EQUIVALENTS
C
      DHYD=DHYM/.3048
      D2=D2M/16.01845
      GT=GTM/4.882428
      VNS=VNSM/.3048
C
      VIS=SLVIS(T)*1000.0
      RE=1488.*D2*DHYD*VNS/VIS
      ENB=1488.*D2*DHYD/VIS
      D12=SQRT(DHYD)
C
C  COMPUTE BUBBLE RISE VELOCITY
C
      VB=5.6745*D12
      VB1=VB*(0.546+8.74E-6*RE)
      VB2=VB*(0.350+8.74E-6*RE)
      ALF=VB*(0.251+8.74E-6*RE)
      VB3=.5*(ALF+SQRT(ALF*ALF+13.59*VIS/D2/D12))
      VR=VB1
      IF(VB2*ENB.GE.8000.0)VR=VB2
      IF(VB3*ENB.GT.3000.0.AND.VB3*ENB.LT.8000.0)VR=VB3
      VISLG=ALOG10(VIS)
      DHLG=ALOG10(DHYD)
      IF(VNS.GT.10.0)GO TO 1
      GAM=0.0130*VISLG/DHYD**(1.38)-0.681
     & +0.232*ALOG10(VNS)-0.428*DHLG
      IF(GAM.LE.-0.065*VNS)GAM=-0.065*VNS
      GO TO 2
    1 GAM=0.045*VISLG/DHYD**(0.799)-0.709-0.888*DHLG
     & -0.162*ALOG10(VNS)
      GTEST=VR*(GT/D2-VNS)/(VR+VNS)/VNS
      IF(GAM.LT.GTEST)GAM=GTEST
    2 VR=VR*.3048
      RETURN
      END
      FUNCTION SURTN(T)
```

```
C
C  SURFACE TENSION FOR WATER
C
C  SURTN = SURFACE TENSION N/M
C  T = TEMP KELVIN
C  VIS = VISCOSITY PA-S
C
      IF(T.GT.647.28)GO TO 1
      DVISC=(SLVIS(T)-SVVIS(T))*1.E6
      IF(DVISC.LE.1.E-3)DVISC=1.E-3
      SURTN=78.609*EXP(-77.225/DVISC)*.001
      RETURN
    1 SURTN=0.
      RETURN
      END
      FUNCTION DENCR(P,T,D)
C
C  COMPUTES DENSITY CONSISTENT WITH P,T
C   DENSITY NEAR D TO INITIALIZE
C
      M=0
      N=0
      CALL STEAM(PTEST,X1,X2,X3,X4,X5,D,T)
      IF(ABS(P-PTEST)/P.LT. 1.E-3)GO TO 1
      IF(PTEST.GT.P)GO TO 2
C
C  PTEST<P
C
      D1=D
      P1=PTEST
      D2=D1
    4 D2=D2*1.10
      IF(M.GT.50)D2=D2*1.50
    9 CALL STEAM(P2,X1,X2,X3,X4,X5,D2,T)
      IF(P2.GT.P)GO TO 3
      M=M+1
      IF(M.GT.200)GO TO 8
      D1=D2
      P1=P2
      GO TO 4
C
C  PTEST>P
C
    2 D2=D
      P2=PTEST
      D1=D2
    5 D1=D1*.90
      IF(M.GT.50)D1=D1*.50
      M=M+1
      IF(M.GT.200)GO TO 8
      CALL STEAM(P1,X1,X2,X3,X4,X5,D1,T)
      IF(P1.LT.P)GO TO 3
      D2=D1
      P2=P1
      GO TO 5
C
C  SPLIT INTERVAL
C
    3 D=D2-(D2-D1)*(P2-P)/(P2-P1)
      CALL STEAM(P3,X1,X2,X3,X4,X5,D,T)
```

```
      N=N+1
      IF(N.GT.100)GO TO 7
      IF(ABS(P-P3)/P.LT.1.E-3)GO TO 1
      IF(ABS(D-D1)/D.LT.1.E-5)GO TO 1
      IF(P3.GT.P)GO TO 6
      P1=P3
      D1=D
      GO TO 3
    6 P2=P3
      D2=D
      GO TO 3
C
    8 D=.5*(D1+D2)
    7 WRITE(6,100)T,D,D1,D2,P,P1,P2
  100 FORMAT(" WARNING-DENSITIES UNRELIABLE: T=",F6.0/
     & " D=",E11.4," D1=",E11.4," D2=",E11.4/
     & " P=",E11.4," P1=",E11.4," P2=",E11.4)
    1 DENCR=D
      RETURN
      END
      FUNCTION RLORK(V1,V2)
C
C  ORKIZEWSKI'S RL FUNCTION FOR BUBBLE FLOW
C
      VNS=V1+V2
      VBUB=.2438
      VNR=VNS/VBUB+1.
      V1R=V1/VBUB
      RAD=VNR*VNR-4.*V1R
      IF(RAD.LE.1.E-12)RAD=1.E-12
      EG=.5*(VNR-SQRT(RAD))
      RLORK=1.-EG
      IF(RLORK.LE.1.E-12)RLORK=1.E-12
      RETURN
      END
      FUNCTION HMIX(G1,G2,D1,D2,T1,P2,DHYD)
C
C  FILM COEFFICIENT DETERMINED BY SIMILARITY ANALYSIS
C
C  CONMX = THERMAL CONDUCTIVITY OF MIXTURE
C  CPMIX = HEAT CAPACITY OF MIXTURE
C  GMIX  = MASS FLUX DENSITY OF THE MIXTURE
C  VSMIX = VISCOSITY OF THE MIXTURE
C
      CALL KSAT(CON1,T1,1)
      CALL KSAT(CON2,T1,2)
      CALL STEAM(X1,X2,X3,X4,X5,DE1,D1,T1)
      CALL STEAM(X1,X2,X3,X4,X5,DE2,D2,T1)
      P1=1.-P2
C
      CONMX=P1*CON1+P2*CON2
      CPMIX=P1*DE1+P2*DE2
      GMIX=G1+G2
      VSMIX=P1*SVVIS(T1)+P2*SLVIS(T1)
C
      RE=GMIX*DHYD/VSMIX
      PR=VSMIX*CPMIX/CONMX
C
      HMIX=0.023*CONMX*RE**0.80*PR**0.35/DHYD
      RETURN
```

```
      END
      FUNCTION H2PR(H2PH,DHYD,KT2P,K,KN)
C
C  THIS FUNCTION COMPUTES THE OVERALL CONDUCTIVITY
C  BETWEEN THE TWO-PHASE STEAM AND THE CENTER OF THE
C  TUBING-CASING ANNULUS
C
C  H2PR = WATT/M-K
C
      COMMON /BLK1/ TW(151,20),TWJ(151,21)
      COMMON /BLK3/ KDR,NZ,NZP1,TD,Z(151),ZC(15),DZ(15),TVD,DDVN
      COMMON /BLK8/ NR,RMAX,R(21),DR(21),AR(20),RI(15),RO(15)
      COMMON /BLK10/ DENST,SHST,CONST,DENC,SHC,CONC
      COMMON /BLK13/ DENFP(5),PVFP(5),YPFP(5),SHFP(5),CONFP(5),
     @IPF,IAF,ISF
C
      KTP=KT2P+5
      R1=RI(KTP)
      R2=RO(KTP)
      R3=R(2)
      A21=ALOG(R2/R1)
      A32=ALOG(R3/R2)
      CON21=CONST*1.730735
C
      IF (.5*(Z(K)+Z(KN)).GT.ZC(KTP)-DZ(KTP))GO TO 10
C
C  CONVECTIN FLUID IN TUBING-CASING ANNULUS
C
      T1=.5*(TW(K,1)+TW(KN,1))
      T2=.5*(TW(K,2)+TW(KN,1))
      VISA=VISC(T1,T2,R1,R2,DENFP(IAF),PVFP(IAF),YPFP(IAF))
      HANN=CONVN(VISA,DENFP(IAF),SHFP(IAF),CONFP(IAF),R2,R3,T1,T2)
      HANN=HANN*1.730735
      R1=DHYD/2.
C
      H2PR=H2PH/(1.+H2PH*R1*(A21/CON21+A32/HANN))
      RETURN
C
C  CEMENT IN ANNULUS
C
   10 CON32=CONC*1.730735
      R1=DHYD*.5
      H2PR=H2PH/(1.+H2PH*R1*(A21/CON21+A32/CON32))
      RETURN
      END
C
C
      FUNCTION TSAT(P)
C
C     COMPUTES SATURATION TEMPERATURE IN KELVINS AS A FUNCTION
C     OF PRESSURE IN PASCALS
C
      DIMENSION B(5)
      DATA B/1.0158658,.53542626,.070704624,-.26191199,0.10003160/
      DATA A/-.45800227/
C
      IF(P.LE.0.0)GO TO 2
      AP=ALOG(P)/ALOG(22.120E6)
      F=A
      DO 1 I=1,5
```

```
      F=F+B(I)*AP**I
    1 CONTINUE
      TSAT=472.5944/(1.73010-F)
      N=0
    3 CALL PSAT(PS,DPS,TSAT)
      DP=P-PS
      IF(ABS(DP/P).LE.1.E-5)GO TO 4
      DTEM=DP/DPS
      TSAT=TSAT+DTEM
      N=N+1
      IF(N.GT.10)GO TO 4
      GO TO 3
    4 RETURN
    2 TSAT=100.
      RETURN
      END
```

/