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Advanced Wellbore Thermal Simulator GEOTEMP2 User Manual

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ADVANCED WELLBORE THERMAL SIMULATOR:

GEOTEMP2

USER MANUAL

By

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1. INTRODUCTION

GEOTEMP2 is a wellbore thermal simulator designed for geothermal well drilling and production problems. GEOTEMP2 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
   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. varying 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 included

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 conductor pipe, surface casing, protective casing and production casing already set. In the annuli between these casings, packer fluids and cement columns of various heights are indicated. The well is now being drilled below the production casing. Three different fluids are indicated 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. More concrete examples are shown in figure 2: a well used in the Los Alamos Hot Dry project and a typical Imperial Valley geothermal well. Thermal simulations of these two well completions have been published as reference 3.

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

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

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.

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 1950's. The GEOTEMP2 gas drilling simulator goes far beyond previously available analysis by including:

1. Balance of aerodynamic drag and bouyancy forces on the cuttings
2. Bottom hole assembly fully described
3. Effects of mist addition and water influx included

Figure 3 illustates 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.

The other 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. 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%. The steam thermodynamic correlations use the equations of state published by Keenan and Keyes in their current edition of steam tables.

The remainder of this user manual is divided into two parts. The first part gives the data input format, along with input examples and comments on special features of the input. The second part consists of ten examples that illustrate all of the flowing options and input options in GEOTEMP2. The code listing with commentary is given in a separately bound appendix. The code operation and theoretical developement of the various flow models are described in the final research report for this project.

FIGURE 1

GEOTEMP WELLBORE THERMAL SIMULATOR

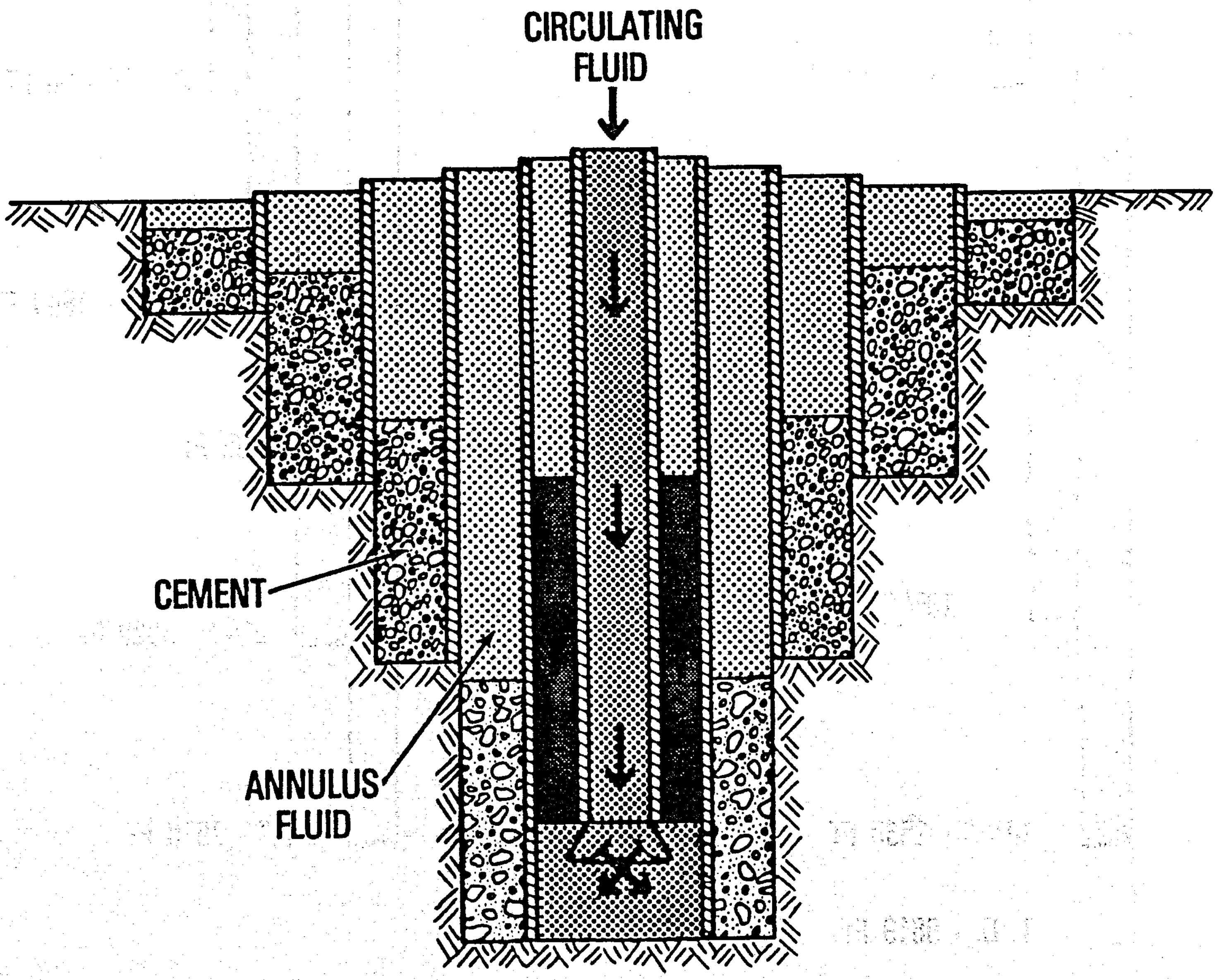


FIGURE 2

GEOTHERMAL WELL CASE STUDIES

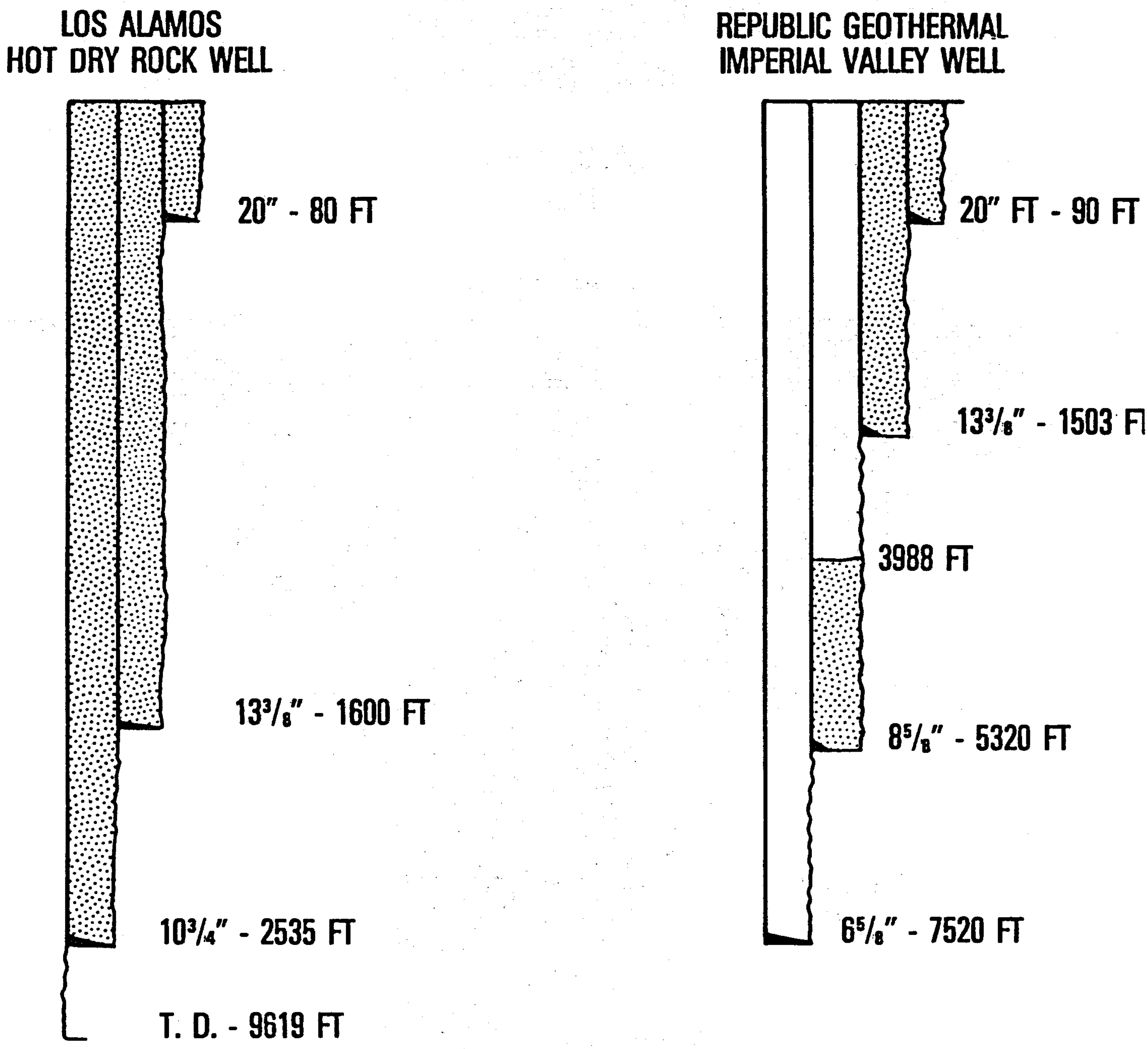
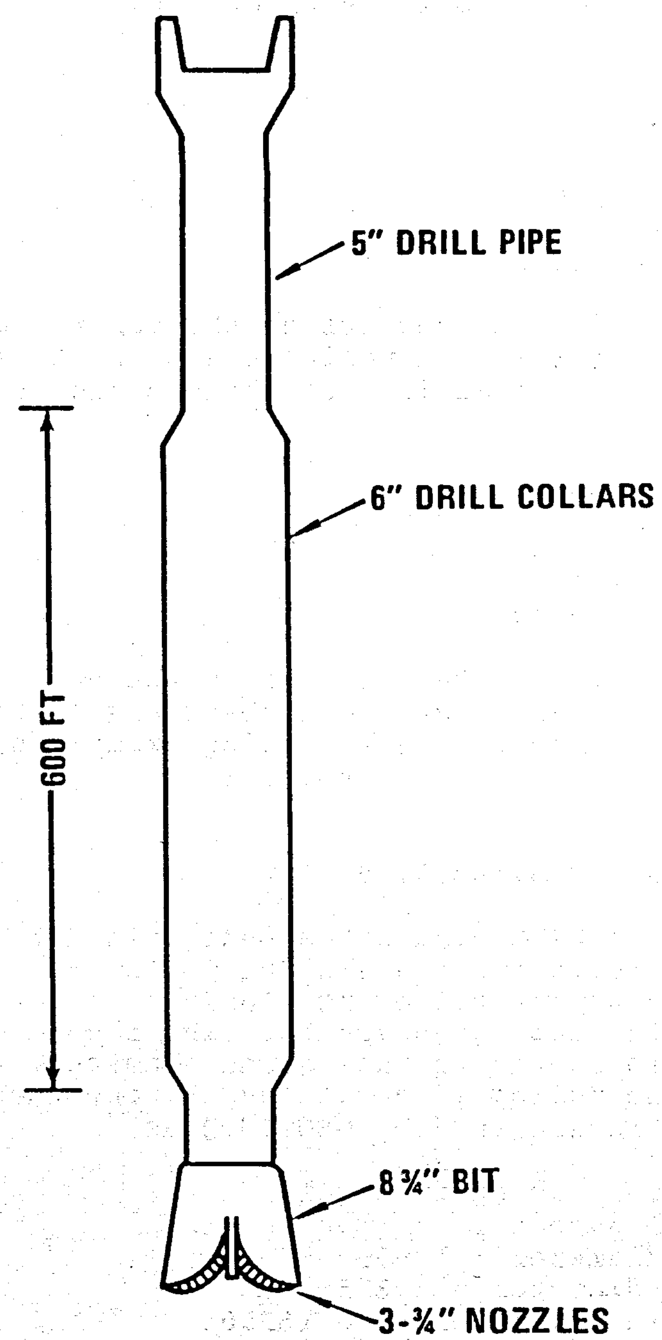


FIGURE 3

BOTTOM HOLE ASSEMBLY



2. 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 cards and options that describe the flow in the wellbore and the time periods defined. 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 cards is 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 card set and illustrates "free" format:

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

The keyword 'TUBING' indicates that this data card and the card immediately following contain the following information about the well tubing: the number following 'TUBING' indicates the number of different size tubing intervals. The second card gives the tubing interval number, the tubing inside diameter, the tubing outside diameter, the tubing interval length, and the cement column length. The data is interpreted by GEOTEMP2 as:

There is 1 tubing interval
Interval number 1
Inside diameter = 1.995
Outside diameter = 2.875
Tubing interval length = 18950.
Cement length = 0.

3. REQUIRED INPUT

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

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

Each required data card 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.

TITLE Card

Data: 78 character title or identifying comment

Comment: The TITLE card is used to identify the problem being run.

Example: PRODUCTION SIMULATION: SOUTH MCGOO #3

TUBING Cards

Data:

Card 1: 'TUBING',NINT
Card 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 cemment column outside tubing, feet

Comment: 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 parameter NINT specifies the number of intervals. Each data card following specifies the bottom of the interval with the parameter ZC, with the top of the interval determined by the bottom of the previous interval. The top of the first interval is the surface.

Example:

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

CASING Cards

Data:

Card 1: 'CASING',NPIPE
Card 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

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

The casing data cards (Card 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.

Example:

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

WELLBORE Card

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.)

Comment: This card 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.

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

TMD = DDVN + (TVD -DDVN)/sin@

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

INITIAL TEMP Card

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

Where:

TSUR = The undisturbed surface temperature, F

BHT = The bottom hole temperature, F

TD1 = The temperature at depth D1, F

D1 = The depth corresponding to TD1, feet

Comment: The bottom hole temperature BHT corresponds to the depth TVD given on the WELLBORE card.

Comment: Two different geothermal gradients can be specified through use of the variables given on this card.

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

FLUIDS Card

Data:

Card 1: 'FLUIDS',NFLUID

Card 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

Comment: The total number of data cards following Card 1 should equal to NFLUID. The ID numbers should be numbered consecutively starting with 1.

Comment: The FLUID cards are used to define the flowing properties of liquid systems such as water based drilling mud.

Example:

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

INITIAL FLUIDS Card

Data: 'INITIAL',IPF,IAF

Where:

IPF = I.D. number of wellbore fluid

IAF = I.D. number of annulus fluids

Comment: This card 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. If all the annuli are cemented to surface, IAF will be ignored, however, a number must be entered for IAF.

Example: 'INITIAL',3,1

SAMPLE SETUP DATA

```
Production of McGoo State #3
'TUBING',1
1,1.995,2.875,18950.,0.
'CASING',2
1,4.670,5.50,23000.,23000.
2,12.145,13.375,4275.,400.
'WELLBORE',23000.,23000.,20000.,2000.,20.
'TEMP',70.,150.,117.,8000.
'FLUIDS',3
1,9.5,9.0,12.0,
2,11.0,18.0,7.0,
3,18.5,28.0,2.0,
'INITIAL',2,1
```

4. CONTROL INPUT

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

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

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

where:

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

 ISEC = 0  no secondary flow change
      = 1  read secondary flow card

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

  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' card or is zero
        for first CHANGE card.
```

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

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

EXAMPLES: FLOW OPTIONS 1-4

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.

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

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

3. Fluid #1 is circulated at 10 bbl/min for 8 hours. Inlet temperature is 70 degrees F.

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

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.
```

FLOW OPTION 5: GAS FORWARD CIRCULATION

The 'CHANGE' card 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 cards of the setup data. For the convenience of the user, all gas properties are defined internally and are not specified in the FLUIDS cards. 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 piece of data is necessary to define the gas flow. This is the inlet or standpipe pressure. When flow option 5 is selected, the CHANGE card must be followed by the following GAS card:

```
'GAS',PSTAND
```

where PSTAND is the standpipe pressure in psia. If this pressure is too low to be consistant 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.
```

FLOW OPTION 6: DRILLING WITH LIQUID SYSTEMS

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

'DRILL',IBH,HRC,DDCHG

where

IBH = 0 no bottom hole assembly change
= 1 change bottom hole assembly (requires BHA card)

HRC = hours of circulation daily (daily snut-in equals 24-HRC)

DDCHG = drilling depth reached at time DAYCH, feet

When IBH is set equal to 1, the following bottom hole assembly or BHA card must immediately follow:

'BHA',DCL,DCRO,DCRI,BITD,BN1,BN2,BN3

where:

DCL = drill collar length, ft

DCOD = drill collar O.D., inches

DCID = drill collar I.D., 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 rederined every time the BHA card is used, but the BHA card does not have to be used with every DRILL card.

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 is was not necessary to repeat the bottom hole assembly information. The BHA card will only be needed when bit, bit nozzles, or drill collars are changed.

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 card defined for option 5 and the DRILL and BHA cards defined for option 6. These cards 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 cards have been defined previously. Note that the units for VFR are SCFM instead of gal/min since this is a gas system. The BHA card 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 card now has flow option 7 designated. Note that the volume flow rate is interpreted as SCFM rather than gal/min. A GAS card follows the CHANGE card with a standpipe pressure of 50 psia indicated. The DRILL and BHA cards are unchanged.

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 cards:

```
'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 card. The parameter VFRM on the MIST card 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 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.
```

FLOW OPTION 9: STEAM PRODUCTION

The 'CHANGE' card 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 piece of data 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 card:

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

```
'STEAM',1,QUAL
```

where 1 indicates wet steam, 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 card is used:

```
'STEAM',2,PIN
```

where 2 indicates single phase and PIN is the inlet pressure. If PIN is strictly 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 card 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 consistant, 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. If the frictional pressure drop term is dominant, the usual cause is a too high flow rate. If the gravitational pressure drop term is 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 .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.
```

FLOW OPTION 10: STEAM INJECTION

The 'CHANGE' card 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 piece of data 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 card:

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

```
'STEAM',1,QUAL
```

where 1 indicates wet steam, 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 card is used:

```
'STEAM',2,PIN
```

where 2 indicates single phase and PIN is the inlet pressure. If PIN is strictly 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 card 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 inlet pressures specified may not be consistant, that is, the flow may be choked before it reaches bottom hole. If this happens, the program will automatically exit, and print a summary of the flow conditions that caused the exit. 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 .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.
```

SECONDARY FLOW Card

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

ISEC = 0 no secondary flow change
     = 1 read secondary flow card

The purpose of the secondary flow option is to simulate the effect of fluid influx on the temperature and flow predictions in GEOTEMP2. This option may be selected with any flow option, however, the only meaningful options are options 2-8. Secondary flow is initialized at zero flow rate by GEOTEMP. To specify different secondary flow parameters, ISEC must be set to 1 and the SECFLOW card added following all other cards in a CHANGE card sequence. The SECFLOW card has the following 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 card in that the secondary flow parameters remain unchanged until a new secondary fluid card is read. Thus secondary flow can be turned on or off as desired, but the secondary flow card does not have to be repeated for every CHANGE card sequence.

EXAMPLE: SECONDARY FLOW

The mist drilling example is repeated here with the addition of 1 bbl/hr 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 cards in the first change card sequence. The SECFLOW card is not repeated for the next CHANGE card sequence because the secondary flow parameters remain unchanged.

5. SAMPLE PROBLEMS

In order to illustrate the use of the many flow options available with GEOTEMP2, ten sample problems have been assembled in this section. The problems have been chosen to be representative of real geothermal operations, and matched to field data when available. The full input data sets are listed in every case, though in a few cases the output has been edited for brevity. Each problem is introduced with some brief explanitory coments, and in some cases figures are included.

Distribution cont.

3141	L. J. Erickson	(5)
3151	W. L. Garner	(3)
5512	L. A. Mondy	
8214	M. A. Pound	
9000	G. A. Fowler	
9700	E. H. Beckner	
9740	R. K. Traeger	
9741	J. R. Kelsey	(25)
9741	C. C. Carson	
9743	H. C. Hardee	
9746	B. Granoff	
9747	P. J. Hommert	
9750	V. L. Dugan	
9756	D. Engi	
9756	C. Hart	

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SAMPLE PROBLEM 1: PRODUCTION WITH FLOW RATE CHANGE

The following tabulated results represent the GEOTEMP2 input and output 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', a 13-3/8" intermediate casing is set at 3000', and a 20" surface casing is 1000' deep. A 30" conductor pipe is set at 100'.

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

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

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 lbm/100 ft2. 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. Initially, at time zero, the flow conditions are defined by production with inlet temperature of 70 F and flow rate of 500 bbl/day. These conditions are set for 10 days, at which time the flow rate is changed to 5000 bbl/day as shown by the data on the next page.

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 five radial positions, the tubing and annulus temperatures, the first two formation temperatures, and the undisturbed temperature. These five temperatures are printed at every depth level in 200' 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 115 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 4 shows the temperature profile from the surface to bottomhole. 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 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.

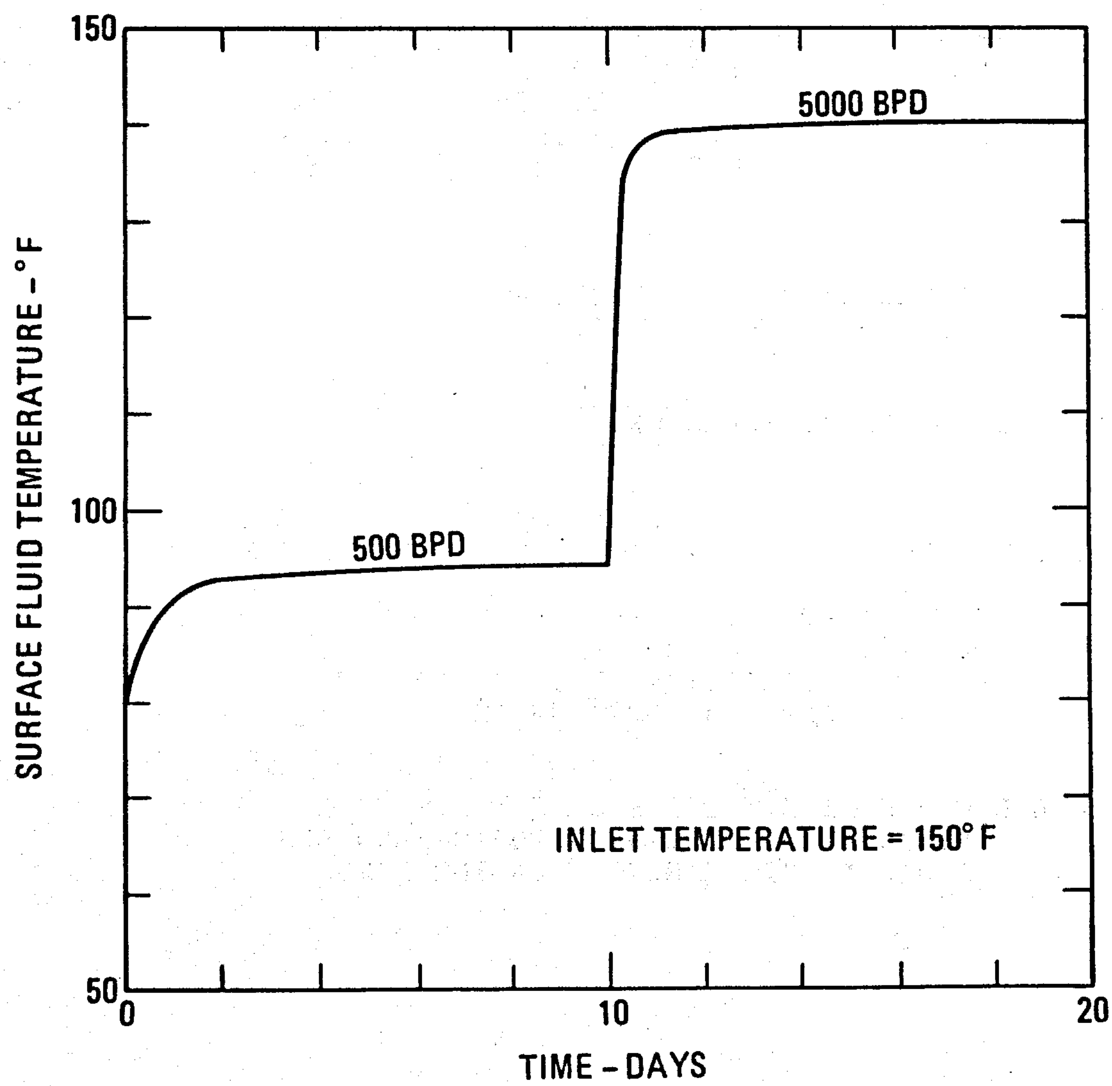
Flowing wellhead temperature of the produced fluid is plotted versus time in Figure 5. Temperatures change rapidly after flow begins, and then quickly approach an equilibrium value. Again, the effect of an increased flow rate is illustrated in this figure.

INPUT DATA

```
SAMPLE PROBLEM #1: PRODUCTION WITH FLOW RATE CHANGE
'TUBING',1
1,3.958,4.500,5000.,5000.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.000,1000.,1000.
4,29.000,30.000,100.0,100.0
'WELLBORE',5000.,5000.,5000.,5000.,31.0
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.0
'INITIAL',1,1
'CHANGE',2,0,1,150.,15.,10.
'CHANGE',2,0,1,150.,150.,20.
```

FIGURE 5

SAMPLE PROBLEM # 1: PRODUCTION WITH FLOW RATE CHANGE
TRANSIENT SURFACE FLUID TEMPERATURE



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	0.1	0.3	1.3	2.5	4.3	50.0
0.	114.7	70.0	70.0	70.0	70.0	70.0
200.	119.9	108.8	83.3	78.8	75.8	73.2
400.	122.0	111.2	86.3	81.9	78.9	76.4
600.	124.0	113.5	89.2	85.0	82.1	79.6
800.	126.0	116.1	91.8	87.9	85.1	82.8
1000.	127.9	117.9	95.2	91.1	88.4	86.0
1200.	129.7	120.1	98.1	94.2	91.5	89.2
1400.	131.6	122.2	101.0	97.2	94.6	92.4
1600.	133.3	124.3	103.9	100.2	97.7	95.6
1800.	135.0	126.4	106.7	103.2	100.9	98.8
2000.	136.6	128.4	109.6	106.3	104.0	102.0
2200.	138.1	130.3	112.4	109.3	107.1	105.2
2400.	139.6	132.2	115.3	112.2	110.2	108.4
2600.	141.0	134.0	118.1	115.2	113.3	111.6
2800.	142.3	135.9	120.7	118.1	116.3	114.8
3000.	143.5	137.2	123.9	121.3	119.5	118.0
3200.	144.6	138.8	126.6	124.2	122.6	121.2
3400.	145.7	140.4	129.3	127.2	125.7	124.4
3600.	146.7	142.0	132.0	130.1	128.8	127.6
3800.	147.5	143.4	134.7	133.0	131.8	130.8
4000.	148.2	144.7	137.3	135.9	134.9	134.0
4200.	148.9	146.0	139.9	138.7	137.9	137.2
4400.	149.3	147.1	142.5	141.6	140.9	140.4
4600.	149.7	148.2	145.0	144.4	144.0	143.6
4800.	149.9	149.2	147.5	147.2	147.0	146.8
5000.	150.0	150.0	150.0	150.0	150.0	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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	0.1	0.3	1.3	2.5	4.3	50.0
0.	145.0	70.0	70.0	70.0	70.0	70.0
200.	145.9	128.8	91.9	84.5	79.2	73.2
400.	146.3	129.8	94.4	87.3	82.2	76.4
600.	146.6	130.8	96.9	90.1	85.2	79.6
800.	146.9	132.0	99.1	92.7	88.1	82.8
1000.	147.2	133.4	101.3	95.3	91.0	86.0
1200.	147.4	134.3	103.8	98.1	94.0	89.2
1400.	147.7	135.3	106.2	100.9	97.0	92.4
1600.	147.9	136.2	108.7	103.6	100.0	95.6
1800.	148.2	137.1	111.2	106.4	102.9	98.8
2000.	148.4	138.0	113.7	109.2	105.9	102.0
2200.	148.6	138.9	116.1	111.9	108.9	105.2
2400.	148.8	139.7	118.6	114.7	111.8	108.4
2600.	149.0	140.6	121.0	117.4	114.8	111.6
2800.	149.1	141.6	123.3	120.1	117.7	114.8
3000.	149.3	142.1	126.1	123.1	120.8	118.0
3200.	149.4	143.0	128.6	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	140.6	139.3	138.4	137.2
4400.	149.9	147.8	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.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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.

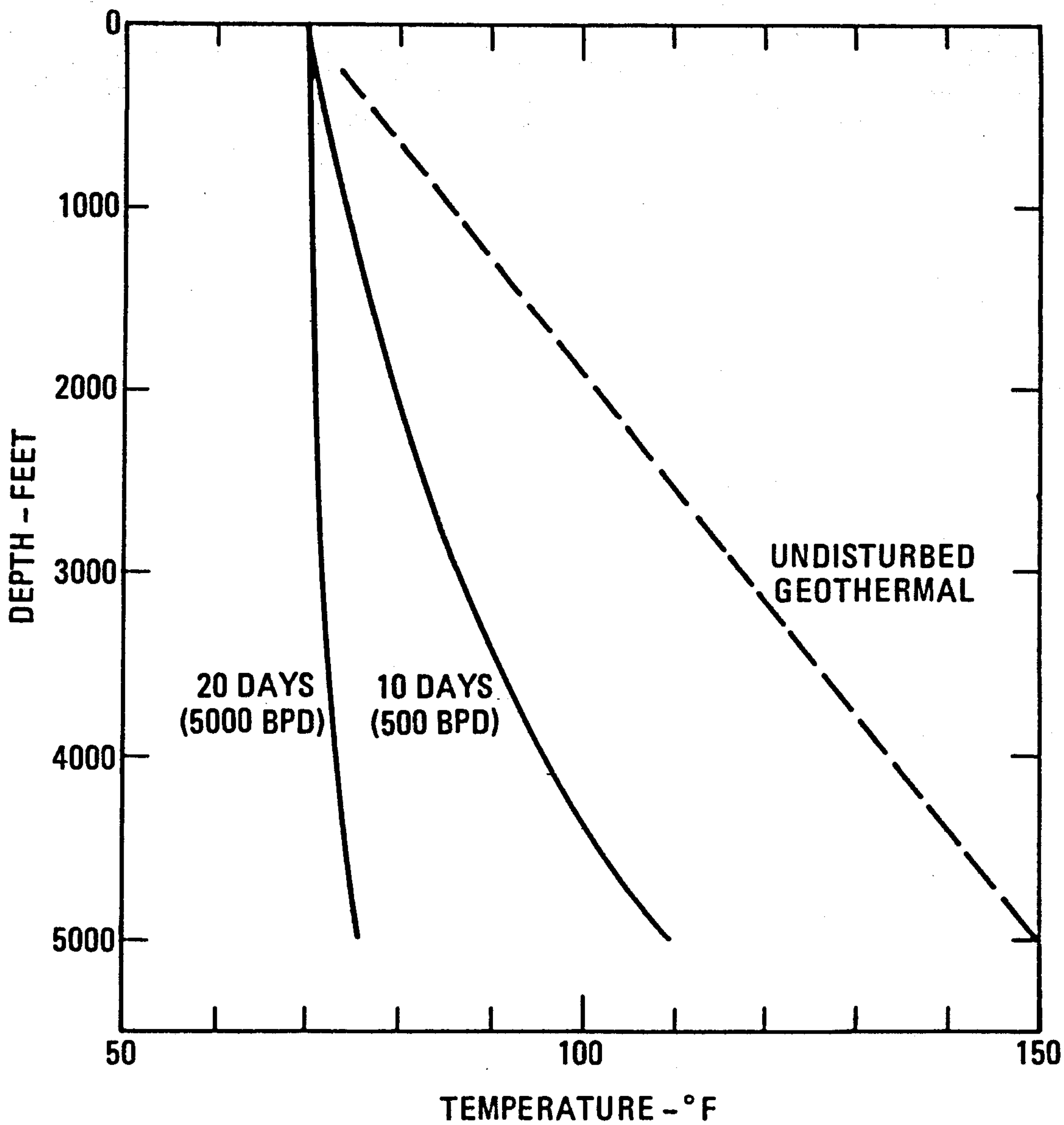
Fluid enters the well at the surface at a temperature of 70 F and leaves the well at a depth of 5000'. Injection rate begins at 500 bbl/day and increases to 5000 bbl/day after 10 days, continuing until 20 days. The second column of the output temperature distribution gives the injected fluid temperature profile. Figure 6 shows the profiles after 10 days and 20 days. The effect of flow rate is evident again as it was for production.

INPUT DATA

```
SAMPLE PROBLEM #2: INJECTION WITH FLOW RATE CHANGE
'TUBING',1
1,3.958,4.500,5000.,5000.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.000,1000.,1000.
4,29.000,30.000,100.0,100.0
'WELLBORE',5000.,5000.,5000.,5000.,31.0
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.0
'INITIAL',1,1
'CHANGE',1,0,1,70.,15.,10.
'CHANGE',1,0,1,70.,150.,20.
```

FIGURE 6

SAMPLE PROBLEM #2: INJECTION WITH FLOW RATE CHANGE
INJECTION FLUID TEMPERATURE PROFILES



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

	RADIAL POSITIONS, FEET				
DEPTH, FT	0.1	0.3	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	71.7	75.1	75.6	76.0	76.4
600.	70.6	72.7	77.6	78.5	79.1	79.6
800.	71.1	73.8	80.3	81.4	82.2	82.8
1000.	71.7	75.1	82.8	84.2	85.2	86.0
1200.	72.4	76.4	85.5	87.1	88.2	89.2
1400.	73.2	77.7	88.2	90.0	91.3	92.4
1600.	74.1	79.2	90.9	92.9	94.4	95.6
1800.	75.1	80.7	93.6	95.9	97.4	98.8
2000.	76.2	82.4	96.3	98.8	100.5	102.0
2200.	77.5	84.0	99.1	101.8	103.6	105.2
2400.	78.8	85.8	101.9	104.7	106.7	108.4
2600.	80.2	87.6	104.7	107.7	109.8	111.6
2800.	81.6	89.3	107.7	110.8	112.9	114.8
3000.	83.2	91.8	110.0	113.5	115.9	118.0
3200.	84.9	93.9	112.8	116.5	119.0	121.2
3400.	86.6	96.0	115.7	119.5	122.1	124.4
3600.	88.5	98.1	118.6	122.6	125.3	127.6
3800.	90.4	100.4	121.5	125.6	128.4	130.8
4000.	92.3	102.6	124.4	128.6	131.5	134.0
4200.	94.3	104.9	127.4	131.7	134.7	137.2
4400.	96.4	107.3	130.3	134.8	137.8	140.4
4600.	98.6	109.7	133.3	137.8	140.9	143.6
4800.	100.7	112.1	136.2	140.9	144.1	146.8
5000.	103.0	114.6	139.2	144.0	147.2	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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	0.1	0.3	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	78.1	78.7	79.6
800.	70.1	72.9	79.6	80.8	81.7	82.8
1000.	70.2	73.7	82.0	83.5	84.6	86.0
1200.	70.3	74.4	84.4	86.2	87.5	89.2
1400.	70.3	75.2	86.8	88.9	90.5	92.4
1600.	70.5	76.0	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	78.5	96.5	99.8	102.2	105.2
2400.	71.0	79.4	99.0	102.6	105.2	108.4
2600.	71.2	80.2	101.4	105.3	108.2	111.6
2800.	71.4	80.9	104.1	108.2	111.2	114.8
3000.	71.6	82.3	106.0	110.6	114.0	118.0
3200.	71.8	83.2	108.5	113.4	116.9	121.2
3400.	72.0	84.1	110.9	116.1	119.9	124.4
3600.	72.3	85.0	113.4	118.9	122.9	127.6
3800.	72.6	86.0	115.9	121.7	125.8	130.8
4000.	72.8	87.0	118.3	124.4	128.8	134.0
4200.	73.1	87.9	120.8	127.2	131.8	137.2
4400.	73.4	88.9	123.3	130.0	134.8	140.4
4600.	73.7	89.9	125.8	132.8	137.8	143.6
4800.	74.1	90.9	128.3	135.6	140.8	146.8
5000.	74.4	91.9	130.8	138.3	143.8	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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. 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 bottomhole at about 139.8 F, crosses over to the annulus, travels up the well, and returns to the surface with a temperature of 72.6 F. At 20 days, after circulating for 10 days at the increased temperature, the bottomhole temperature is 139.1 F, nearly the same as before, and the return temperature is 93 F. These results indicate that the flow rate is slow enough to allow the bottomhole temperature to reach approximately the same value for the two different inlet temperatures. Note that the maximum circulating temperature occurs in the annulus above bottomhole.

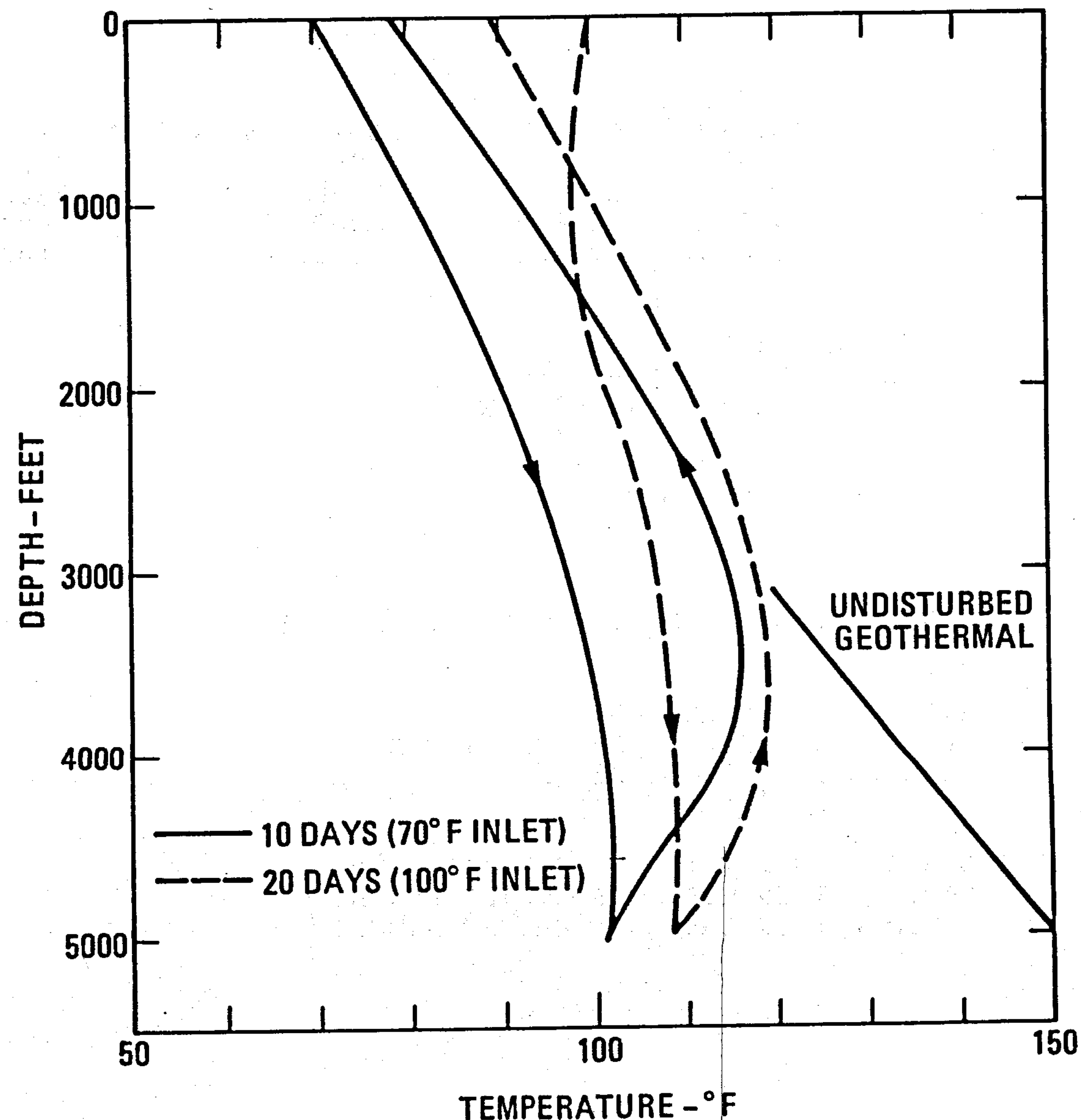
Predicted results are plotted in Figure 7. These curves may be compared to those for injection to determine the influence of the returning annulus fluid during circulation.

INPUT DATA

```
SAMPLE PROBLEM #3: FORWARD CIRCULATION W/ INLET TEMP CHANGE
'TUBING',1
1,3.958,4.500,5000.,5000.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.000,1000.,1000.
4,29.000,30.000,100.0,100.0
'WELLBORE',5000.,5000.,5000.,5000.,31.0
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.0
'INITIAL',1,1
'CHANGE',3,0,1,70.,10.,10.
'CHANGE',3,0,1,100.,10.,20.
```

FIGURE 7

SAMPLE PROBLEM #3: FORWARD CIRCULATION
CIRCULATING FLUID TEMPERATURE PROFILES



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 =   2

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	0.1	0.3	1.3	2.5	4.3	50.0
0.	70.0	72.7	70.0	70.0	70.0	70.0
200.	72.2	75.3	73.9	73.6	73.4	73.2
400.	74.6	77.9	76.9	76.7	76.5	76.4
600.	77.2	80.6	80.0	79.8	79.7	79.6
800.	80.0	83.5	83.0	82.9	82.9	82.8
1000.	82.8	86.4	86.2	86.1	86.0	86.0
1200.	85.8	89.4	89.3	89.2	89.2	89.2
1400.	88.8	92.5	92.4	92.4	92.4	92.4
1600.	91.9	95.5	95.6	95.6	95.6	95.6
1800.	95.0	98.7	98.7	98.8	98.8	98.8
2000.	98.2	101.8	101.9	102.0	102.0	102.0
2200.	101.4	104.9	105.1	105.2	105.2	105.2
2400.	104.6	108.1	108.3	108.3	108.4	108.4
2600.	107.8	111.3	111.5	111.5	111.6	111.6
2800.	111.0	114.4	114.7	114.7	114.8	114.8
3000.	114.2	117.6	117.9	117.9	118.0	118.0
3200.	117.4	120.7	121.0	121.1	121.2	121.2
3400.	120.6	123.9	124.2	124.3	124.4	124.4
3600.	123.8	126.9	127.3	127.5	127.5	127.6
3800.	126.9	129.9	130.5	130.6	130.7	130.8
4000.	129.9	132.7	133.5	133.7	133.9	134.0
4200.	132.7	135.4	136.5	136.8	137.0	137.2
4400.	135.3	137.6	139.3	139.8	140.1	140.4
4600.	137.5	139.4	141.9	142.7	143.2	143.6
4800.	139.1	140.2	144.2	145.4	146.1	146.8
5000.	139.8	139.8	145.9	147.7	148.9	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

```
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 = 2

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	0.1	0.3	1.3	2.5	4.3	50.0
0.	100.0	92.6	70.0	70.0	70.0	70.0
200.	95.5	91.2	79.9	77.1	75.1	73.2
400.	92.9	90.4	81.6	79.4	77.8	76.4
600.	91.5	90.5	83.6	81.9	80.7	79.6
800.	91.1	91.1	85.7	84.4	83.6	82.8
1000.	91.5	92.3	88.3	87.3	86.6	86.0
1200.	92.4	94.0	90.9	90.2	89.7	89.2
1400.	93.9	96.0	93.7	93.1	92.7	92.4
1600.	95.8	98.2	96.5	96.1	95.8	95.6
1800.	98.0	100.7	99.5	99.2	99.0	98.8
2000.	100.4	103.3	102.5	102.2	102.1	102.0
2200.	103.0	106.1	105.5	105.4	105.3	105.2
2400.	105.8	108.9	108.6	108.5	108.4	108.4
2600.	108.7	111.9	111.7	111.6	111.6	111.6
2800.	111.6	114.8	114.8	114.8	114.8	114.8
3000.	114.6	117.9	117.9	117.9	118.0	118.0
3200.	117.7	120.9	121.1	121.1	121.1	121.2
3400.	120.7	123.9	124.2	124.3	124.3	124.4
3600.	123.8	126.9	127.3	127.4	127.5	127.6
3800.	126.8	129.8	130.3	130.5	130.6	130.8
4000.	129.7	132.5	133.4	133.6	133.8	134.0
4200.	132.4	135.0	136.3	136.6	136.9	137.2
4400.	134.9	137.2	139.0	139.5	139.9	140.4
4600.	137.0	138.8	141.5	142.3	142.9	143.6
4800.	138.5	139.6	143.6	144.8	145.7	146.8
5000.	139.1	139.1	145.1	146.9	148.3	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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 bottomhole and the two fluids travel together up the well. As shown in the following input data, the SECFLOW card is inserted with the CHANGE card in the last time interval, namely between 10 and 20 days. The data-cards for the two fluid types are listed under the FLUIDS card. The property data for the two fluids is printed in the output.

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.

INPUT DATA

```
SAMPLE PROBLEM #4: REVERSE CIRCULATION W/ SECONDARY FLOW
'TUBING',1
1,3.958,4.500,5000.,0.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.000,1000.,1000.
4,29.000,30.000,100.0,100.0
'WELLBORE',5000.,5000.,5000.,5000.,31.0
'TEMP',70.,150.,110.,2500.
'FLUIDS',2
1,10.,15.,5.0
2,8.34,15.,5.0
'INITIAL',1,1
'CHANGE',4,0,1,70.,10.,10.
'CHANGE',4,1,1,100.,10.,20.
'SECFLOW',2,150.,146.
```

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	0.1	0.3	1.3	2.5	4.3	50.0
0.	74.0	70.0	70.0	70.0	70.0	70.0
200.	77.0	73.0	73.1	73.2	73.2	73.2
400.	80.1	76.1	76.3	76.3	76.4	76.4
600.	83.2	79.2	79.5	79.5	79.6	79.6
800.	86.3	82.4	82.7	82.7	82.8	82.8
1000.	89.4	85.6	85.8	85.9	86.0	86.0
1200.	92.5	88.7	89.0	89.1	89.2	89.2
1400.	95.7	91.9	92.2	92.3	92.4	92.4
1600.	98.8	95.1	95.4	95.5	95.6	95.6
1800.	102.0	98.3	98.6	98.7	98.8	98.8
2000.	105.1	101.5	101.8	101.9	102.0	102.0
2200.	108.3	104.7	105.0	105.1	105.2	105.2
2400.	111.4	107.9	108.2	108.3	108.4	108.4
2600.	114.5	111.1	111.4	111.5	111.6	111.6
2800.	117.6	114.3	114.6	114.7	114.8	114.8
3000.	120.7	117.4	117.8	117.9	117.9	118.0
3200.	123.7	120.6	121.0	121.1	121.1	121.2
3400.	126.7	123.7	124.1	124.3	124.3	124.4
3600.	129.6	126.7	127.3	127.4	127.5	127.6
3800.	132.5	129.7	130.4	130.6	130.7	130.8
4000.	135.1	132.5	133.5	133.7	133.9	134.0
4200.	137.6	135.3	136.5	136.8	137.0	137.2
4400.	139.8	137.8	139.4	139.9	140.2	140.4
4600.	141.5	140.0	142.3	142.9	143.3	143.6
4800.	142.8	141.9	144.9	145.8	146.3	146.8
5000.	143.2	143.2	147.4	148.6	149.4	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

S E T   V A R I A B L E S   AT TIME =   10.000 DAYS
FLOWING OPTION = REVERSE CIRCULATION
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	0.1	0.3	1.3	2.5	4.3	50.0
0.	140.5	100.0	70.0	70.0	70.0	70.0
200.	142.1	119.0	89.7	82.6	77.6	73.2
400.	143.2	128.2	95.1	87.0	81.4	76.4
600.	143.9	132.7	98.8	90.5	84.7	79.6
800.	144.4	135.1	100.8	93.0	87.6	82.8
1000.	144.9	136.6	104.7	96.6	91.0	86.0
1200.	145.4	137.6	107.1	99.3	93.9	89.2
1400.	145.8	138.6	109.5	102.1	96.9	92.4
1600.	146.2	139.4	111.8	104.8	99.9	95.6
1800.	146.6	140.3	114.2	107.5	102.9	98.8
2000.	147.0	141.1	116.5	110.2	105.9	102.0
2200.	147.3	141.8	118.8	112.9	108.8	105.2
2400.	147.6	142.6	121.1	115.6	111.8	108.4
2600.	147.9	143.3	123.4	118.3	114.7	111.6
2800.	148.2	144.0	125.3	120.7	117.6	114.8
3000.	148.5	144.6	128.7	124.1	120.9	118.0
3200.	148.7	145.1	130.9	126.7	123.8	121.2
3400.	149.0	145.7	133.0	129.3	126.7	124.4
3600.	149.2	146.3	135.1	131.9	129.6	127.6
3800.	149.4	146.8	137.3	134.4	132.5	130.8
4000.	149.5	147.4	139.4	137.0	135.4	134.0
4200.	149.7	147.9	141.5	139.6	138.3	137.2
4400.	149.8	148.4	143.5	142.1	141.1	140.4
4600.	149.9	148.8	145.6	144.6	144.0	143.6
4800.	149.9	149.2	147.6	147.1	146.8	146.8
5000.	150.0	149.6	149.6	149.6	149.6	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

SAMPLE PROBLEM 5: GAS FORWARD CIRCULATION WITH INLET TEMP 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. The results are quite comparable, suggesting the importance of mass flow rate in comparison to other factors. 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. 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 bottomhole at about 147 F, with an exit temperature at the surface of 70.8 F. This compares to 139.8 F bottom hole and 72.6 F exit temperatures in the liquid flow case. At 20 days, after circulating for 10 days at the increased temperature, the bottomhole temperature is 146.9 F, nearly the same as before, and the return temperature is 83.8 F. These temperatures compare with 139.1 F bottom hole and 92.6 F exit for the liquid flow case of example #3. The temperatures predicted in example #3 and #5 are very nearly the same, especially considering the large differences in density, velocity, viscosity, and thermal conductivity between the liquid and the gas. The results indicate that the flow rate is slow enough to allow the bottomhole temperature to reach approximately the same value, independant of the inlet temperatures. Note that the maximum circulating temperature occurs in the annulus above bottomhole in the liquid flow case but at bottom hole in the gas flow case.

INPUT DATA

```
SAMPLE PROBLEM #5: GAS FORWARD CIRCULATION W/ INLET TEMP CHANGE
'TUBING',1
1,3.958,4.500,5000.,5000.
'CASING',4
1,8.681,9.625,5000.,2200.
2,12.347,13.375,3000.,2200.
3,19.124,20.000,1000.,1000.
4,29.000,30.000,100.0,100.0
'WELLBORE',5000.,5000.,5000.,5000.,31.0
'TEMP',70.,150.,110.,2500.
'FLUIDS',1
1,10.,15.,5.0
'INITIAL',1,1
'CHANGE',5,0,1,70.,327.,10.
'GAS',50.
'CHANGE',5,0,1,100.,327.,20.
'GAS',50.
```

SAMPLE PROBLEM #5: 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	0.1	0.3	1.3	2.5	4.3	50.0
0.	70.0	70.8	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.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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	70.0	0.255	0.000	0.000	19.1
200.	50.2	72.0	0.255	0.000	0.000	19.1
400.	50.4	74.9	0.255	0.000	0.000	19.1
600.	50.7	78.0	0.254	0.000	0.000	19.1
800.	50.9	81.1	0.254	0.000	0.000	19.2
1000.	51.1	84.3	0.254	0.000	0.000	19.2
1200.	51.3	87.5	0.253	0.000	0.000	19.2
1400.	51.5	90.7	0.253	0.000	0.000	19.3
1600.	51.7	93.9	0.252	0.000	0.000	19.3
1800.	52.0	97.1	0.252	0.000	0.000	19.3
2000.	52.2	100.3	0.251	0.000	0.000	19.4
2200.	52.4	103.5	0.251	0.000	0.000	19.4
2400.	52.6	106.7	0.251	0.000	0.000	19.4
2600.	52.8	109.9	0.250	0.000	0.000	19.5
2800.	53.0	113.1	0.250	0.000	0.000	19.5
3000.	53.2	116.3	0.249	0.000	0.000	19.5
3200.	53.4	119.5	0.249	0.000	0.000	19.6
3400.	53.6	122.7	0.249	0.000	0.000	19.6
3600.	53.8	125.9	0.248	0.000	0.000	19.6
3800.	54.1	129.1	0.248	0.000	0.000	19.7
4000.	54.3	132.3	0.247	0.000	0.000	19.7
4200.	54.5	135.5	0.247	0.000	0.000	19.7
4400.	54.7	138.7	0.247	0.000	0.000	19.7
4600.	54.9	141.9	0.246	0.000	0.000	19.8
4800.	55.1	145.2	0.246	0.000	0.000	19.8
5000.	55.3	147.0	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	70.8	0.237	0.000	0.000	0.000	5.8	0.0
200.	46.9	73.5	0.238	0.000	0.000	0.000	5.8	0.0
400.	47.3	76.5	0.238	0.000	0.000	0.000	5.8	0.0
600.	47.6	79.6	0.238	0.000	0.000	0.000	5.8	0.0
800.	47.9	82.8	0.239	0.000	0.000	0.000	5.8	0.0
1000.	48.3	86.0	0.239	0.000	0.000	0.000	5.8	0.0
1200.	48.6	89.2	0.239	0.000	0.000	0.000	5.8	0.0
1400.	49.0	92.4	0.239	0.000	0.000	0.000	5.8	0.0
1600.	49.3	95.6	0.240	0.000	0.000	0.000	5.8	0.0
1800.	49.7	98.8	0.240	0.000	0.000	0.000	5.8	0.0
2000.	50.0	102.0	0.240	0.000	0.000	0.000	5.8	0.0
2200.	50.4	105.2	0.241	0.000	0.000	0.000	5.8	0.0
2400.	50.7	108.4	0.241	0.000	0.000	0.000	5.7	0.0
2600.	51.1	111.6	0.241	0.000	0.000	0.000	5.7	0.0
2800.	51.4	114.8	0.241	0.000	0.000	0.000	5.7	0.0
3000.	51.8	118.0	0.242	0.000	0.000	0.000	5.7	0.0
3200.	52.1	121.2	0.242	0.000	0.000	0.000	5.7	0.0
3400.	52.4	124.4	0.242	0.000	0.000	0.000	5.7	0.0
3600.	52.8	127.6	0.243	0.000	0.000	0.000	5.7	0.0
3800.	53.1	130.8	0.243	0.000	0.000	0.000	5.7	0.0
4000.	53.5	134.0	0.243	0.000	0.000	0.000	5.7	0.0
4200.	53.8	137.2	0.243	0.000	0.000	0.000	5.7	0.0
4400.	54.2	140.4	0.244	0.000	0.000	0.000	5.7	0.0
4600.	54.5	143.6	0.244	0.000	0.000	0.000	5.7	0.0
4800.	54.9	147.0	0.244	0.000	0.000	0.000	5.7	0.0
5000.	55.2	147.0	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	0.1	0.3	1.3	2.5	4.3	50.0
0.	100.0	83.8	70.0	70.0	70.0	70.0
200.	81.5	77.9	74.2	73.7	73.5	73.2
400.	78.0	77.9	76.7	76.6	76.5	76.4
600.	79.0	80.1	79.7	79.7	79.6	79.6
800.	81.5	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.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

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.	50.0	100.0	0.241	0.000	0.000	20.2
200.	50.2	81.5	0.250	0.000	0.000	19.4
400.	50.4	78.0	0.253	0.000	0.000	19.2
600.	50.6	79.0	0.254	0.000	0.000	19.2
800.	50.9	81.5	0.254	0.000	0.000	19.2
1000.	51.1	84.4	0.253	0.000	0.000	19.2
1200.	51.3	87.5	0.253	0.000	0.000	19.3
1400.	51.5	90.7	0.253	0.000	0.000	19.3
1600.	51.7	93.9	0.252	0.000	0.000	19.3
1800.	51.9	97.1	0.252	0.000	0.000	19.3
2000.	52.1	100.3	0.251	0.000	0.000	19.4
2200.	52.4	103.5	0.251	0.000	0.000	19.4
2400.	52.6	106.7	0.251	0.000	0.000	19.4
2600.	52.8	109.9	0.250	0.000	0.000	19.5
2800.	53.0	113.1	0.250	0.000	0.000	19.5
3000.	53.2	116.3	0.249	0.000	0.000	19.5
3200.	53.4	119.5	0.249	0.000	0.000	19.6
3400.	53.6	122.7	0.248	0.000	0.000	19.6
3600.	53.8	125.9	0.248	0.000	0.000	19.6
3800.	54.0	129.1	0.248	0.000	0.000	19.7
4000.	54.2	132.3	0.247	0.000	0.000	19.7
4200.	54.4	135.5	0.247	0.000	0.000	19.7
4400.	54.6	138.7	0.246	0.000	0.000	19.8
4600.	54.8	141.9	0.246	0.000	0.000	19.8
4800.	55.0	145.2	0.246	0.000	0.000	19.8
5000.	55.2	146.9	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	83.8	0.231	0.000	0.000	0.000	6.0	0.0
200.	46.9	77.9	0.235	0.000	0.000	0.000	5.9	0.0
400.	47.2	77.9	0.237	0.000	0.000	0.000	5.8	0.0
600.	47.6	80.1	0.238	0.000	0.000	0.000	5.8	0.0
800.	47.9	83.0	0.238	0.000	0.000	0.000	5.8	0.0
1000.	48.3	86.1	0.239	0.000	0.000	0.000	5.8	0.0
1200.	48.6	89.2	0.239	0.000	0.000	0.000	5.8	0.0
1400.	48.9	92.4	0.239	0.000	0.000	0.000	5.8	0.0
1600.	49.3	95.6	0.240	0.000	0.000	0.000	5.8	0.0
1800.	49.6	98.8	0.240	0.000	0.000	0.000	5.8	0.0
2000.	50.0	102.0	0.240	0.000	0.000	0.000	5.8	0.0
2200.	50.3	105.2	0.240	0.000	0.000	0.000	5.8	0.0
2400.	50.7	108.4	0.241	0.000	0.000	0.000	5.7	0.0
2600.	51.0	111.6	0.241	0.000	0.000	0.000	5.7	0.0
2800.	51.4	114.8	0.241	0.000	0.000	0.000	5.7	0.0
3000.	51.7	118.0	0.242	0.000	0.000	0.000	5.7	0.0
3200.	52.1	121.2	0.242	0.000	0.000	0.000	5.7	0.0
3400.	52.4	124.4	0.242	0.000	0.000	0.000	5.7	0.0
3600.	52.8	127.6	0.242	0.000	0.000	0.000	5.7	0.0
3800.	53.1	130.8	0.243	0.000	0.000	0.000	5.7	0.0
4000.	53.5	134.0	0.243	0.000	0.000	0.000	5.7	0.0
4200.	53.8	137.2	0.243	0.000	0.000	0.000	5.7	0.0
4400.	54.2	140.4	0.244	0.000	0.000	0.000	5.7	0.0
4600.	54.5	143.6	0.244	0.000	0.000	0.000	5.7	0.0
4800.	54.9	146.9	0.244	0.000	0.000	0.000	5.7	0.0
5000.	55.2	146.9	0.246	0.000	0.000	0.000	5.6	0.0

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-card.

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. The drilling is described with six sets of CHANGE cards. The six sets include three drilling (depth penetration) time intervals, each followed by a cementing time interval. The drilling reaches 1000' on day 3, 3000' on day 9, and bottomhole at 5000' 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 GEOTEMP 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.

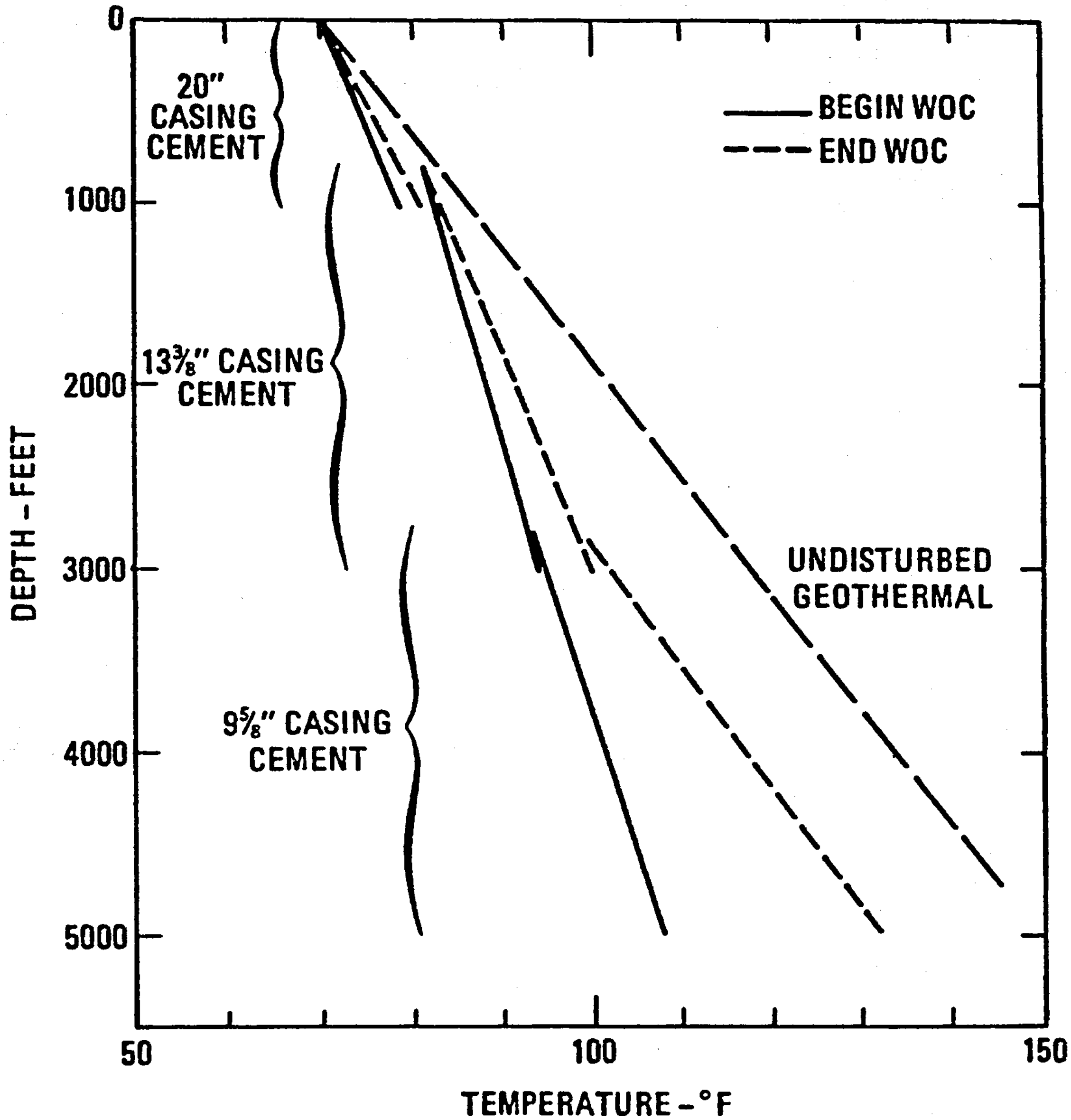
A temperature distribution is printed twice for each time interval, once at the end of circulation and once after shut-in on the last day of each time interval. The first temperature printout in the example occurs on day 3 and shows the distribution down to 1000' for 2.33 days (end of 8 hours of circulation). 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 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 during the cementing periods for each of the three casings are plotted in Figure 8. The depth profiles for each cement column are shown in the figure.

FIGURE 8

SAMPLE PROBLEM # 6 DRILLING WITH MULTIPLE FLUIDS

WAITING ON CEMENT TEMPERATURE PROFILES



INPUT DATA

```
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.
4,29.00,30.,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',1,8.0,1000.
'BHA',600.,2.5,6.0,22.0,.75,.75,.75
'CHANGE',6,0,2,70.,100.,4.0
'DRILL',0,4.,1000.
'CHANGE',6,0,3,70.,100.,9.
'DRILL',1,8.,3000.
'BHA',600.,2.5,6.0,15.0,.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.,2.5,6.0,9.875,.75,.75,.75
'CHANGE',6,0,2,70.,100.,21.
'DRILL',0,4.0,5000.
```

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.= 2.500 IN,   O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER= 22.000 IN, NOZZLE SIZES=  0.750  0.750  0.750 IN
```

TIME =   2.333 DAYS   ITERATIONS = 6

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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	71.5	70.0	70.0	70.0	70.0
200.	70.8	72.4	72.4	72.8	73.1	73.2
400.	71.6	73.1	73.5	75.6	76.2	76.4
600.	72.4	73.7	74.5	78.5	79.5	79.6
800.	73.0	74.0	75.4	81.9	82.8	82.8
1000.	73.4	73.4	76.7	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 = 5

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	0.1	0.3	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	75.3	75.4	75.6	76.2	76.4
600.	78.0	78.1	78.2	78.6	79.4	79.6
800.	80.9	81.1	81.4	81.9	82.7	82.8
1000.	81.0	84.4	84.7	85.4	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.= 2.500 IN,    O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER= 22.000 IN, NOZZLE SIZES=  0.750  0.750  0.750 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 = 7

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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	71.4	70.0	70.0	70.0	70.0
200.	71.4	72.8	72.9	72.9	73.1	73.2
400.	72.8	74.1	74.4	75.6	76.2	76.4
600.	74.0	75.0	75.6	78.5	79.4	79.6
800.	74.8	75.4	76.5	81.7	82.6	82.8
1000.	75.2	75.2	76.9	85.0	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 = 4

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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	70.0	70.0	70.0	70.0	70.0
200.	72.8	72.9	72.9	72.9	73.1	73.2
400.	75.4	75.5	75.6	75.7	76.1	76.4
600.	78.0	78.3	78.4	78.6	79.3	79.6
800.	80.6	81.2	81.3	81.7	82.5	82.8
1000.	78.1	84.3	84.4	85.0	85.8	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.= 2.500 IN, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 15.000 IN, NOZZLE SIZES= 0.750 0.750 0.750 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

	RADIAL POSITIONS, FEET					
DEPTH, FT	0.1	0.3	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	76.2	76.2	76.4
600.	76.0	80.1	79.4	79.1	79.2	79.6
800.	78.1	82.2	82.2	82.1	82.4	82.8
1000.	80.2	84.3	84.6	84.9	85.4	86.0
1200.	82.3	86.3	87.2	88.1	88.7	89.2
1400.	84.4	88.2	89.6	91.0	91.9	92.4
1600.	86.4	90.1	92.0	94.0	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	108.1	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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.3	70.3	70.0	70.0	70.0	70.0
200.	73.6	73.6	73.4	73.3	73.2	73.2
400.	76.4	76.4	76.2	76.2	76.2	76.4
600.	79.1	79.1	79.1	79.1	79.3	79.6
800.	82.0	82.0	82.1	82.2	82.4	82.8
1000.	84.8	84.8	84.9	85.0	85.4	86.0
1200.	87.9	87.9	88.0	88.2	88.7	89.2
1400.	90.7	90.8	90.9	91.2	91.8	92.4
1600.	93.6	93.7	93.9	94.2	95.0	95.6
1800.	96.6	96.6	96.9	97.3	98.2	98.8
2000.	99.5	99.6	99.9	100.4	101.5	102.0
2200.	102.5	102.6	103.0	103.5	104.7	105.2
2400.	105.5	105.6	106.1	106.8	108.0	108.4
2600.	108.6	108.7	109.3	110.1	111.3	111.6
2800.	111.7	111.9	112.7	113.5	114.6	114.8
3000.	109.2	113.3	116.2	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.= 2.500 IN,   O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER= 15.000 IN, NOZZLE SIZES=  0.750  0.750  0.750 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 = 10
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 0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	73.0	70.0	70.0	70.0	70.0
200.	72.9	75.8	73.9	73.3	73.2	73.2
400.	75.7	78.4	76.7	76.2	76.2	76.4
600.	78.4	81.0	79.6	79.2	79.3	79.6
800.	81.0	83.5	82.5	82.2	82.4	82.8
1000.	83.5	86.0	85.5	85.0	85.4	86.0
1200.	86.0	88.3	88.3	88.2	88.7	89.2
1400.	88.4	90.6	91.0	91.2	91.8	92.4
1600.	90.6	92.7	93.6	94.2	95.0	95.6
1800.	92.8	94.7	96.2	97.3	98.2	98.8
2000.	94.7	96.5	98.7	100.4	101.5	102.0
2200.	96.4	98.0	101.1	103.5	104.7	105.2
2400.	97.9	99.1	103.4	106.7	108.0	108.4
2600.	99.0	99.9	105.5	110.0	111.3	111.6
2800.	99.7	100.2	107.5	113.4	114.6	114.8
3000.	99.9	99.9	109.3	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

IME = 10.000 DAYS ITERATIONS = 5
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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.3	70.2	70.0	70.0	70.0	70.0
200.	73.6	73.6	73.4	73.3	73.2	73.2
400.	76.5	76.5	76.3	76.2	76.2	76.4
600.	79.4	79.4	79.3	79.2	79.3	79.6
800.	82.3	82.3	82.3	82.3	82.4	82.8
1000.	85.2	85.2	85.2	85.2	85.4	86.0
1200.	88.2	88.3	88.3	88.3	88.7	89.2
1400.	91.1	91.2	91.3	91.4	91.8	92.4
1600.	94.0	94.2	94.3	94.4	95.0	95.6
1800.	97.0	97.2	97.3	97.5	98.2	98.8
2000.	99.9	100.2	100.3	100.6	101.4	102.0
2200.	102.8	103.2	103.4	103.7	104.6	105.2
2400.	105.7	106.2	106.5	106.9	107.9	108.4
2600.	108.5	109.2	109.6	110.1	111.2	111.6
2800.	111.1	112.3	112.8	113.4	114.5	114.8
3000.	105.2	115.8	116.2	116.9	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.= 2.500 IN, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 9.875 IN, NOZZLE SIZES= 0.750 0.750 0.750 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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	74.1	70.0	70.0	70.0	70.0
200.	72.3	76.4	74.6	73.8	73.4	73.2
400.	74.5	78.6	77.4	76.8	76.5	76.4
600.	76.8	80.9	80.2	79.7	79.5	79.6
800.	79.1	83.2	82.9	82.7	82.6	82.8
1000.	81.4	85.4	85.7	85.6	85.6	86.0
1200.	83.7	87.6	88.5	88.6	88.7	89.2
1400.	85.9	89.8	91.3	91.6	91.8	92.4
1600.	88.2	92.0	94.0	94.5	94.9	95.6
1800.	90.4	94.2	96.7	97.5	98.0	98.8
2000.	92.6	96.3	99.5	100.4	101.0	102.0
2200.	94.7	98.4	102.2	103.4	104.1	105.2
2400.	96.8	100.4	104.9	106.4	107.2	108.4
2600.	98.9	102.4	107.6	109.3	110.3	111.6
2800.	101.0	104.4	110.3	112.3	113.4	114.8
3000.	102.9	106.3	111.1	114.4	116.1	118.0
3200.	104.9	108.1	113.5	117.3	119.2	121.2
3400.	106.7	109.7	115.9	120.3	122.4	124.4
3600.	108.4	111.3	118.3	123.3	125.7	127.6
3800.	110.0	112.7	120.7	126.4	129.0	130.8
4000.	111.5	113.9	123.0	129.6	132.4	134.0
4200.	112.7	114.8	125.4	132.9	135.8	137.2
4400.	113.8	115.6	127.7	136.3	139.3	140.4
4600.	114.6	115.9	130.1	140.0	142.9	143.6
4800.	115.2	115.9	132.7	144.1	146.5	146.8
5000.	115.3	115.3	136.2	149.0	150.0	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

TIME = 20.000 DAYS ITERATIONS = 8
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE = 0. GAL/MIN CIRCULATION DEPTH = 5000. FT

TEMPERATURE DISTRIBUTION

	RADIAL POSITIONS, FEET					
DEPTH, FT	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.5	70.5	70.0	70.0	70.0	70.0
200.	74.2	74.1	73.9	73.8	73.5	73.2
400.	77.0	76.9	76.8	76.7	76.5	76.4
600.	79.7	79.7	79.7	79.7	79.5	79.6
800.	82.5	82.6	82.6	82.6	82.6	82.8
1000.	85.3	85.3	85.5	85.6	85.6	86.0
1200.	88.2	88.2	88.5	88.6	88.7	89.2
1400.	90.9	91.0	91.4	91.6	91.8	92.4
1600.	93.7	93.8	94.4	94.6	94.9	95.6
1800.	96.5	96.6	97.3	97.5	98.0	98.8
2000.	99.3	99.3	100.2	100.5	101.0	102.0
2200.	102.0	102.1	103.1	103.5	104.1	105.2
2400.	104.8	104.9	106.1	106.5	107.2	108.4
2600.	107.6	107.7	109.0	109.4	110.3	111.6
2800.	110.2	110.3	111.9	112.4	113.4	114.8
3000.	112.5	112.7	114.1	114.6	116.1	118.0
3200.	115.2	115.4	117.0	117.6	119.2	121.2
3400.	117.9	118.1	119.9	120.6	122.4	124.4
3600.	120.6	120.8	122.8	123.6	125.6	127.6
3800.	123.4	123.6	125.9	126.7	128.9	130.8
4000.	126.1	126.3	128.9	129.9	132.2	134.0
4200.	128.9	129.1	132.1	133.2	135.6	137.2
4400.	131.6	132.0	135.3	136.6	139.1	140.4
4600.	134.5	134.9	138.8	140.2	142.7	143.6
4800.	137.6	138.1	142.5	144.1	146.2	146.8
5000.	133.9	142.1	146.9	148.6	149.8	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

```
S E T   V A R I A B L E S   AT TIME =    20.000 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 =    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.= 2.500 IN,   O.D.= 6.000 IN
          DRILL BIT:
            DIAMETER=  9.875 IN, NOZZLE SIZES=  0.750  0.750  0.750 IN

FLUIDS IN WELL UPDATED AT TIME=    20.055 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 = 9
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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.0	73.1	70.0	70.0	70.0	70.0
200.	72.9	75.9	74.2	73.8	73.5	73.2
400.	75.8	78.6	77.0	76.7	76.5	76.4
600.	78.6	81.4	79.9	79.7	79.5	79.6
800.	81.3	84.0	82.8	82.6	82.6	82.8
1000.	84.1	86.7	85.8	85.6	85.6	86.0
1200.	86.8	89.4	88.7	88.6	88.7	89.2
1400.	89.5	92.1	91.6	91.6	91.8	92.4
1600.	92.1	94.7	94.5	94.6	94.9	95.6
1800.	94.8	97.4	97.5	97.5	98.0	98.8
2000.	97.5	100.0	100.4	100.5	101.0	102.0
2200.	100.2	102.7	103.3	103.5	104.1	105.2
2400.	102.9	105.3	106.2	106.5	107.2	108.4
2600.	105.5	107.9	109.1	109.5	110.3	111.6
2800.	108.2	110.5	112.0	112.4	113.4	114.8
3000.	110.8	113.1	114.2	114.7	116.1	118.0
3200.	113.3	115.6	117.1	117.6	119.2	121.2
3400.	115.8	118.0	119.9	120.6	122.4	124.4
3600.	118.2	120.2	122.9	123.7	125.6	127.6
3800.	120.5	122.3	125.8	126.8	128.9	130.8
4000.	122.5	124.2	128.7	130.0	132.2	134.0
4200.	124.3	125.7	131.6	133.2	135.6	137.2
4400.	125.9	126.9	134.6	136.6	139.1	140.4
4600.	127.0	127.8	137.7	140.2	142.6	143.6
4800.	127.8	128.2	140.9	144.1	146.2	146.8
5000.	128.1	128.1	144.5	148.5	149.8	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

TIME = 21.000 DAYS ITERATIONS = 5
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	0.1	0.3	1.3	2.6	4.5	50.0
0.	70.4	70.3	70.0	70.0	70.0	70.0
200.	74.0	74.0	73.8	73.7	73.5	73.2
400.	76.9	76.9	76.7	76.7	76.5	76.4
600.	79.9	79.8	79.7	79.6	79.5	79.6
800.	82.8	82.8	82.7	82.6	82.6	82.8
1000.	85.7	85.7	85.6	85.6	85.6	86.0
1200.	88.6	88.7	88.7	88.7	88.8	89.2
1400.	91.5	91.6	91.6	91.7	91.8	92.4
1600.	94.5	94.5	94.6	94.7	94.9	95.6
1800.	97.4	97.4	97.6	97.7	98.0	98.8
2000.	100.3	100.4	100.6	100.7	101.1	102.0
2200.	103.2	103.3	103.6	103.7	104.2	105.2
2400.	106.1	106.2	106.6	106.7	107.2	108.4
2600.	109.0	109.2	109.5	109.7	110.3	111.6
2800.	111.9	112.1	112.5	112.7	113.4	114.8
3000.	114.4	114.5	114.9	115.1	116.1	118.0
3200.	117.2	117.4	117.9	118.1	119.2	121.2
3400.	120.1	120.3	120.9	121.1	122.4	124.4
3600.	123.0	123.3	123.9	124.2	125.6	127.6
3800.	125.9	126.2	127.0	127.3	128.9	130.8
4000.	128.8	129.2	130.1	130.5	132.2	134.0
4200.	131.7	132.2	133.3	133.8	135.5	137.2
4400.	134.5	135.2	136.6	137.2	139.0	140.4
4600.	137.3	138.2	140.0	140.7	142.5	143.6
4800.	140.0	141.4	143.6	144.4	146.0	146.8
5000.	134.7	145.4	147.6	148.5	149.6	150.0
5200.	150.0	150.0	150.0	150.0	150.0	150.0
5400.	150.0	150.0	150.0	150.0	150.0	150.0

SAMPLE PROBLEMS 7 & 8: AIR AND MIST DRILLING

Sample problems #7 and #8 are combined in one section because it gives 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' 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 5400 ft. At this point, mist drilling is started and continued to 9000 ft.

The volume flow rate requirements are shown in Figure 9. The volumes used for the air drilling case are based on the Angel charts(ref 1), and were adequate to clean the hole. However, in the mist drilling case, significant increases in the volume flow rate were needed when water was added to the air. Figure 10 shows the standpipe pressures needed to maintain the flow rates. A large increase in pressure was needed when mist was used as a drilling fluid. Figure 11 shows the predicted bottom hole velocities for these cases. The predicted cuttings velocities are much lower than the air velocities. Interestingly, the cuttings velocities increase for mist drilling. Because of the higher pressures needed for mist drilling, the bottom hole air density is higher. As a result, the buoyant weight of the cuttings is lower, resulting in a slightly higher velocity.

Note: the computer print outs for problems #7 and #8 have been edited down to the input data and the last drilling simulation. The complete output was simply too long to include all of it.

FIGURE 9

SAMPLE PROBLEMS #7 AND #8
GAS VOLUME REQUIREMENTS

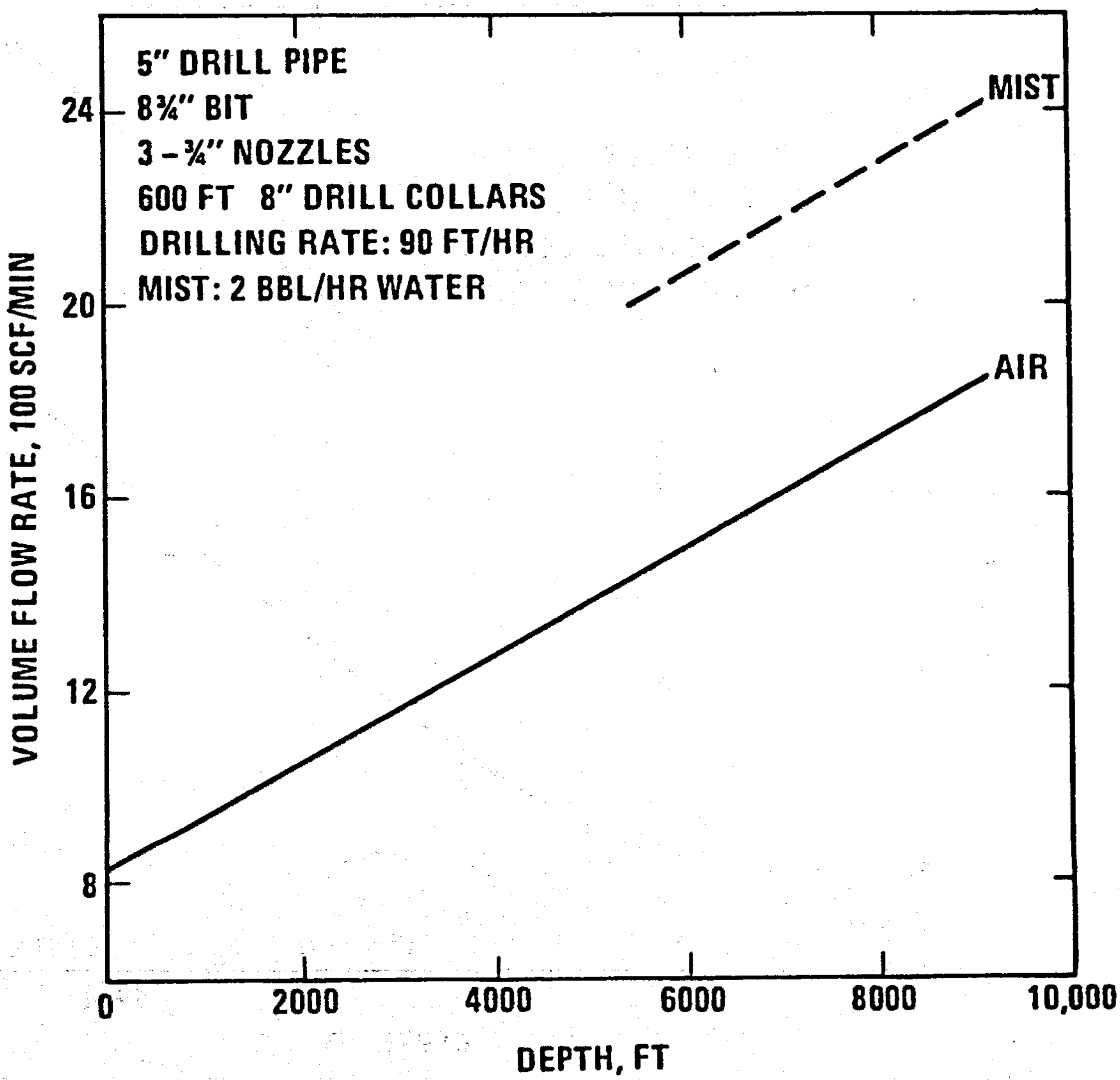


FIGURE 10

SAMPLE PROBLEMS #7 AND #8

STANDPIPE PRESSURE

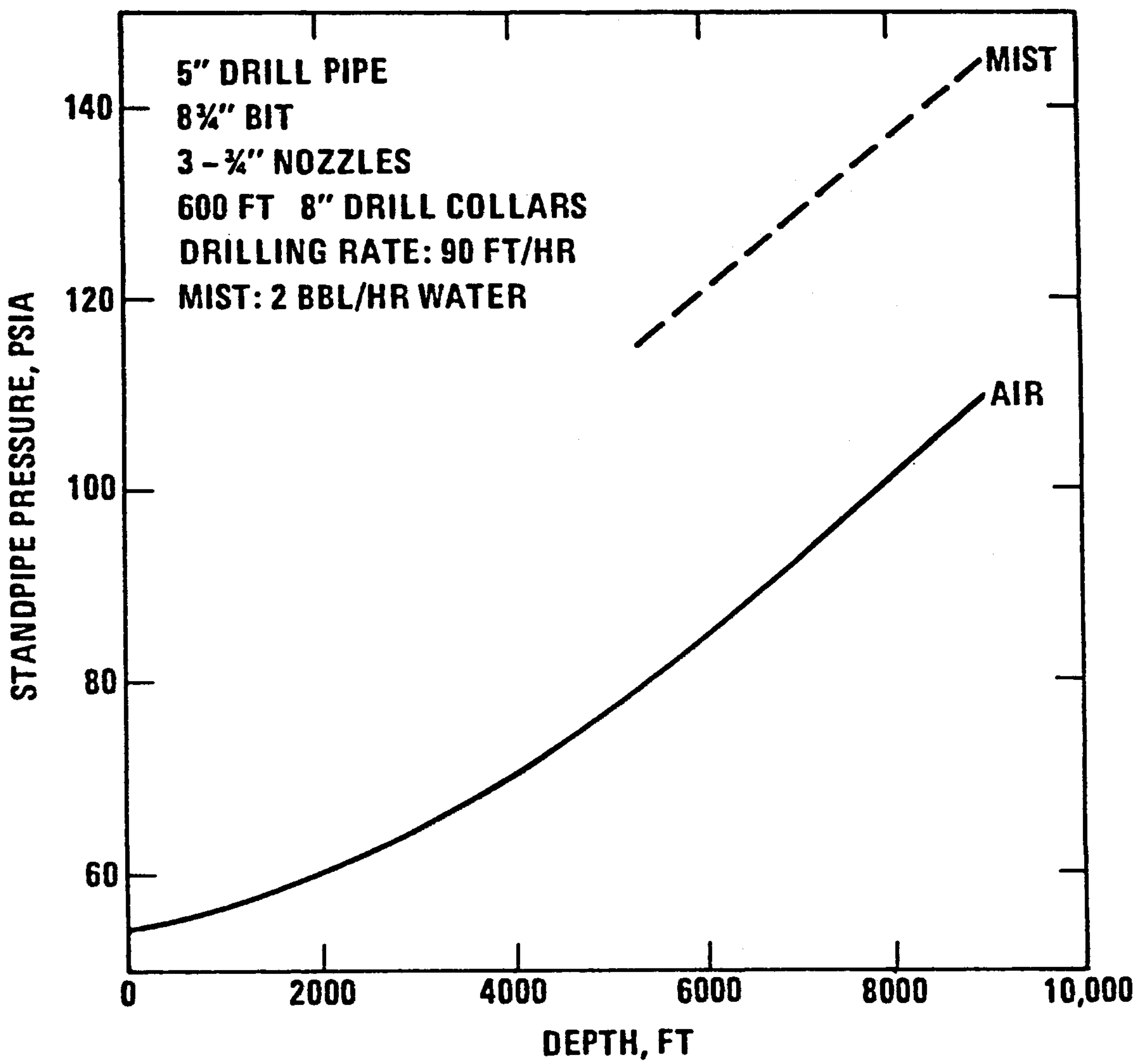
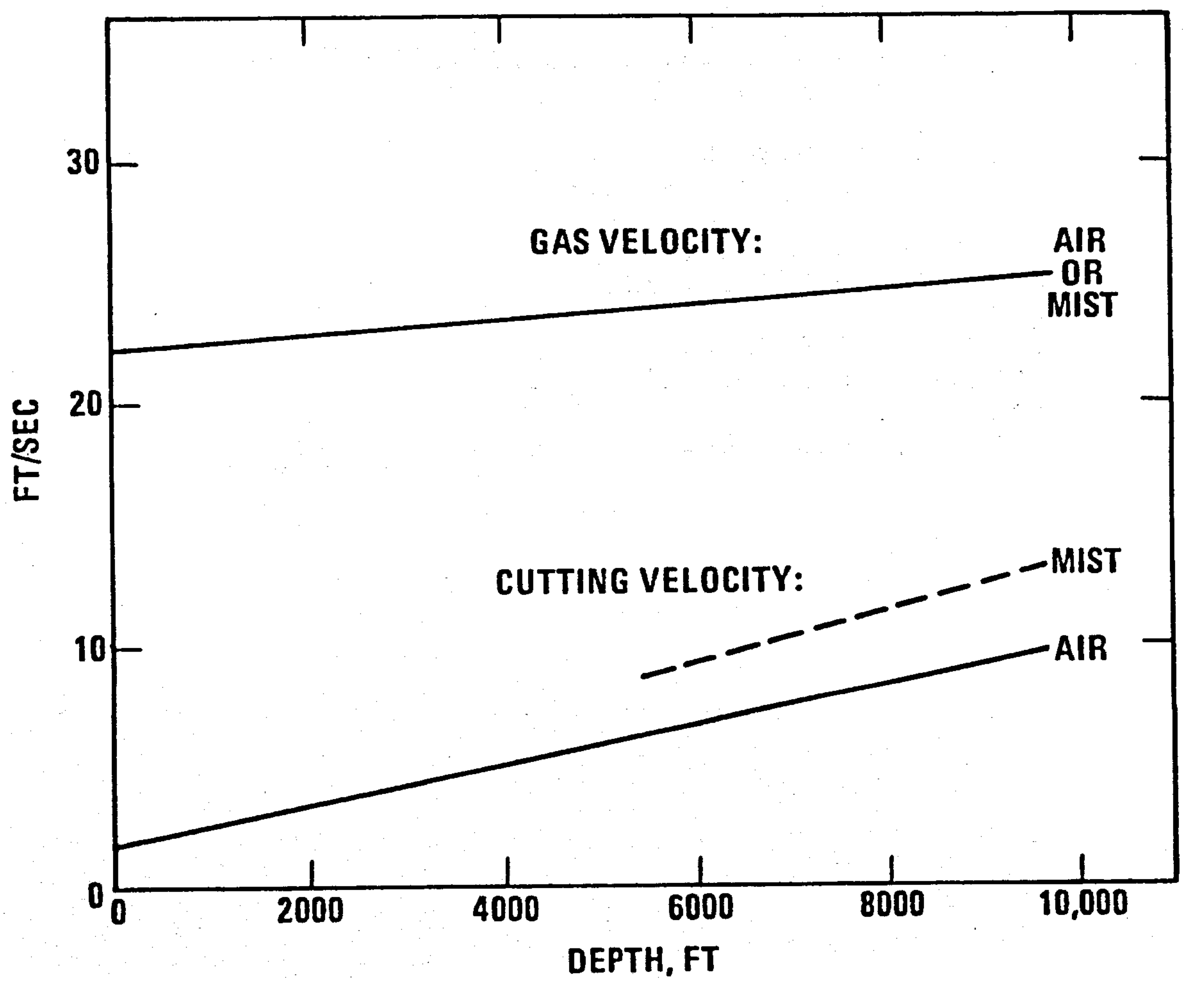


FIGURE 11

SAMPLE PROBLEMS #7 AND #8

GAS AND CUTTINGS VELOCITIES

5" DRILL PIPE
8¾" BIT
3 - ¾" NOZZLES
600 FT 8" DRILL COLLARS
DRILLING RATE: 90 FT/HR
MIST: 2 BBL/HR WATER



INPUT DATA

```
SAMPLE PROBLEM #7: AIR DRILLING
'TUBING',1
1,4.408,5.0,9000.,0.
'CASING',1
1,8.921,9.625,100.,100.
'WELLBORE',0.,9000.,9000.,0.,20.,
'TEMP',80.,170.,105.,2500.,
'FLUIDS',2
1,8.330,1.0,0.,
2,9.250,10.0,3.0,
'INITIAL',2,2,
'CHANGE',7,0,1,80.,1028.,2.
'GAS',40.
'DRILL',1,10.0,1800.
'BHA',600.,6.0,2.5,8.75,.75,.75,.75
'CHANGE',7,0,1,80.,1230.,4.
'GAS',55.
'DRILL',0,10.0,3600.
'CHANGE',7,0,1,80.,1432.,6.
'GAS',70.
'DRILL',0,10.0,5400.
'CHANGE',7,0,1,80.,1633.,8.
'GAS',90.
'DRILL',0,10.0,7200.
'CHANGE',7,0,1,80.,1835.,10.
'GAS',110.
'DRILL',0,10.0,9000.
```

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 = 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= 0.750 0.750 0.750 IN

TIME = 9.417 DAYS ITERATIONS = 4
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =1835. SCF/MIN CIRCULATION DEPTH = 9000. FT

TEMPERATURE DISTRIBUTION

	RADIAL POSITIONS, FEET					
DEPTH, FT	0.1	0.3	0.8	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	84.2	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.	149.0	150.1	150.1	150.0	150.0	150.0
7200.	151.0	152.2	152.1	152.0	152.0	152.0
7400.	153.0	154.2	154.1	154.0	154.0	154.0
7600.	155.0	156.1	156.1	156.0	156.0	156.0
7800.	156.9	158.1	158.0	158.0	158.0	158.0
8000.	158.9	160.2	160.1	160.0	160.0	160.0
8200.	160.9	161.9	162.0	162.0	162.0	162.0
8400.	162.7	163.6	163.8	163.9	164.0	164.0
8600.	164.8	165.8	165.8	165.9	166.0	166.0
8800.	167.1	168.1	168.0	168.0	168.0	168.0
9000.	168.8	169.0	169.5	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.	175.1	80.0	0.876	0.000	0.000	25.2
200.	175.7	81.4	0.876	0.000	0.000	25.1
400.	176.3	83.1	0.877	0.000	0.000	25.1
600.	176.9	85.0	0.876	0.000	0.000	25.1
800.	177.4	86.9	0.876	0.000	0.000	25.1
1000.	178.0	88.9	0.876	0.000	0.000	25.2
1200.	178.6	90.9	0.875	0.000	0.000	25.2
1400.	179.2	92.9	0.875	0.000	0.000	25.2
1600.	179.7	94.9	0.875	0.000	0.000	25.2
1800.	180.3	96.9	0.874	0.000	0.000	25.2
2000.	180.9	98.9	0.874	0.000	0.000	25.2
2200.	181.5	100.9	0.874	0.000	0.000	25.2
2400.	182.0	102.9	0.873	0.000	0.000	25.2
2600.	182.6	104.9	0.873	0.000	0.000	25.2
2800.	183.2	106.9	0.873	0.000	0.000	25.2
3000.	183.8	108.9	0.872	0.000	0.000	25.3
3200.	184.3	110.9	0.872	0.000	0.000	25.3
3400.	184.9	112.9	0.872	0.000	0.000	25.3
3600.	185.5	114.9	0.871	0.000	0.000	25.3
3800.	186.0	116.9	0.871	0.000	0.000	25.3
4000.	186.6	118.9	0.870	0.000	0.000	25.3
4200.	187.2	120.9	0.870	0.000	0.000	25.3
4400.	187.7	122.9	0.870	0.000	0.000	25.3
4600.	188.3	124.9	0.869	0.000	0.000	25.3
4800.	188.8	126.9	0.869	0.000	0.000	25.4
5000.	189.4	128.9	0.869	0.000	0.000	25.4
5200.	190.0	130.9	0.868	0.000	0.000	25.4
5400.	190.5	132.9	0.868	0.000	0.000	25.4
5600.	191.1	134.9	0.867	0.000	0.000	25.4
5800.	191.6	136.9	0.867	0.000	0.000	25.4
6000.	192.2	138.9	0.867	0.000	0.000	25.4
6200.	192.8	140.9	0.866	0.000	0.000	25.4
6400.	193.3	142.9	0.866	0.000	0.000	25.4
6600.	193.9	144.9	0.865	0.000	0.000	25.5
6800.	194.4	146.9	0.865	0.000	0.000	25.5
7000.	195.0	149.0	0.865	0.000	0.000	25.5
7200.	195.5	151.0	0.864	0.000	0.000	25.5
7400.	196.1	153.0	0.864	0.000	0.000	25.5
7600.	196.6	155.0	0.863	0.000	0.000	25.5
7800.	197.2	156.9	0.863	0.000	0.000	25.5
8000.	197.7	158.9	0.863	0.000	0.000	25.5
8200.	198.3	160.9	0.862	0.000	0.000	25.5
8400.	198.8	162.7	0.862	0.000	0.000	25.6
8600.	186.5	164.8	0.806	0.000	0.000	85.0
8800.	174.0	167.1	0.749	0.000	0.000	91.4
9000.	160.3	168.8	0.688	0.000	0.000	99.5

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.	41.9	80.7	0.209	0.000	0.000	0.257	39.7	17.0
200.	43.1	82.4	0.215	0.000	0.000	0.250	40.9	18.5
400.	44.4	84.2	0.220	0.000	0.000	0.261	39.9	17.8
600.	45.7	86.2	0.226	0.000	0.000	0.272	38.9	17.1
800.	47.0	88.1	0.231	0.000	0.000	0.283	37.9	16.4
1000.	48.3	90.1	0.237	0.000	0.000	0.294	37.0	15.8
1200.	49.6	92.1	0.242	0.000	0.000	0.306	36.2	15.2
1400.	50.9	94.1	0.248	0.000	0.000	0.318	35.4	14.6
1600.	52.3	96.1	0.254	0.000	0.000	0.330	34.6	14.0
1800.	53.6	98.1	0.259	0.000	0.000	0.343	33.9	13.5
2000.	55.0	100.1	0.265	0.000	0.000	0.356	33.1	13.0
2200.	56.4	102.1	0.271	0.000	0.000	0.370	32.5	12.5
2400.	57.8	104.1	0.276	0.000	0.000	0.384	31.8	12.1
2600.	59.2	106.1	0.282	0.000	0.000	0.399	31.1	11.6
2800.	60.6	108.1	0.288	0.000	0.000	0.415	30.5	11.2
3000.	62.1	110.1	0.294	0.000	0.000	0.431	29.9	10.8
3200.	63.6	112.1	0.300	0.000	0.000	0.448	29.3	10.3
3400.	65.2	114.1	0.306	0.000	0.000	0.466	28.7	9.9
3600.	66.8	116.1	0.313	0.000	0.000	0.486	28.1	9.5
3800.	68.4	118.1	0.319	0.000	0.000	0.505	27.5	9.2
4000.	70.1	120.1	0.326	0.000	0.000	0.527	26.9	8.8
4200.	71.8	122.1	0.333	0.000	0.000	0.550	26.4	8.4
4400.	73.5	124.1	0.340	0.000	0.000	0.575	25.8	8.1
4600.	75.4	126.1	0.347	0.000	0.000	0.600	25.3	7.7
4800.	77.2	128.1	0.354	0.000	0.000	0.629	24.8	7.4
5000.	79.2	130.1	0.362	0.000	0.000	0.659	24.2	7.0
5200.	81.2	132.1	0.370	0.000	0.000	0.693	23.7	6.7
5400.	83.3	134.1	0.378	0.000	0.000	0.728	23.2	6.4
5600.	85.5	136.1	0.387	0.000	0.000	0.769	22.7	6.0
5800.	87.8	138.1	0.396	0.000	0.000	0.811	22.2	5.7
6000.	90.2	140.1	0.406	0.000	0.000	0.863	21.6	5.4
6200.	92.8	142.1	0.416	0.000	0.000	0.915	21.1	5.1
6400.	95.5	144.1	0.426	0.000	0.000	0.982	20.6	4.7
6600.	98.3	146.1	0.438	0.000	0.000	1.048	20.1	4.4
6800.	101.3	148.1	0.450	0.000	0.000	1.140	19.5	4.1
7000.	104.6	150.1	0.463	0.000	0.000	1.228	19.0	3.8
7200.	108.1	152.2	0.477	0.000	0.000	1.362	18.4	3.4
7400.	112.0	154.2	0.492	0.000	0.000	1.491	17.8	3.1
7600.	116.2	156.1	0.509	0.000	0.000	1.711	17.2	2.7
7800.	121.0	158.1	0.528	0.000	0.000	1.923	16.6	2.4
8000.	126.4	160.2	0.550	0.000	0.000	2.370	16.0	2.0
8200.	133.0	161.9	0.577	0.000	0.000	2.811	15.2	1.6
8400.	139.1	163.6	0.602	0.000	0.000	4.959	14.6	0.9
8600.	149.7	165.8	0.646	0.000	0.000	1.582	16.6	3.7
8800.	154.9	168.1	0.665	0.000	0.000	1.721	16.1	3.4
9000.	160.3	169.0	0.688	0.000	0.000	1.899	15.6	3.1

INPUT DATA

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SAMPLE PROBLEM #8: MIST DRILLING
'TUBING',1
1,4.408,5.0,9000.,0.
'CASING',1
1,8.921,9.625,100.,100.
'WELLBORE',0.,9000.,9000.,0.,20.,
'TEMP',80.,170.,105.,2500.,
'FLUIDS',2
1,8.330,1.0,0.,
2,9.250,10.0,3.0,
'INITIAL',2,2,
'CHANGE',7,0,1,80.,1028.,2.
'GAS',40.
'DRILL',1,10.0,1800.
'BHA',600.,6.0,2.5,8.75,.75,.75,.75
'CHANGE',7,0,1,80.,1230.,4.
'GAS',55.
'DRILL',0,10.0,3600.
'CHANGE',8,0,1,80.,2000.,6.
'GAS',115.
'MIST',1.4
'DRILL',0,10.0,5400.
'CHANGE',8,0,1,80.,2200.,8.
'GAS',120.
'MIST',1.4
'DRILL',0,10.0,7200.
'CHANGE',8,0,1,80.,2400.,10.
'GAS',140.
'MIST',1.4
'DRILL',0,10.0,9000.
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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 = 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, O.D.= 6.000 IN
DRILL BIT:
DIAMETER= 8.750 IN, NOZZLE SIZES= 0.750 0.750 0.750 IN

CHOKED FLOW: STANDPIPE PRESSURE INCREASED TO 145.1 PSI

TIME = 9.417 DAYS ITERATIONS = 8
CONDITIONS SINCE LAST TIME STEP:
FLOW RATE =2400. 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	0.1	0.3	0.8	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	90.0	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	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.	100.9	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	122.1	122.0	122.0
4400.	122.9	124.2	124.1	124.1	124.0	124.0
4600.	124.9	126.2	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	132.2	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	148.3	148.1	148.0	148.0
7000.	149.2	150.6	150.3	150.1	150.0	150.0
7200.	151.4	152.8	152.5	152.1	152.0	152.0
7400.	153.7	155.1	154.7	154.2	154.0	154.0
7600.	156.2	157.9	156.8	155.9	156.0	156.0
7800.	159.3	161.2	159.3	157.9	158.0	158.0
8000.	160.8	159.5	159.6	159.8	160.0	160.0
8200.	158.7	158.3	160.0	161.7	162.0	162.0
8400.	159.5	162.0	162.9	163.8	164.0	164.0
8600.	163.8	165.3	165.6	165.9	166.0	166.0
8800.	166.7	167.7	167.8	168.0	168.0	168.0
9000.	168.3	168.6	169.3	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	0.075	0.002	24.0
200.	241.0	81.4	1.202	0.075	0.002	24.0
400.	242.0	83.1	1.203	0.075	0.002	23.9
600.	243.0	85.0	1.204	0.075	0.002	23.9
800.	244.0	86.9	1.205	0.075	0.002	23.9
1000.	245.0	88.9	1.205	0.075	0.002	23.9
1200.	246.0	90.9	1.206	0.075	0.002	23.9
1400.	246.9	92.9	1.206	0.075	0.002	23.9
1600.	247.9	94.9	1.207	0.074	0.002	23.9
1800.	248.9	96.8	1.207	0.074	0.003	23.9
2000.	249.9	98.8	1.208	0.074	0.003	23.9
2200.	250.9	100.9	1.208	0.074	0.003	23.8
2400.	251.9	102.9	1.209	0.074	0.003	23.8
2600.	253.0	104.9	1.209	0.074	0.003	23.8
2800.	254.0	106.9	1.210	0.074	0.003	23.8
3000.	255.0	108.9	1.210	0.074	0.004	23.8
3200.	256.0	110.9	1.211	0.073	0.004	23.8
3400.	257.0	112.9	1.211	0.073	0.004	23.8
3600.	258.0	114.9	1.212	0.073	0.004	23.8
3800.	259.0	116.9	1.212	0.073	0.005	23.8
4000.	260.0	118.9	1.213	0.073	0.005	23.8
4200.	261.0	120.9	1.213	0.072	0.005	23.7
4400.	262.0	122.9	1.214	0.072	0.005	23.7
4600.	263.0	124.9	1.214	0.072	0.006	23.7
4800.	264.0	126.9	1.215	0.072	0.006	23.7
5000.	265.1	128.9	1.216	0.071	0.006	23.7
5200.	266.1	130.9	1.216	0.071	0.007	23.7
5400.	267.1	132.9	1.217	0.071	0.007	23.7
5600.	268.1	134.9	1.217	0.070	0.007	23.7
5800.	269.1	136.9	1.218	0.070	0.008	23.7
6000.	270.1	138.9	1.218	0.070	0.008	23.7
6200.	271.2	140.9	1.219	0.069	0.008	23.6
6400.	272.2	143.0	1.219	0.069	0.009	23.6
6600.	273.2	145.0	1.220	0.069	0.009	23.6
6800.	274.2	147.1	1.220	0.068	0.010	23.6
7000.	275.3	149.2	1.220	0.068	0.010	23.6
7200.	276.3	151.4	1.220	0.067	0.011	23.6
7400.	277.3	153.7	1.220	0.067	0.011	23.6
7600.	278.3	156.2	1.220	0.066	0.012	23.6
7800.	279.4	159.3	1.218	0.065	0.013	23.7
8000.	280.4	160.8	1.220	0.065	0.013	23.6
8200.	281.4	158.7	1.228	0.066	0.013	23.5
8400.	282.5	159.5	1.231	0.066	0.013	23.4
8600.	268.2	163.8	1.161	0.010	0.014	77.2
8800.	253.9	166.7	1.094	0.007	0.015	81.9
9000.	238.4	168.3	1.025	0.005	0.016	87.4

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.	66.6	80.8	0.332	0.055	0.002	0.387	32.2	11.3
200.	68.4	82.5	0.340	0.054	0.002	0.329	33.2	14.1
400.	70.1	84.3	0.348	0.055	0.002	0.341	32.5	13.6
600.	71.8	86.2	0.355	0.056	0.002	0.353	31.9	13.1
800.	73.6	88.2	0.362	0.057	0.002	0.366	31.2	12.7
1000.	75.4	90.2	0.370	0.058	0.002	0.379	30.6	12.2
1200.	77.2	92.2	0.378	0.059	0.002	0.393	30.0	11.8
1400.	79.1	94.2	0.385	0.060	0.002	0.408	29.4	11.4
1600.	81.0	96.2	0.393	0.061	0.003	0.423	28.8	11.0
1800.	82.9	98.2	0.401	0.062	0.003	0.438	28.2	10.6
2000.	84.9	100.2	0.409	0.064	0.003	0.455	27.6	10.2
2200.	87.0	102.2	0.418	0.065	0.003	0.473	27.1	9.8
2400.	89.1	104.2	0.426	0.066	0.003	0.491	26.5	9.4
2600.	91.3	106.2	0.435	0.067	0.003	0.511	26.0	9.1
2800.	93.5	108.2	0.444	0.069	0.004	0.532	25.5	8.7
3000.	95.8	110.2	0.453	0.070	0.004	0.554	25.0	8.4
3200.	98.1	112.2	0.463	0.071	0.004	0.577	24.4	8.0
3400.	100.6	114.2	0.473	0.073	0.004	0.602	23.9	7.7
3600.	103.1	116.2	0.483	0.074	0.004	0.630	23.4	7.4
3800.	105.7	118.2	0.493	0.075	0.005	0.659	22.9	7.0
4000.	108.4	120.2	0.504	0.077	0.005	0.691	22.4	6.7
4200.	111.2	122.2	0.516	0.079	0.005	0.725	21.9	6.4
4400.	114.2	124.2	0.527	0.080	0.005	0.762	21.4	6.1
4600.	117.2	126.2	0.540	0.082	0.006	0.803	21.0	5.8
4800.	120.4	128.1	0.553	0.084	0.006	0.849	20.5	5.5
5000.	123.8	130.1	0.566	0.086	0.006	0.899	20.0	5.2
5200.	127.3	132.2	0.580	0.088	0.007	0.957	19.5	4.8
5400.	131.0	134.2	0.595	0.090	0.007	1.020	19.0	4.5
5600.	135.0	136.2	0.611	0.092	0.007	1.094	18.5	4.2
5800.	139.2	138.2	0.628	0.094	0.008	1.177	18.0	3.9
6000.	143.7	140.2	0.646	0.097	0.008	1.278	17.5	3.6
6200.	148.6	142.2	0.666	0.100	0.009	1.395	17.0	3.3
6400.	153.8	144.3	0.687	0.103	0.009	1.543	16.5	3.0
6600.	159.6	146.3	0.711	0.106	0.009	1.721	15.9	2.7
6800.	166.0	148.4	0.737	0.110	0.010	1.964	15.4	2.4
7000.	173.3	150.6	0.766	0.114	0.010	2.281	14.8	2.0
7200.	181.7	152.8	0.800	0.119	0.011	2.783	14.1	1.7
7400.	191.7	155.1	0.841	0.125	0.012	3.558	13.4	1.3
7600.	203.7	157.9	0.890	0.132	0.012	5.311	12.7	0.9
7800.	211.8	161.2	0.920	0.136	0.013	11.008	12.3	0.4
8000.	207.5	159.5	0.904	0.134	0.013	26.508	12.5	0.2
8200.	190.3	158.3	0.831	0.122	0.012	65.556	13.6	0.1
8400.	210.5	162.0	0.914	0.135	0.014	3.353	12.4	1.4
8600.	222.9	165.3	0.962	0.112	0.015	2.112	14.5	2.8
8800.	231.4	167.7	0.995	0.115	0.015	1.684	14.1	3.5
9000.	238.5	168.6	1.025	0.005	0.016	1.707	13.7	3.5

SAMPLE PROBLEM 9: STEAM PRODUCTION

Sample problem #9 is based on geothermal well production data published by Gould in 1974 (ref 2). The well being modeled is well BR-13 in the Broadlands geothermal field in New Zealand. This well has a surface flowing pressure of 159.7 psia with a steam quality of .241. The GEOTEMP2 output predicts a surface flowing pressure of 162.3 psia, or about 2% too high. The steam quality predicted is .255 or about 6% too high. This well flowed in the slug flow regime, which was verified by the two-phase flow model. The results predicted are within the range of accuracy claimed for the Orkiszewski correlations and probably within the accuracy of the field data.

INPUT DATA

```
SAMPLE PROBLEM #9: STEAM PRODUCTION: WELL BR-13
'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.,31.0
'TEMP',70.,460.,70.,10.
'FLUIDS',1
1,8.33,1.,0.0
'INITIAL',1,1
'CHANGE',9,0,1,460.0,580.,1.00
'STEAM',1,.160
```

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 = 0.160
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	0.1	0.4	1.3	2.4	3.9	50.0
0.	364.6	70.0	70.0	70.0	70.0	70.0
200.	380.5	316.0	168.9	120.8	103.5	101.0
400.	392.3	332.7	196.4	151.9	136.0	133.6
600.	401.8	347.5	223.5	182.9	168.4	166.3
800.	409.9	361.2	250.1	213.8	200.8	198.9
1000.	416.9	374.2	276.5	244.6	233.2	231.5
1200.	423.2	386.5	302.8	275.4	265.6	264.2
1400.	428.9	396.4	327.0	305.6	297.9	296.8
1600.	434.1	403.5	349.0	334.9	330.1	329.5
1800.	441.6	418.3	376.9	366.3	362.6	362.1
2000.	448.3	432.6	404.7	397.5	395.1	394.7
2200.	454.4	446.5	432.4	428.8	427.5	427.4
2400.	460.0	460.0	460.0	460.0	460.0	460.0
2600.	460.0	460.0	460.0	460.0	460.0	460.0
2800.	460.0	460.0	460.0	460.0	460.0	460.0

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	PRESSURE	TEMP	DENSITY-LBM/FT3		VELOCITY	
FT	PSIA	F	VAPOR	LIQUID	FT/SEC	
0.	162.3	364.6	0.353	1.034	173.9	SLUG
200.	197.0	380.5	0.423	1.338	136.9	SLUG
400.	226.4	392.3	0.481	1.618	114.9	SLUG
600.	252.6	401.8	0.532	1.883	99.8	SLUG
800.	276.4	409.9	0.578	2.139	88.7	SLUG
1000.	298.7	416.9	0.620	2.390	80.1	SLUG
1200.	319.6	423.2	0.660	2.638	73.1	SLUG
1400.	339.7	428.9	0.697	2.887	67.3	SLUG
1600.	358.9	434.1	0.732	3.136	78.6	SLUG
1800.	388.1	441.6	0.784	3.546	70.2	SLUG
2000.	415.5	448.3	0.831	3.960	63.4	SLUG
2200.	441.7	454.4	0.876	4.381	57.8	SLUG
2400.	466.9	460.0	0.917	4.813	53.0	

SAMPLE PROBLEM 10: STEAM INJECTION

Sample problem 10 is interesting because it illustrates typical two-phase flow phenomena. First, the flowing temperature in the wet steam is controlled by the pressure drop. The printout illustrates that the fluid temperature is dropping even though the formation temperature is increasing with depth. Second, the change of phase of the steam is controlled by heat transfer to the fluid combined with the imposed temperature. Enough steam condenses in the flowing steam to satisfy the energy equation consistent with the other imposed conditions

INPUT DATA

```
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.,31.0
'TEMP',100.,410.1,400.,800.
'FLUIDS',1
1,8.33,1.,0.0
'INITIAL',1,1
'CHANGE',10,0,1,410.1,50.,.50
'STEAM',2,200.
```

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 = 0.500 DAYS

TIME = 0.500 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	0.2	0.4	1.3	2.4	3.9	50.0
0.	410.1	100.0	100.0	100.0	100.0	100.0
200.	379.9	307.3	229.0	184.6	175.6	175.0
400.	378.8	333.5	284.1	256.1	250.4	250.0
600.	377.6	359.2	339.0	327.5	325.2	325.0
800.	376.3	384.6	393.7	398.9	399.9	400.0
1000.	375.0	384.9	395.6	401.7	403.0	403.1
1200.	373.5	385.0	397.5	404.6	406.0	406.1
1400.	371.9	385.1	399.3	407.5	409.1	409.2
1600.	410.1	410.1	410.1	410.1	410.1	410.1
1800.	410.1	410.1	410.1	410.1	410.1	410.1

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	0.417	0.000	49.9	
200.	195.5	379.9	0.431	0.005	47.7	SLUG
400.	192.9	378.8	0.425	0.009	47.9	SLUG
600.	190.2	377.6	0.419	0.010	48.4	SLUG
800.	187.4	376.3	0.413	0.010	49.1	SLUG
1000.	184.4	375.0	0.407	0.009	50.0	SLUG
1200.	181.1	373.5	0.400	0.008	51.0	SLUG
1400.	177.6	371.9	0.392	0.007	52.1	SLUG

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