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# Offshore Gas Condensate Pipeline

## Problem Description

Wet gas is produced offshore and subsequently transported to shore through a 32-inch pipeline. As shown in Figure P1.1, the wet gas passes through a booster platform where the gas is separated and compressed. This gas is then re-combined with the condensate and sent to the onshore destination. The process conditions are given in Table P1.1.

You are required to:

1. Determine the onshore slug catcher size. To do this, you must calculate the onshore fluid temperature, pressure, liquid and vapor rate, and total liquid holdup.
2. Generate fluid phase envelope and hydrate curves. Assuming that the average seabed temperature is 10°C, you are assigned to determine if hydrate will form in the line by using PIPEPHASE's point-by-point hydrate prediction cap.

**Figure P1.1: Offshore Gas Condensate Pipeline System**

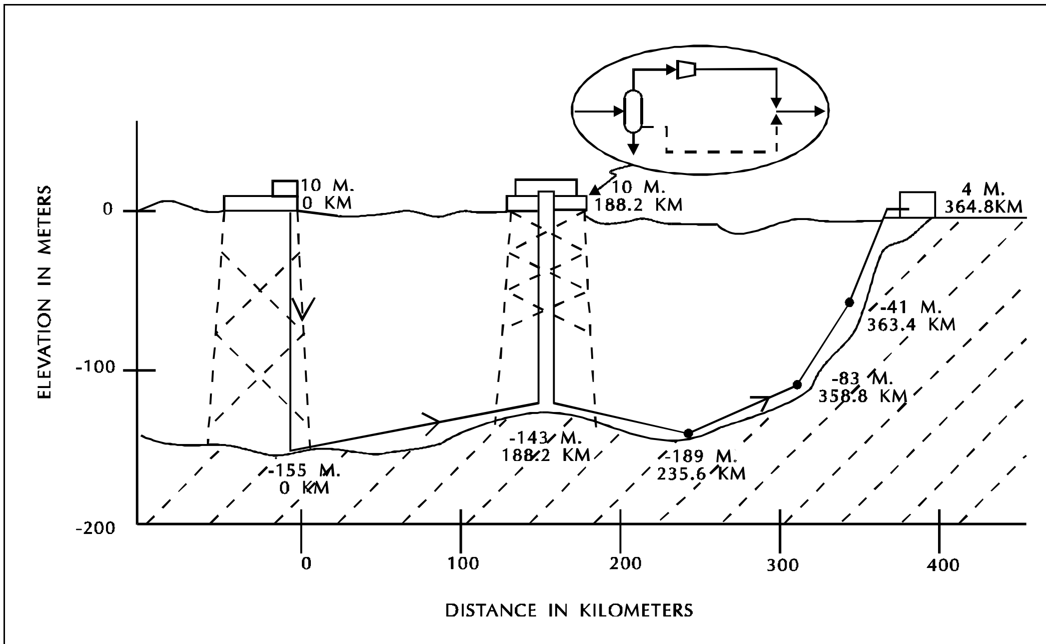


**Table P1.1: Process Information**

| **Pipeline Data** | |
|---|---|
| Inside Diameter | 30.5 inches |
| Wall Thickness | 19.05 milimeters |
| Insulation Thickness | 1.8 inches |
| Pipe Roughness | 0.056 milimeters |
| **Heat Transfer Data** | |
| Water Temperature | 10 C° |
| Normal Water Velocity | 5 km/hr |
| Insulation Conductivity | 0.4 Btu/ft-hr-F |
| No Other Data | use default |
| **Fluid Rate and Composition** | |
| Fluid Rate | $10^6$ Kg/hr |
| **Component** | **Mole%** |
| H20 | 0.08 |
| N2 | 0.19 |
| C02 | 2.07 |
| C1 | 87.18 |
| C2 | 4.93 |
| C3 | 2.98 |
| IC4 | 0.54 |
| NC4 | 0.69 |
| IC5 | 0.29 |
| NC5 | 0.20 |
| NC6 | 0.30 |
| NC7 | 0.55 |

## PIPEPHASE Features Used In This Problem

- Rigorous heat transfer for submerged pipeline is necessary for simulating gas condensate pipeline in cold environments.
- Compositional analysis using library components provides accurate phase behavior and fluid properties. A phase envelope is generated. The envelope also shows the fluid path.
- The SRK equation of state for all PVT is used for accurate modeling of gas condensates.
- Compositional separator and re-injection are easily simulated.
- The Taitel-Dukler-Barnea flow regime predictor is used to accurately predict the flow pattern.
- Holdup, velocity, temperature, pressure and fluid property details are requested in the output report.
- Link pressure, link temperature and phase envelope plots are requested in the output report.

## Results and Discussions

1. Partial output listings are shown at the end of this document; the following results were obtained:

| | |
|---|---|
| Onshore temperature | 5.6°C |
| Onshore pressure | 73.39 bars |
| Onshore liquid rate (*in situ*) | 110.8 $m^3$/hr |
| Onshore vapor rate (*in situ*) | 12.32 x $10^3$ $m^3$/hr |
| Total liquid holdup: | |
| - main to booster platform | 3630.7 $m^3$ |
| - booster platform to shore | 5924.1 $m^3$ |

2. The PIPEPHASE output shows a possibility of formation of type II hydrate below 22.3°C (about 26 kilometers from the inlet). To avoid hydrate formation, addition of a hydrate inhibitor should be considered.

## Simulation Highlights

INPUT

- The Beggs and Brill-Moody correlation was chosen for pressure drop and holdup calculations.
- Since the vertical pipes are not insulated, heat transfer coefficients of 0.25 Btu/ft$^2$-hr-F and 1.6 Btu/ft$^2$-hr-F are assumed for heat loss to air and water respectively.
- A roughness factor of 0.056 mm is used for all pipe sections.

TECHNIQUE

- The rigorous heat transfer for pipe laid along the ocean floor is calculated based on pipe thickness, insulation (concrete) thickness, normal water velocity, pipe and concrete conductivities, and seabed temperature.

## Input Data

Metric units of measure are used throughout the simulation. Selected data are input using petroleum units of measure. The keyword input data file for this simulation is given below.

## Keyword Input Data File

```
TITLE   PROB=OFFSHORE, PROJ=PIPE1, USER=SIMSCI
DESC    COMPOSITIONAL MODEL FOR GAS CONDENSATE LINE
DIME    METRIC, PRES=BAR
OUTDIME PETRO
CALC    SINGLE, COMPOSITION
PRINT   DEVICE=FULL, MAP=TAITEL, PROP=FULL, PLOT=FULL
DEFAULT TAMB=10, IDPIPE(IN)=30.5, THKP(MM)=19.05,ROUG(MM)=.056,*
        THKI(IN)=1.875, CONI(BTUFTF)=.40,*
        WATER, VELOCITY=5.0
FCODE   PIPE=BBM
SEGMENT DLHOR(KM)=2, DLVERT=1000
$
COMPONENT DATA
        LIBID H2O/N2/CO2/C1/C2/C3/IC4/NC4/IC5/NC5/NC6/NC7
$
METHOD DATA
        THERMO SYSTEM=SRK
$
STRUCTURE DATA
        SOURCE NAME=1,PRES=140,TEMP=47,RATE(W,KGHR)=1000000,*
        COMP=0.08/0.19/2.07/87.18/4.93/2.98/*
        0.54/0.69/0.29/0.20/0.3/0.55
$ VERTICAL PIPE IN AIR (U=0.25) AND WATER (U=1.6)
        PIPE LENGTH=10, ECHG=-10, U(BTUFTF)=0.25
        PIPE LENGTH=155, ECHG=-155, U(BTUFTF)=1.6
$ PIPE ON SEABED
        PIPE LENGTH(KM)=188.2, ECHG=8
$ VERTICAL PIPE IN AIR (U=0.25) AND WATER (U=1.6)
        PIPE LENGTH=143, ECHG=143, U(BTUFTF)=1.6
        PIPE LENGTH=10, ECHG=10, U(BTUFTF)=0.25
$ OFF-SHORE EQUIPMENT
        SEPARATOR NAME=SEPT, PERCENT(COND)=100,PERCENT(WATER)=100
        COMPRESSOR PRES=120, EFF=85
        INJECT FROM=SEPT, COND
$ DOWNCOMERS IN AIR (U=0.25) AND WATER (U=1.6)
        PIPE LENGTH=10, ECHG=-10, U(BTUFTF)=0.25
        PIPE LENGTH=143, ECHG=-143, U(BTUFTF)=1.6
$ PIPES ON SEABED
        PIPE LENGTH(KM)=47.4, ECHG=-46
        PIPE LENGTH(KM)=123.2, ECHG=106
        PIPE LENGTH(KM)=4.6, ECHG=42
        PIPE LENGTH(KM)=1.4, ECHG=45
END
```

## Output

- Compositional runs provide flash reports at the inlet and outlet of the pipeline. These reports show a detailed breakdown of gas and condensate compositions and associated properties.
- Compositional runs provide separator reports which show the main and separated stream compositions and their associated properties.
- The device detail report shows that the offshore processing facility removes 642 Kg/hr of water. The compressor requires approximately 6300 Kw to increase the stream pressure to 120 bar.
- A heat transfer coefficient of 13.4 kcal/hr-m$^2$-C is calculated by the program for most pipe sections.
- Plots of pressure and temperature profiles were requested. The pressure and temperature increases across the compressor are clearly shown. In addition, the Joule-Thomson temperature effect is evident.
- The Taitel-Dukler-Barnea flow pattern map is also printed. The results indicate single-phase and stratified flow through most of the pipeline. The last vertical pipes are shown to be in annular or intermittent flow.

## Partial Output

The phase envelope for the pipeline fluid is shown in Figure P1.2 below.

**Figure P1.2: Fluid Composition and Phase Envelope**

```
        P H A S E   E N V E L O P E

P   150.+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        :           :           :           :           :           :
R       :           :           :           :           :          X:
        :           :           :           :           :      XXX X:
E   135.+           :           :           :           :   XX      +
        :           :           :           :           :  XX       :
S       :           :           :           :           :  X        :
        :           :           :           :           PIXX X      :
S   120.+-----------+-----------+-----------+-------D---+-XXXX------+
        :           :           :           :           : XX        :
U       :           :           :           :           : XX  D     :
        :           :           :           :   D       : X         :
R   105.+           :           :           :           : X         +
        :           :           :           :           : X     D   :
E       :           :           :           :           :XX         :
        :           :           :           :           : X         :
     90.+-----------+-----------+-----------+D----------+-X---------+
B       :           :           :           :           : X         :
A       :           :           :           :           : X         :
R       :           :           :          D:           : X         :
     75.+           :           :         D :           :XX       I +
        :           :           :         C :           :           :
        :           :           :        BB :           :         D :
        :           :           :        B  :           :           :
     60.+-----------+-----------+-------BB--+-----------+-----------+
        :           :           :           :           :           :
        :           :           :      B    :           :          T:
        :           :           :     B     :           :           :
     45.+           :           :     B     :           :          D+
        :           :           :    B      :           :           :
        :           :           :   B       :           :           :
        :           :           :  B        :           :           :
     30.+-----------+-----------+-B---------+-----------+---------D-+
        :           :           :B          :           :           :
        :           :           B           :           :           :
        :           :         BB:           :           :        D  :
     15.+           :        B  :           :           :      D    +
        :           :      BB   :           :           :           :
        :           :    BB     :           :           :   DD      :
        :           BBBBB       :           :           :DD         :
      0.+-----+--BBB+-----+-----+-----+-----+-----+--D--+-----+-----+
     -200. -175. -150. -125. -100.  -75.  -50.  -25.    0.   25.   50.

                T E M P E R A T U R E   C

        I = INTERPOLATED     B = BUBBLE           D = DEW
        X = TRAVERSE         T = T EXTREMUM       P = P EXTREMUM
        C = CRITICAL
```

## Partial Output (continued)

The flash report for the outlet of the link is shown below.

```
 NODE      AT      5.6 DEG C           AND      73.4 BAR

                    --------------------MOLE FRACTION-------------------

                    ----HYDROCARBON----  COMBINED             TOTAL
COMPONENT           VAPOR      LIQUID1   VAP+LIQ1   LIQUID2   STREAM
-----------------   --------   --------  --------   --------  --------
H2O                 0.000097   0.000230  0.000100   0.000000  0.000100
N2                  0.001945   0.000279  0.001901   0.000000  0.001901
CO2                 0.020770   0.018642  0.020714   0.000000  0.020714
C1                  0.885803   0.373512  0.872410   0.000000  0.872410
C2                  0.048564   0.078035  0.049335   0.000000  0.049335
C3                  0.027457   0.117891  0.029821   0.000000  0.029821
IC4                 0.004564   0.036680  0.005404   0.000000  0.005404
NC4                 0.005491   0.059590  0.006905   0.000000  0.006905
IC5                 0.001888   0.040676  0.002902   0.000000  0.002902
NC5                 0.001194   0.032063  0.002001   0.000000  0.002001
NC6                 0.001135   0.072557  0.003002   0.000000  0.003002
NC7                 0.001092   0.169844  0.005504   0.000000  0.005504

TOTAL RATE (INLET TO NODE IF JUNCTION)
          KG/HR     934863.2    64494.9  999358.1        0.0  999358.1
          MOLE/HR   49551.71    1330.18  50881.89       0.00  50881.89
WT FRAC LIQ                              0.064536             0.064536

PHASE PROPERTIES
----------------
MASS FRACTION       0.935464   0.064536  1.000000   0.000000  1.000000
VOLUME FRAC         0.991088   0.008912  1.000000   0.000000  1.000000
DENSITY KG/M3          75.88     582.12                 0.00
SPECIFIC GRAV       0.651195   0.582695             0.000000
VISCOSITY CP          0.0129     0.1006               0.0000
ENTHALPY  KCAL/KG     -0.667     -5.045                0.000    -0.949
SURF TENS NEWTON/M                0.007                0.000
MOLECULAR WT         18.8664    48.4858   19.6407     0.0000   19.6407
```

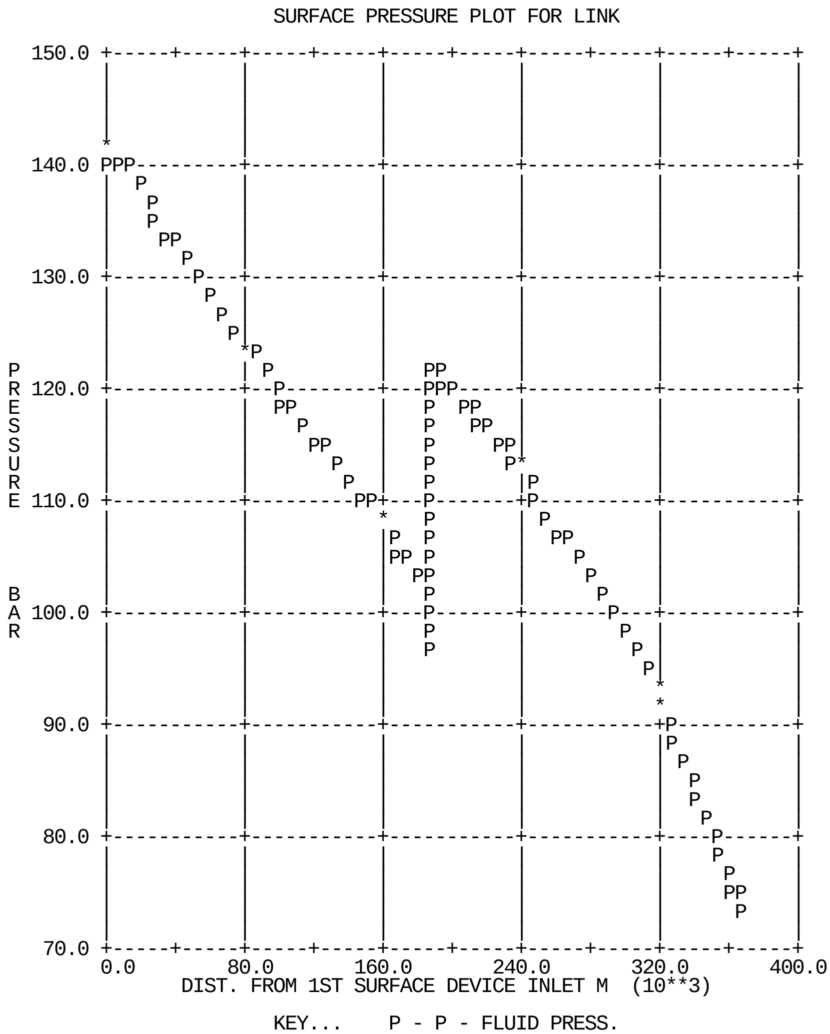
## Partial Output (continued)

The following separator report shows the fluid compositions for separator inlet and outlet.

```
SEPARATOR SEPT AT      6.0 DEG C        AND     95.9 BAR

                          ----------- MOLE FRACTION ------------

                                             FLUID         FLUID
COMPONENT                     FEED         REMAINING      REMOVED
---------                  ----------    ----------    ----------
H2O                         0.000800      0.000096      0.029127
N2                          0.001900      0.001937      0.000402
CO2                         0.020700      0.020713      0.020195
C1                          0.871800      0.882167      0.454876
C2                          0.049300      0.048634      0.076066
C3                          0.029800      0.028091      0.098548
IC4                         0.005400      0.004834      0.028163
NC4                         0.006900      0.005960      0.044721
IC5                         0.002900      0.002242      0.029375
NC5                         0.002000      0.001473      0.023176
NC6                         0.003000      0.001716      0.054628
NC7                         0.005500      0.002138      0.140721

PHASE                          MIXED         VAPOR         MIXED

TOTAL, 10**3 KG/HR           1000.00        947.88         52.12
WT PCT TOTAL LIQUID             5.21          0.00         99.99
ENTHALPY                      -14.39        -14.49        -12.60
MOLECULAR WEIGHT               19.64         19.08         42.19

VAPOR PHASE
-----------
GAS MM M3/HR                  0.0088        0.0088      4.948E-8
DENSITY KG/M3                 107.61        107.61        107.62
VISCOSITY CP                   0.015         0.015         0.015
ENTHALPY                      -14.49        -14.49        -14.49
MOLECULAR WEIGHT               19.08         19.08         19.08

LIQUID PHASE
------------
LIQUID M3/HR                   88.52          0.00         88.51
DENSITY KG/M3                 588.85          0.00        588.85
VISCOSITY CP                   0.091         0.000         0.091
ENTHALPY                      -12.36          0.00        -12.36
MOLECULAR WEIGHT               41.71          0.00         41.71
```

## Partial Output (continued)

The following is a plot of the total pipeline pressure profile.



## Partial Output (continued)

Link and node summaries shown below are generated for every PIPEPHASE run. Also shown is the device summary.

```
                         LINK SUMMARY

  RATE, PRESSURE AND TEMPERATURE SUMMARY
  --------------------------------------

      FROM(F)
      AND
      TO(T)   ----ACTUAL FLOW RATES***--            PRESS:       ----HOLDUP**---
 LINK NODE      GAS      OIL      WATER   PRESS:   DROP   TEMP:    GAS      LIQ
              (MMCMHR) (CMHR)   (CMHR)   (BAR)    (BAR)   (C)   (MM      (ACM)
                                                                 SCM)
 ---- ------- -------- -------- -------- -------- ------- ----- ------- -------
 LINK SORS(F) 0.007907    0.000    0.000 140.00*          47.0
      SNK (T) 0.012321  110.785    0.000   73.39    66.61   5.6 2.486E1 9557.85
                       SPHERE GENERATED VOLUME (BASED ON HL)       =     8708.0
                       SPHERE GENERATED VOLUME (BASED ON (HL-HLNS))=     7961.0

   * - INDICATES KNOWN PRESSURE
   **  REPORTED VOLUME AT 14.7 PSIA AND 60 F (GAS ONLY)
   *** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

==============================================================================
                       NODE SUMMARY

 NODE   PRES.   -------GAS---- ------OIL------ ----WATER------  TOTAL    TEMP
                 RATE     GRAV  RATE     GRAV  RATE    GRAV     RATE
      (BAR)    (KGHR)          (KGHR)          (KGHR)          (KGHR)    (C)
 ---- ------- --------- ------ -------- ------ -------- ----- -------- -------
 SORS  140.00 *1000000.   0.68        0.  0.00        0.  0.00 1000000. *4.700E1
         1.202323(MMCMHR)   0.000(CMHR)     0.000(CMHR)
 SNK    73.39   999358.   0.68        0.  0.00        0.  0.00  999358.  5.56366
         1.201476(MMCMHR)   0.000(CMHR)     0.000(CMHR)

   * INDICATES KNOWN PRESSURE OR FLOW
   ** FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

==============================================================================
                                  DEVICE SUMMARY

                C
                O                                  ------- OUTLET ------ AVG.
 LINK DEVI DEVI R   INSIDE   MEAS      ELEV                      INSITU  LIQ
 NAME NAME TYPE R   DIAM     LENGTH    CHNG     PRESS:  TEMP: QUALITY HOLDUP
                    (MM)     (M)       (M)     (BAR)   (C)    (FRAC)
 ---- ---- ---- ---- -------- --------- ------- ------- ------ ------- ------
 LINK   ***SOURCE*** RATE= 1.000E6 (KGHR)       140.00   47.0 QUAL=    1.00
      SORS                                      140.00   47.0
      P001 PIPE BM     774.70     10.00  -10.00 140.12   47.1    1.00   0.00
      P002 PIPE BM     774.70    155.00 -155.00 142.02   47.9    1.00   0.00
      P003 PIPE BM     774.70 188199.89    8.00  99.98    7.8    0.96   0.04
      P004 PIPE BM     774.70    143.00  143.00  96.19    6.1    0.95   0.33
      P005 PIPE BM     774.70     10.00   10.00  95.92    6.0    0.95   0.34
      SEPT SEPR LQ       0.00      0.00    0.00  95.92    6.0    0.00   0.00
      C007 COMP XX       0.00      0.00    0.00 120.00   22.0    0.00   0.00
      I008 INJE          0.00      0.00    0.00 120.00   20.4    0.00   0.00
      P009 PIPE BM     774.70     10.00  -10.00 120.13   20.4    1.00   0.00
      P010 PIPE BM     774.70    143.00 -143.00 121.93   21.4    1.00   0.00
      P011 PIPE BM     774.70  47400.04  -46.00 113.16   10.6    0.98   0.03
      P012 PIPE BM     774.70 123200.10  106.00  76.84    6.3    0.94   0.09
      P013 PIPE BM     774.70   4599.98   42.00  74.58    6.0    0.94   0.10
      P014 PIPE BM     774.70   1400.00   45.00  73.39    5.6    0.94   0.13
           *** SINK *** PRES=    73.39 (BAR)   TEMP=    5.6 (C)
```

## Partial Output (continued)

The following abridged device detail shows how liquid starts dropping out before and after the separator.

```
                 LINK "LINK" DEVICE DETAIL REPORT

 PRESSURE AND TEMPERATURE REPORT
 -------------------------------
 DEVICE                 MWD OR      TVD
 NAME                   LENGTH   I  OR
 AND    SEGM INSIDE      FROM    &  ELEV     CALC    CALC   OVERALL AMB
 TYPE   NO   DIAM.      INLET    O  CHNG     PRESS   TEMP   U-FACT  TEMP   QUAL
             (MM)       (M)         (M)      (BAR)   (C)    (KCMC)  (C)    (FRAC)
 ------ ---- ------ --------- - -------- ------- ------ ------- ------ -------
  P001  0000 774.70      0.00 I     0.00  140.00   47.0            10.0     1.00
 (PIPE) 0001            10.00 O   -10.00  140.12   47.1    1.22    10.0     1.00
  P002  0000 774.70      0.00 I     0.00  140.12   47.1            10.0     1.00
 (PIPE) 0001            77.50     -77.50  141.07   47.5    7.81    10.0     1.00
        0002           155.00 O   -77.50  142.02   47.9    7.81    10.0     1.00
  P003  0000 774.70      0.00 I     0.00  142.02   47.9            10.0     1.00
 (PIPE) 0001          1524.00       0.06  141.72   45.5   13.41    10.0     1.00
        0002          6162.05       0.20  140.54   39.1   13.41    10.0     1.00
          :
          :
  P005  0000 774.70      0.00 I     0.00   96.19    6.1            10.0     0.95
 (PIPE) 0001            10.00 O    10.00   95.92    6.0    1.22    10.0     0.95
  SEPT  0000             0.00 I     0.00   95.92 IN              OUT
 (SEPR)                                     RATE     SP. GR  RATE       SP. GR
                            GAS KG/HR     947877.      0.66  947877.    0.66
                            OIL KG/HR      51481.      0.58       0.    0.58
                          WATER KG/HR        642.      1.00       0.    1.00
                         0.00 O     0.00   95.92    6.0
  C007  0000             0.00 I     0.00   95.92    6.0 AVG.POWER/STAGE KW
 (COMP)                                                 AVAILABLE             0.0
                         0.00 O     0.00  120.00   22.0 REQUIRED           6301.4
  I008  0000             0.00 I     0.00  120.00   22.0 RATE IN 947877. KG/HR
 (INJ )                                      INJ.  PRESSURE    120.00 BAR
                                          INJ.  TEMPERATURE      6.0 DEG C
                                                       RATE OUT 999358. KG/HR
                         0.00 O     0.00  120.00   20.4
  P009  0000 774.70      0.00 I     0.00  120.00   20.4            10.0     1.00
 (PIPE) 0001            10.00 O   -10.00  120.13   20.4    1.22    10.0     1.00
  P010  0000 774.70      0.00 I     0.00  120.13   20.4            10.0     1.00
 (PIPE) 0001            71.50     -71.50  121.03   20.9    7.81    10.0     1.00
        0002           143.00 O   -71.50  121.93   21.4    7.81    10.0     1.00
          :
          :
  P013  0000 774.70      0.00 I     0.00   76.84    6.3            10.0     0.94
 (PIPE) 0001          1524.00      13.91   76.09    6.2   13.39    10.0     0.94
        0002          3523.79      18.26   75.11    6.0   13.39    10.0     0.94
        0003          4599.98 O     9.83   74.58    6.0   13.39    10.0     0.94
  P014  0000 774.70      0.00 I     0.00   74.58    6.0            10.0     0.94
 (PIPE) 0001           700.00      22.50   73.98    5.8   13.39    10.0     0.94
        0002          1400.00 O    22.50   73.39    5.6   13.39    10.0     0.94
```

## Partial Output (continued)

The flow regime column indicates that segregated flow pressure drop equations were used with the Beggs-Brill-Moody option. However, the actual flow regime is more likely to be as predicted by the Taitel-Dukler correlation.

```
                 LINK "LINK"  DEVICE DETAIL REPORT

 HOLDUP AND VELOCITY DETAIL REPORT
 ---------------------------------
 DEVICE
 NAME         ---LIQUID HOLDUP---          ACTUAL               T-D
 AND    SEG. NO                      LIQ     GAS     MIX .  FLOW FLOW   SONIC
 TYPE   NO.  SLIP  SLIP   TOTAL      VEL     VEL     VEL    REGM REGM    VEL
                          (ACM)     (MPS)   (MPS)   (MPS)               (MPS)
 ------ ---- ----- ----- -------- ------- ------- ------- ---- ---- -------
  P001  0000
 (PIPE) 0001  0.00  0.00     0.00    0.00    4.66    4.66 1-PH 1-PH  393.94
  P002  0000
 (PIPE) 0001  0.00  0.00     0.00    0.00    4.65    4.65 1-PH 1-PH  394.79
        0002  0.00  0.00     0.00    0.00    4.63    4.63 1-PH 1-PH  395.27
  P003  0000
 (PIPE) 0001  0.00  0.00     0.00    0.00    4.59    4.59 1-PH 1-PH  393.14
        0002 3.E-5 5.E-3    11.81    0.02    4.50    4.48 SEGR STRT  311.99
         :
         :
        0022 9.E-3  0.09  3527.13    0.48    5.39    4.95 SEGR STRT  405.75
        0023 9.E-3  0.09  3606.89    0.50    5.49    5.04 SEGR STRT  405.12
  P004  0000
 (PIPE) 0001 9.E-3  0.33  3617.89    0.14    7.50    5.10 SEGR ANNU  403.55
        0002 1.E-2  0.33  3629.14    0.15    7.71    5.19 SEGR ANNU  401.34
  P005  0000
 (PIPE) 0001 1.E-2  0.34  3630.72    0.15    7.82    5.24 SEGR ANNU  400.45
 (SEPR) 0000
  SEPT  0001
 (COMP) 0000
  C007  0001
  I008  0000
  I008  0001
  P009  0000
 (PIPE) 0001  0.00  0.00  3630.72    0.00    4.52    4.52 1-PH 1-PH  359.31
  P010  0000
 (PIPE) 0001  0.00  0.00  3630.72    0.00    4.51    4.51 1-PH 1-PH  360.22
        0002  0.00  0.00  3630.72    0.00    4.49    4.49 1-PH 1-PH  360.81
  P011  0000
 (PIPE) 0001  0.00  0.00  3630.72    0.00    4.47    4.47 1-PH 1-PH  359.69
        0002  0.00  0.00  3630.72    0.00    4.45    4.45 1-PH 1-PH  358.27
        0003  0.00  0.00  3630.72    0.00    4.43    4.43 1-PH 1-PH  356.79
         :
         :
        0020 4.E-3  0.06  4245.89    0.29    4.71    4.43 SEGR STRT  403.54
        0021 4.E-3  0.06  4271.26    0.30    4.72    4.44 SEGR STRT  404.52
  P012  0000
 (PIPE) 0001 4.E-3  0.07  4318.59    0.30    4.74    4.45 SEGR STRT  405.13
        0002 5.E-3  0.07  4518.55    0.31    4.79    4.48 SEGR STRT  406.64
        0003 5.E-3  0.07  4730.76    0.34    4.86    4.53 SEGR STRT  408.38
        0004 6.E-3  0.08  4953.35    0.36    4.93    4.58 SEGR STRT  409.21
         :
         :
        0020 9.E-3  0.09  9072.09    0.70    7.19    6.62 SEGR STRT  392.07
        0021 9.E-3  0.09  9262.62    0.72    7.44    6.85 SEGR STRT  391.16
  P013  0000
 (PIPE) 0001 9.E-3  0.10  9332.41    0.65    7.68    7.00 SEGR ANNU  390.91
        0002 9.E-3  0.10  9423.50    0.66    7.78    7.09 SEGR ANNU  390.39
        0003 9.E-3  0.10  9472.29    0.67    7.87    7.17 SEGR ANNU  390.16
  P014  0000
 (PIPE) 0001 9.E-3  0.13  9513.63    0.52    8.20    7.23 SEGR INTR  389.82
        0002 9.E-3  0.13  9554.87    0.52    8.26    7.29 SEGR INTR  389.45
```

## Partial Output (continued)

A two-phase flow pattern map is output when two-phase flow occurs at the end of a link. The operating point (+) indicates that the flow at the end of the link is close to the intermittent-annular boundary.

```
          !+----------------+-----------------+----------------+-------+!
    20.00+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAA!
    10.00+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
     1.00+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
VSL      ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
     0.10+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIII+ AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
     0.01+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA+
         !+----------------+-----------------+----------------+-------+!
         0.1              1.0              10.0             100.0   300.0

                                   VSG
VSL = SUPERFICIAL LIQUID VELOCITY (MPS)
VSG = SUPERFICIAL GAS VELOCITY (MPS)
+   = OPERATING POINT
   PRESSURE=       73.3863(BAR)
   TEMP:   =        5.5637(C)
   ANGLE   =        1.8422(DEG)
```

## Partial Output (continued)

The following are the point-by-point fluid properties calculated by PIPEPHASE.

LINK "LINK" PROPERTY DETAIL REPORT

VISCOSITY AND DENSITY RESULTS

| DEVICE NAME AND TYPE | SEGM NO | VISCOSITY OIL (CP) | VISCOSITY LIQ (CP) | VISCOSITY VAP (CP) | DENSITY LIQ (KG/M3) | DENSITY VAP (KG/M3) | DENSITY SLIP (KG/M3) | DENSITY NO-SLIP (KG/M3) |
|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | |
| (PIPE) | 0001 | 0.000 | 0.000 | 0.017 | 0.00 | 126.50 | 126.50 | 126.50 |
| P002 | 0000 | | | | | | | |
| (PIPE) | 0001 | 0.000 | 0.000 | 0.017 | 0.00 | 126.82 | 126.82 | 126.82 |
| | 0002 | 0.000 | 0.000 | 0.017 | 0.00 | 127.36 | 127.36 | 127.36 |
| | : | | | | | | | |
| P013 | 0000 | | | | | | | |
| (PIPE) | 0001 | 0.097 | 0.097 | 0.013 | 580.86 | 79.62 | 128.32 | 84.16 |
| | 0002 | 0.098 | 0.098 | 0.013 | 581.15 | 78.53 | 127.11 | 83.06 |
| | 0003 | 0.099 | 0.099 | 0.013 | 581.43 | 77.59 | 126.05 | 82.10 |
| P014 | 0000 | | | | | | | |
| (PIPE) | 0001 | 0.100 | 0.100 | 0.013 | 581.68 | 76.91 | 140.16 | 81.42 |
| | 0002 | 0.100 | 0.100 | 0.013 | 581.98 | 76.22 | 139.45 | 80.73 |

FRICTION AND SURFACE TENSION RESULTS

| DEVICE NAME AND TYPE | SEGM NUM. | FRICTION DENSITY (KG/M3) | FRICTION VELO (MPS) | FRICTION ID. (MM) | FRICTION VISCOSITY (CP) | FRIC. FACTOR | REYNOLDS NUMBER | LIQ SURFACE TENSION (NEWT/M) |
|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | |
| (PIPE) | 0001 | 126.50 | 4.66 | 774.70 | 0.017 | 0.0114 | 2.6705E7 | 0.00000 |
| P002 | 0000 | | | | | | | |
| (PIPE) | 0001 | 126.82 | 4.65 | 774.70 | 0.017 | 0.0114 | 2.6660E7 | 0.00000 |
| | 0002 | 127.36 | 4.63 | 774.70 | 0.017 | 0.0114 | 2.6583E7 | 0.00000 |
| P003 | 0000 | | | | | | | |
| (PIPE) | 0001 | 128.47 | 4.59 | 774.70 | 0.017 | 0.0114 | 2.6514E7 | 0.00000 |
| | 0002 | 131.52 | 4.48 | 774.70 | 0.017 | 0.0149 | 2.6382E7 | 0.06925 |
| | : | | | | | | | |
| P013 | 0000 | | | | | | | |
| (PIPE) | 0001 | 84.16 | 7.00 | 774.70 | 0.014 | 0.0142 | 3.2834E7 | 0.00633 |
| | 0002 | 83.06 | 7.09 | 774.70 | 0.014 | 0.0141 | 3.2957E7 | 0.00643 |
| | 0003 | 82.10 | 7.17 | 774.70 | 0.014 | 0.0140 | 3.3064E7 | 0.00653 |
| P014 | 0000 | | | | | | | |
| (PIPE) | 0001 | 81.42 | 7.23 | 774.70 | 0.014 | 0.0148 | 3.3143E7 | 0.00660 |
| | 0002 | 80.73 | 7.29 | 774.70 | 0.014 | 0.0148 | 3.3224E7 | 0.00668 |

## Partial Output (continued)

Pipe segment friction and surface tension results are shown below.

FRICTION AND SURFACE TENSION RESULTS

| DEVICE NAME AND TYPE | SEGM NUM. | FRICTION | | | | FRIC. FACTOR | REYNOLDS NUMBER | LIQ SURFACE TENSION (NEWT/M) |
|---|---|---|---|---|---|---|---|---|
| | | DENSITY (KG/M3) | VELO (MPS) | ID. (MM) | VISCOSITY (CP) | | | |
| P001 | 0000 | | | | | | | |
| (PIPE) | 0001 | 126.50 | 4.66 | 774.70 | 0.017 | 0.0114 | 2.6705E7 | 0.00000 |
| P002 | 0000 | | | | | | | |
| (PIPE) | 0001 | 126.82 | 4.65 | 774.70 | 0.017 | 0.0114 | 2.6660E7 | 0.00000 |
| | 0002 | 127.36 | 4.63 | 774.70 | 0.017 | 0.0114 | 2.6583E7 | 0.00000 |
| P003 | 0000 | | | | | | | |
| (PIPE) | 0001 | 128.47 | 4.59 | 774.70 | 0.017 | 0.0114 | 2.6514E7 | 0.00000 |
| | 0002 | 131.52 | 4.48 | 774.70 | 0.017 | 0.0149 | 2.6382E7 | 0.06925 |
| | ⋮ | | | | | | | |
| P013 | 0000 | | | | | | | |
| (PIPE) | 0001 | 84.16 | 7.00 | 774.70 | 0.014 | 0.0142 | 3.2834E7 | 0.00633 |
| | 0002 | 83.06 | 7.09 | 774.70 | 0.014 | 0.0141 | 3.2957E7 | 0.00643 |
| | 0003 | 82.10 | 7.17 | 774.70 | 0.014 | 0.0140 | 3.3064E7 | 0.00653 |
| P014 | 0000 | | | | | | | |
| (PIPE) | 0001 | 81.42 | 7.23 | 774.70 | 0.014 | 0.0148 | 3.3143E7 | 0.00660 |
| | 0002 | 80.73 | 7.29 | 774.70 | 0.014 | 0.0148 | 3.3224E7 | 0.00668 |

## Partial Output (continued)

Thermal conductivities, film resistances, etc. used to calculate the heat transfer coefficient are output. Point-by-point hydrate prediction is shown - "N" indicating no hydrate formation and "II" indicating possibility of type "II" hydrate formation.

HEAT TRANSFER CALCULATIONS

| DEVICE NAME AND (TYPE) | SEGM NO: | FLUID THERMAL CONDUCT-IVITY (KCMC) | THERMAL RESISTANCE: INSIDE FILM (HR-M2-C/KCAL) | THERMAL RESISTANCE: PIPE (HR-M2-C/KCAL) | THERMAL RESISTANCE: INSULAT-ION (HR-M2-C/KCAL) | THERMAL RESISTANCE: SURROUN-DING (HR-M2-C/KCAL) | ENTHALPY: LIQ (KCALKG) | ENTHALPY: VAP (KCALKG) | HYD |
|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | 14.432 | N |
| P002 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | 14.569 | N |
| | 0002 | 0.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | 14.708 | N |
| P003 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.046 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 0.000 | 12.880 | N |
| | 0002 | 0.046 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 42.075 | 8.000 | N |
| | 0003 | 0.046 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 36.261 | 3.506 | N |
| | ⋮ | | | | | | | | |
| | 0021 | 0.040 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.199 | -8.548 | II |
| | 0022 | 0.040 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.055 | -7.897 | II |
| | 0023 | 0.040 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.031 | -7.759 | II |
| P004 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -6.478 | -7.903 | II |
| | 0002 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -6.925 | -8.029 | II |
| P005 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -6.997 | -8.050 | II |
| SEPT | 0000 | | | | | | | | |
| (SEPR) | 0001 | | | | | | | | |
| C007 | 0000 | | | | | | | | |
| (COMP) | 0001 | | | | | | | | |
| I008 | 0000 | | | | | | | | |
| (INJ ) | 0001 | | | | | | | | |
| P009 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | -2.552 | II |
| P010 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | -2.392 | II |
| | 0002 | 0.040 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.000 | -2.230 | N |
| P011 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.043 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 0.000 | -2.766 | II |
| | 0002 | 0.043 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 0.000 | -3.546 | II |
| | 0003 | 0.043 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | 0.000 | -4.246 | II |
| | ⋮ | | | | | | | | |
| | 0020 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -5.573 | -9.204 | II |
| | 0021 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -5.609 | -9.221 | II |
| P012 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -5.678 | -9.254 | II |
| | 0002 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -5.907 | -9.322 | II |
| | 0003 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.067 | -9.297 | II |
| | 0004 | 0.042 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.171 | -9.196 | II |
| | 0005 | 0.041 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.230 | -9.030 | II |
| | 0006 | 0.041 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.251 | -8.808 | II |
| | 0007 | 0.041 | 0.0009 | 0.0004 | 0.0721 | 0.0012 | -6.244 | -8.539 | II |
| | ⋮ | | | | | | | | |
| | 0020 | 0.035 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.982 | -1.865 | II |
| | 0021 | 0.035 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.881 | -1.287 | II |
| P013 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.035 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.885 | -1.119 | II |
| | 0002 | 0.035 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.891 | -0.896 | II |
| | 0003 | 0.034 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.893 | -0.776 | II |
| P014 | 0000 | | | | | | | | |
| (PIPE) | 0001 | 0.034 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -4.970 | -0.723 | II |
| | 0002 | 0.034 | 0.0010 | 0.0004 | 0.0721 | 0.0012 | -5.043 | -0.667 | II |

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# Gas Pipeline Sizing

P2 Gas Pipeline Sizing

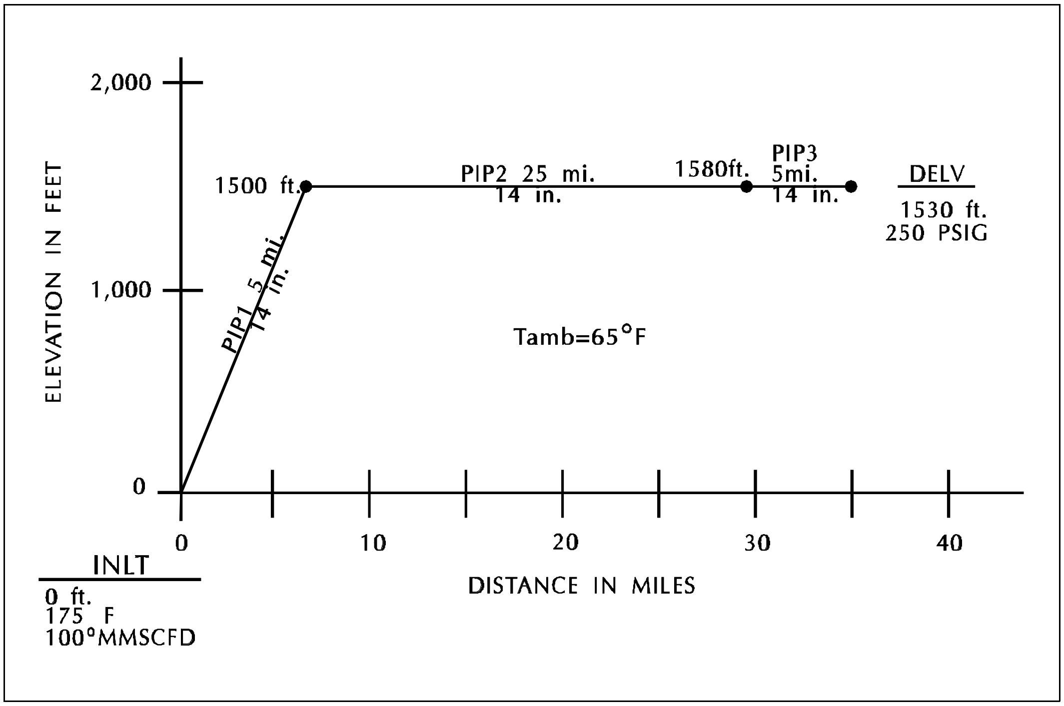
## Problem Description

An existing 14-inch pipeline is used to transport 50 MMscfd of gas across the countryside to a gas distribution station. A new field is developed and an additional 50 MMscfd of gas will be transported through the same pipeline to this gas distribution facility. The required inlet pressure for the gas distribution station is 250 psig. Figure P2.1 illustrates this system. Process conditions are given in Table P2.1.

You are required to:

1. Determine the minimum pipeline inlet pressure to satisfy the downstream pressure requirement for the throughput of 100 MMscfd.
2. Determine the minimum inside diameter required for the pipeline section PIP2, assuming the pipeline inlet pressure is limited at 650 psig, and that changing the size of the section is an acceptable alternative.

**Figure P2.1: Pipeline System**



| Table P2.1: Process Information | |
|---|---|
| **Fluid Properties** | |
| Gas Gravity | 0.88 |
| **Pipeline Data** | |
| Inside Diameter | 14 inches |
| Roughness | 0.0018 inch |
| **Heat Transfer Data** | |
| Overall U-factor | 0.4 Btu/hr - $ft^2$-F |
| Ambient Temperature | 65° F |

## PIPEPHASE Features Used In This Problem

- The line sizing feature with pressure constraint is used to automatically determine the line size.
- The American Gas Association (AGA) gas pressure drop correlation is chosen because it is best suited to the system.
- Rigorous heat transfer calculation is required for more accurate heat balance and property calculations.
- The device detail report is requested to examine the *in situ* (actual) velocity.
- The single-phase gas model is used to demonstrate the use of single-phase gas properties.

## Results and Discussions

1. When the sink pressure is set at 250 psig and the flowrate is set at 100 MMscfd, the inlet pressure to the pipeline is calculated to be 754.0 psig (case A).
2. If the inlet pressure of 650 psig and the outlet minimum pressure of 250 psig are given, the program calculates the required pipe (PIP2) diameter of 16.876 inches (Schedule 40, 18-inch pipe). The second input file shown represents this case (case B).

## Simulation Highlights

INPUT

- Two sets of input are presented on the following pages to demonstrate the different calculation requirements.
- The pipe roughness is the same as the program default value (0.0018 inches), and therefore not input.
- The pipe inside diameter and overall U-value are entered on the DEFAULT statement instead of on the individual PIPE statements.

TECHNIQUE

- To determine the inlet pressure, network calculation is chosen. The SOURCE pressure is estimated and the rate is given.
- To determine the minimum diameter for PIP2, the line size feature is used. In this case, the SOURCE and SINK pressures and SOURCE rate are given. In the input file, the sizing option is appended with the device name specified as PIP2.

## Input Data

The keyword input data files for both cases are given below.

P2 Gas Pipeline Sizing

## Keyword Input Data File

INPUT FOR INLET PRESSURE DETERMINATION (Case A)

```
TITLE   PROBLEM=PIPE2A, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP PRESSURE DETERMINATION OF GAS CONDENSATE PIPELINE
DIMENSI PETRO, RATE(GV)=CFD
CALCULA GAS, NETWORK
FCODE   PIPE=AGA
DEFAULT IDPIPE=14, UPIPE=0.4, TAMB=65
SEGMENT DLHOR(MI)=1
PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
$
PVT DATA
        SET     SETN=1, GRAV(GAS)=0.88
$
STRUCTURE DATA
SOURCE  NAME=INLT, SETN=1, TEMP=175, PRES(ESTI)=650, *
        RATE=100
$
LINK    NAME=1, FROM=INLT, TO=DELV
        PIPE    LENGTH(MI)=5, ECHG=1500
        PIPE    LENGTH(MI)=25, ECHG=80
        PIPE    LENGTH(MI)=5, ECHG=-50
$
SINK    NAME=DELV, PRES=250, RATE(ESTI)=100
$
END
```

## Keyword Input Data File

INPUT FOR PIP2 LINE SIZING (Case B)

```
TITLE   PROBLEM=PIPE2B, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP SIZE DETERMINATION OF GAS CONDENSATE PIPELINE
DIMENSI RATE(GV)=CFD
CALCULA SINGLE, GAS
FCODE   PIPE=AGA
DEFAULT IDPIPE=14, UPIPE=0.4, TAMB=65
SEGMENT DLHOR(MI)=1
PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
$
PVT DATA
SET     SETN=1, GRAV(GAS)=0.88
$
STRUCTURE DATA
SOURCE  NAME=INLT, SETN=1, TEMP=175, PRES=650, RATE=100
$
LINK    NAME=1, FROM=INLT, TO=DELV
        PIPE    LENGTH(MI)=5, ECHG=1500
        PIPE    NAME=PIP2, LENGTH(MI)=25, ECHG=80
        PIPE    LENGTH(MI)=5, ECHG=-50
$
SINK    NAME=DELV, PRES=250, RATE(ESTI)=100
$
SIZE DATA
        DEVICE  NAME=PIP2
END
```

## Output

- Device summary and velocity reports for two runs are presented, along with plots of pressure versus distance.
- The velocity report for case A shows gradually increasing velocities due to pressure loss and the associated fluid expansion. The velocity report for case B shows a sudden velocity drop at the entrance of the higher-diameter pipe PIP2.

## Partial Output (Case A)

The following output shows the inlet pressure required for the increased throughput is 754.0 psig.

LINK "1 " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) |
|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 14.000 | 0.0 | I | 0.0 | **754.0** | 175.0 | | 65.0 |
| (PIPE) | 0001 | | 5280.0 | | 300.0 | 737.2 | 168.5 | 0.400 | 65.0 |
| | 0002 | | 10560.0 | | 300.0 | 720.4 | 162.3 | 0.400 | 65.0 |
| | 0003 | | 15840.0 | | 300.0 | 703.5 | 156.5 | 0.400 | 65.0 |
| | 0004 | | 21120.0 | | 300.0 | 686.6 | 150.9 | 0.400 | 65.0 |
| | 0005 | | 26400.0 | O | 300.0 | 669.7 | 145.6 | 0.400 | 65.0 |
| P002 | 0000 | 14.000 | 0.0 | I | 0.0 | 669.7 | 145.6 | | 65.0 |
| (PIPE) | 0001 | | 6600.0 | | 4.0 | 656.6 | 139.4 | 0.400 | 65.0 |
| | 0002 | | 13200.0 | | 4.0 | 643.4 | 133.6 | 0.400 | 65.0 |
| | 0003 | | 19800.0 | | 4.0 | 630.1 | 128.1 | 0.400 | 65.0 |
| | 0004 | | 26400.0 | | 4.0 | 616.6 | 123.1 | 0.400 | 65.0 |
| | 0005 | | 33000.0 | | 4.0 | 603.0 | 118.4 | 0.400 | 65.0 |
| | 0006 | | 39600.0 | | 4.0 | 589.2 | 114.1 | 0.400 | 65.0 |
| | 0007 | | 46200.0 | | 4.0 | 575.2 | 110.0 | 0.400 | 65.0 |
| | 0008 | | 52800.0 | | 4.0 | 561.0 | 106.3 | 0.400 | 65.0 |
| | 0009 | | 59400.0 | | 4.0 | 546.5 | 102.8 | 0.400 | 65.0 |
| | 0010 | | 66000.0 | | 4.0 | 531.6 | 99.6 | 0.400 | 65.0 |
| | 0011 | | 72600.0 | | 4.0 | 516.4 | 96.7 | 0.400 | 65.0 |
| | 0012 | | 79200.0 | | 4.0 | 500.9 | 94.0 | 0.400 | 65.0 |
| | 0013 | | 85800.0 | | 4.0 | 484.9 | 91.5 | 0.400 | 65.0 |
| | 0014 | | 92400.0 | | 4.0 | 468.3 | 89.2 | 0.400 | 65.0 |
| | 0015 | | 99000.0 | | 4.0 | 451.2 | 87.1 | 0.400 | 65.0 |
| | 0016 | | 105600.0 | | 4.0 | 433.5 | 85.2 | 0.400 | 65.0 |
| | 0017 | | 112200.0 | | 4.0 | 415.0 | 83.4 | 0.400 | 65.0 |
| | 0018 | | 118800.0 | | 4.0 | 395.7 | 81.8 | 0.400 | 65.0 |
| | 0019 | | 125400.0 | | 4.0 | 375.3 | 80.3 | 0.400 | 65.0 |
| | 0020 | | 132000.0 | O | 4.0 | 353.8 | 78.9 | 0.400 | 65.0 |
| P003 | 0000 | 14.000 | 0.0 | I | 0.0 | 353.8 | 78.9 | | 65.0 |
| (PIPE) | 0001 | | 5280.0 | | -10.0 | 335.7 | 77.9 | 0.400 | 65.0 |
| | 0002 | | 10560.0 | | -10.0 | 316.6 | 77.0 | 0.400 | 65.0 |
| | 0003 | | 15840.0 | | -10.0 | 296.1 | 76.2 | 0.400 | 65.0 |
| | 0004 | | 21120.0 | | -10.0 | 274.1 | 75.4 | 0.400 | 65.0 |
| | 0005 | | 26400.0 | O | -10.0 | 250.1 | 74.6 | 0.400 | 65.0 |

## Partial Output (Case B)

The following output from line size run shows the required diameter of PIP2 is calculated to be 16.876 inches.

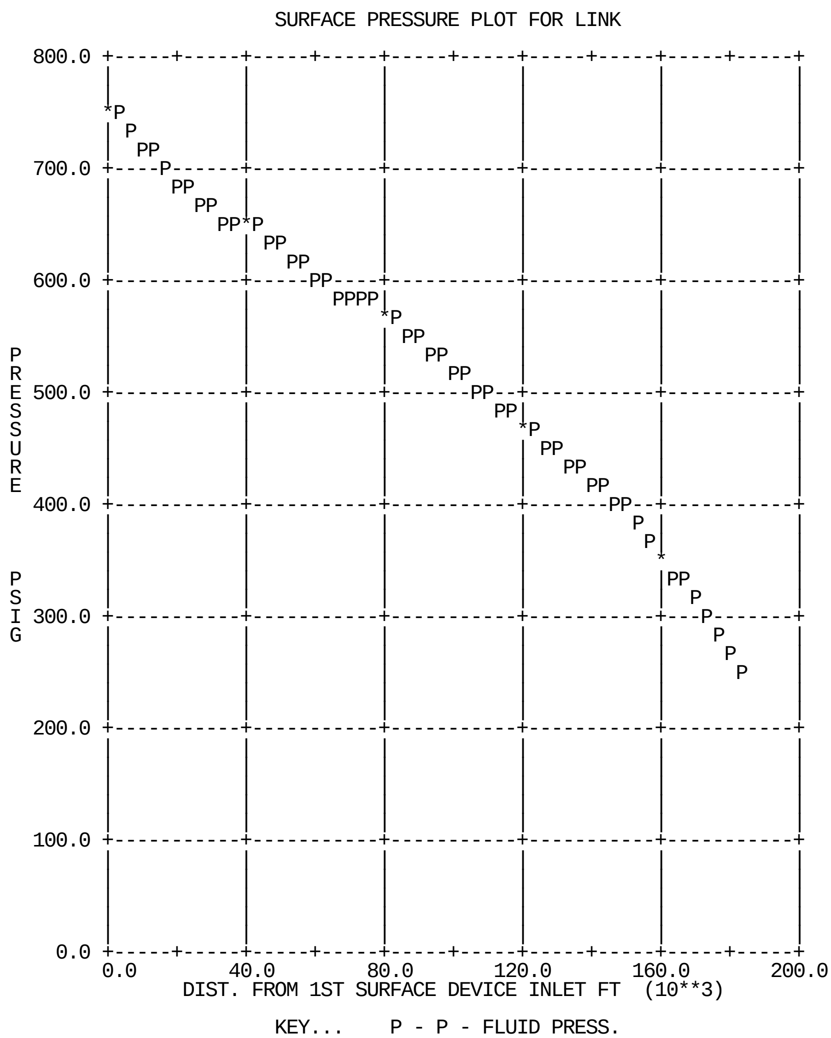
LINK "1 " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) |
|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 14.000 | 0.0 | I | 0.0 | 650.0 | 175.0 | | 65.0 |
| (PIPE) | 0001 | | 5280.0 | | 300.0 | 632.5 | 168.5 | 0.400 | 65.0 |
| | 0002 | | 10560.0 | | 300.0 | 614.9 | 162.3 | 0.400 | 65.0 |
| | 0003 | | 15840.0 | | 300.0 | 597.2 | 156.4 | 0.400 | 65.0 |
| | 0004 | | 21120.0 | | 300.0 | 579.4 | 150.9 | 0.400 | 65.0 |
| | 0005 | | 26400.0 | O | 300.0 | 561.4 | 145.5 | 0.400 | 65.0 |
| PIP2 | 0000 | **16.876** | 0.0 | I | 0.0 | 561.4 | 145.5 | | 65.0 |
| (PIPE) | 0001 | | 6600.0 | | 4.0 | 555.4 | 138.0 | 0.400 | 65.0 |
| | 0002 | | 13200.0 | | 4.0 | 549.3 | 131.2 | 0.400 | 65.0 |
| | 0003 | | 19800.0 | | 4.0 | 543.4 | 124.9 | 0.400 | 65.0 |
| | 0004 | | 26400.0 | | 4.0 | 537.4 | 119.2 | 0.400 | 65.0 |
| | 0005 | | 33000.0 | | 4.0 | 531.4 | 114.0 | 0.400 | 65.0 |
| | 0006 | | 39600.0 | | 4.0 | 525.5 | 109.2 | 0.400 | 65.0 |
| | 0007 | | 46200.0 | | 4.0 | 519.5 | 104.8 | 0.400 | 65.0 |
| | 0008 | | 52800.0 | | 4.0 | 513.5 | 100.8 | 0.400 | 65.0 |
| | 0009 | | 59400.0 | | 4.0 | 507.6 | 97.2 | 0.400 | 65.0 |
| | 0010 | | 66000.0 | | 4.0 | 501.6 | 94.0 | 0.400 | 65.0 |
| | 0011 | | 72600.0 | | 4.0 | 495.5 | 91.0 | 0.400 | 65.0 |
| | 0012 | | 79200.0 | | 4.0 | 489.5 | 88.3 | 0.400 | 65.0 |
| | 0013 | | 85800.0 | | 4.0 | 483.4 | 85.9 | 0.400 | 65.0 |
| | 0014 | | 92400.0 | | 4.0 | 477.2 | 83.7 | 0.400 | 65.0 |
| | 0015 | | 99000.0 | | 4.0 | 471.1 | 81.8 | 0.400 | 65.0 |
| | 0016 | | 105600.0 | | 4.0 | 464.8 | 80.0 | 0.400 | 65.0 |
| | 0017 | | 112200.0 | | 4.0 | 458.5 | 78.4 | 0.400 | 65.0 |
| | 0018 | | 118800.0 | | 4.0 | 452.1 | 77.0 | 0.400 | 65.0 |
| | 0019 | | 125400.0 | | 4.0 | 445.7 | 75.7 | 0.400 | 65.0 |
| | 0020 | | 132000.0 | O | 4.0 | 439.1 | 74.6 | 0.400 | 65.0 |
| P003 | 0000 | 14.000 | 0.0 | I | 0.0 | 439.1 | 74.6 | | 65.0 |
| (PIPE) | 0001 | | 5280.0 | | -10.0 | 425.3 | 73.9 | 0.400 | 65.0 |
| | 0002 | | 10560.0 | | -10.0 | 411.0 | 73.3 | 0.400 | 65.0 |
| | 0003 | | 15840.0 | | -10.0 | 396.1 | 72.7 | 0.400 | 65.0 |
| | 0004 | | 21120.0 | | -10.0 | 380.6 | 72.1 | 0.400 | 65.0 |
| | 0005 | | 26400.0 | O | -10.0 | 364.3 | 71.6 | 0.400 | 65.0 |

## Partial Output (Case A)

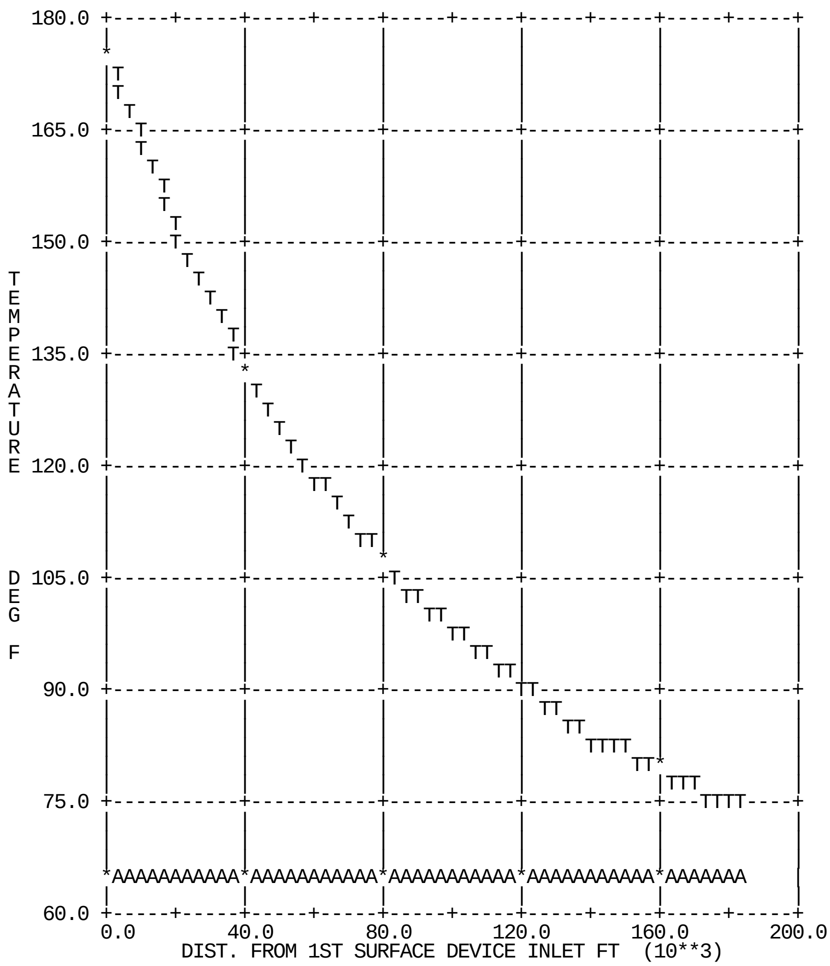
The figure below shows the surface pressure plot for case A.



## Partial Output (Case A)

The figure below shows the surface temperature plot for case A.

SURFACE TEMPERATURE PLOT FOR LINK




KEY...    T - T - FLUID TEMP.    A - A - AMB. TEMP.

## Partial Output (Case B)

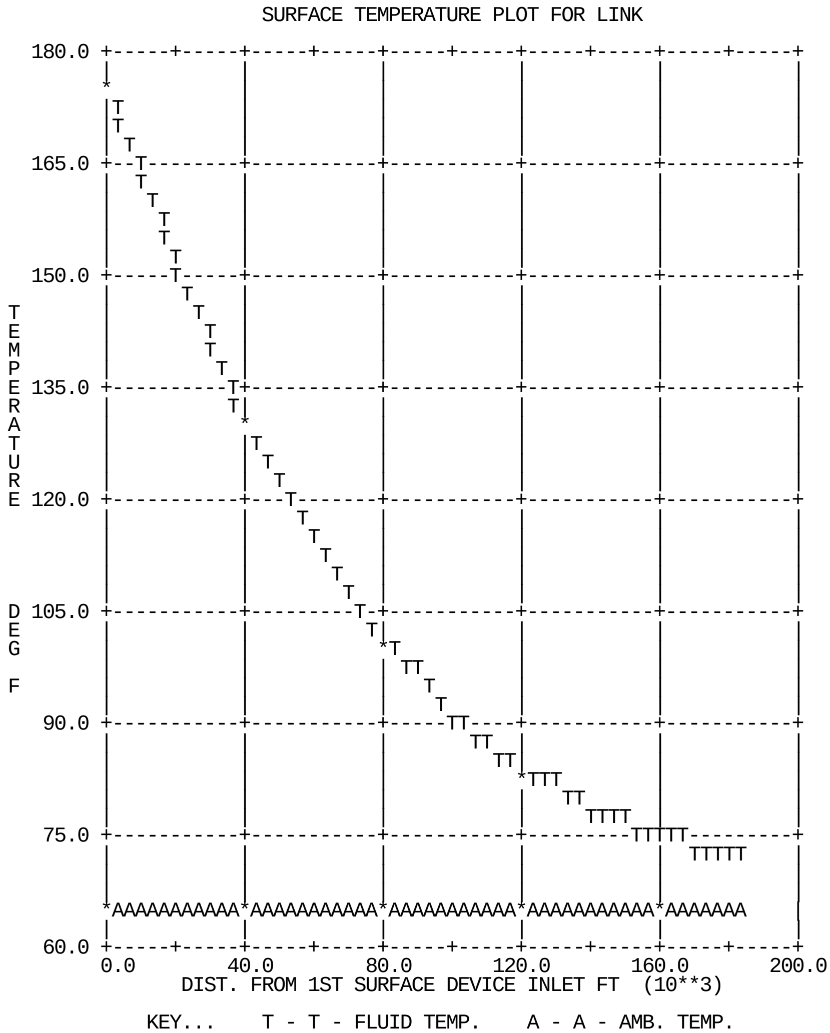
The figure below shows the surface pressure plot for case B.

```
                      SURFACE PRESSURE PLOT FOR LINK
  660.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        *           |           |           |           |           |
        |P          |           |           |           |           |
        |P          |           |           |           |           |
  630.0 + P         |           |           |           |           +
        |  P        |           |           |           |           |
        |  P        |           |           |           |           |
        |   P       |           |           |           |           |
  600.0 +----P------+-----------+-----------+-----------+-----------+
        |    P      |           |           |           |           |
        |     P     |           |           |           |           |
        |     P     |           |           |           |           |
P 570.0 +      P    |           |           |           |           +
R       |       PP  |           |           |           |           |
E       |         PP|           |           |           |           |
S       |           *P          |           |           |           |
S 540.0 +-----------+-PPPP------+-----------+-----------+-----------+
U       |           |     PP    |           |           |           |
R       |           |       PP  |           |           |           |
E       |           |         PP|           |           |           |
  510.0 +           |           *PPP        |           |           +
        |           |           |   PP      |           |           |
        |           |           |     PP    |           |           |
        |           |           |       PP  |           |           |
P 480.0 +-----------+-----------+---------PPPP----------+-----------+
S       |           |           |           | PP        |           |
I       |           |           |           |   PP      |           |
G       |           |           |           |     PP    |           |
  450.0 +           |           |           |       PP  |           +
        |           |           |           |         PP*           |
        |           |           |           |           |P          |
        |           |           |           |           |P          |
  420.0 +-----------+-----------+-----------+-----------+-P---------+
        |           |           |           |           |  P        |
        |           |           |           |           |   P       |
        |           |           |           |           |   P       |
  390.0 +           |           |           |           |    P      +
        |           |           |           |           |     P     |
        |           |           |           |           |      P    |
        |           |           |           |           |      P    |
  360.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        0.0        40.0        80.0       120.0       160.0       200.0
               DIST. FROM 1ST SURFACE DEVICE INLET FT  (10**3)

                      KEY...    P - P - FLUID PRESS.
```

## Partial Output (Case B)

The figure below shows the surface temperature plot for case B.



## Partial Output (Case A)

Following is a partial detail report for Case A.

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 21.95 | 21.95 | ---- | 1-PH | 1212.38 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 22.17 | 22.17 | ---- | 1-PH | 1204.77 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 22.41 | 22.41 | ---- | 1-PH | 1197.34 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 22.68 | 22.68 | ---- | 1-PH | 1190.36 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 22.99 | 22.99 | ---- | 1-PH | 1183.89 |
| P002 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 23.23 | 23.23 | ---- | 1-PH | 1178.45 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 23.38 | 23.38 | ---- | 1-PH | 1170.60 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 23.58 | 23.58 | ---- | 1-PH | 1163.71 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 23.82 | 23.82 | ---- | 1-PH | 1157.41 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 24.12 | 24.12 | ---- | 1-PH | 1151.94 |
| | 0006 | 0.00 | 0.00 | 0.0 | 0.00 | 24.43 | 24.43 | ---- | 1-PH | 1146.42 |
| | 0007 | 0.00 | 0.00 | 0.0 | 0.00 | 24.81 | 24.81 | ---- | 1-PH | 1141.72 |
| | 0008 | 0.00 | 0.00 | 0.0 | 0.00 | 25.24 | 25.24 | ---- | 1-PH | 1137.58 |
| | 0009 | 0.00 | 0.00 | 0.0 | 0.00 | 25.73 | 25.73 | ---- | 1-PH | 1134.11 |
| | 0010 | 0.00 | 0.00 | 0.0 | 0.00 | 26.30 | 26.30 | ---- | 1-PH | 1131.25 |
| | 0011 | 0.00 | 0.00 | 0.0 | 0.00 | 26.94 | 26.94 | ---- | 1-PH | 1128.96 |
| | 0012 | 0.00 | 0.00 | 0.0 | 0.00 | 27.64 | 27.64 | ---- | 1-PH | 1126.62 |
| | 0013 | 0.00 | 0.00 | 0.0 | 0.00 | 28.43 | 28.43 | ---- | 1-PH | 1124.68 |
| | 0014 | 0.00 | 0.00 | 0.0 | 0.00 | 29.32 | 29.32 | ---- | 1-PH | 1123.24 |
| | 0015 | 0.00 | 0.00 | 0.0 | 0.00 | 30.34 | 30.34 | ---- | 1-PH | 1122.25 |
| | 0016 | 0.00 | 0.00 | 0.0 | 0.00 | 31.51 | 31.51 | ---- | 1-PH | 1121.58 |
| | 0017 | 0.00 | 0.00 | 0.0 | 0.00 | 32.83 | 32.83 | ---- | 1-PH | 1121.08 |
| | 0018 | 0.00 | 0.00 | 0.0 | 0.00 | 34.37 | 34.37 | ---- | 1-PH | 1120.89 |
| | 0019 | 0.00 | 0.00 | 0.0 | 0.00 | 36.17 | 36.17 | ---- | 1-PH | 1120.94 |
| | 0020 | 0.00 | 0.00 | 0.0 | 0.00 | 38.29 | 38.29 | ---- | 1-PH | 1121.14 |
| P003 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 40.56 | 40.56 | ---- | 1-PH | 1125.14 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 42.94 | 42.94 | ---- | 1-PH | 1125.70 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 45.80 | 45.80 | ---- | 1-PH | 1126.16 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 49.31 | 49.31 | ---- | 1-PH | 1126.34 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 53.75 | 53.75 | ---- | 1-PH | 1125.96 |

## Partial Output (Case B)

Following is a partial detail report for Case B.

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 25.97 | 25.97 | ---- | 1-PH | 1223.85 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 26.39 | 26.39 | ---- | 1-PH | 1216.82 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 26.84 | 26.84 | ---- | 1-PH | 1209.72 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 27.33 | 27.33 | ---- | 1-PH | 1202.96 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 27.90 | 27.90 | ---- | 1-PH | 1196.94 |
| PIP2 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 19.35 | 19.35 | ---- | 1-PH | 1195.12 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 19.24 | 19.24 | ---- | 1-PH | 1185.32 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 19.15 | 19.15 | ---- | 1-PH | 1176.51 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 19.10 | 19.10 | ---- | 1-PH | 1168.54 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 19.06 | 19.06 | ---- | 1-PH | 1161.04 |
| | 0006 | 0.00 | 0.00 | 0.0 | 0.00 | 19.04 | 19.04 | ---- | 1-PH | 1154.15 |
| | 0007 | 0.00 | 0.00 | 0.0 | 0.00 | 19.05 | 19.05 | ---- | 1-PH | 1148.03 |
| | 0008 | 0.00 | 0.00 | 0.0 | 0.00 | 19.08 | 19.08 | ---- | 1-PH | 1142.61 |
| | 0009 | 0.00 | 0.00 | 0.0 | 0.00 | 19.14 | 19.14 | ---- | 1-PH | 1137.85 |
| | 0010 | 0.00 | 0.00 | 0.0 | 0.00 | 19.21 | 19.21 | ---- | 1-PH | 1133.17 |
| | 0011 | 0.00 | 0.00 | 0.0 | 0.00 | 19.28 | 19.28 | ---- | 1-PH | 1128.76 |
| | 0012 | 0.00 | 0.00 | 0.0 | 0.00 | 19.38 | 19.38 | ---- | 1-PH | 1124.92 |
| | 0013 | 0.00 | 0.00 | 0.0 | 0.00 | 19.50 | 19.50 | ---- | 1-PH | 1121.61 |
| | 0014 | 0.00 | 0.00 | 0.0 | 0.00 | 19.65 | 19.65 | ---- | 1-PH | 1118.78 |
| | 0015 | 0.00 | 0.00 | 0.0 | 0.00 | 19.81 | 19.81 | ---- | 1-PH | 1116.39 |
| | 0016 | 0.00 | 0.00 | 0.0 | 0.00 | 20.00 | 20.00 | ---- | 1-PH | 1114.53 |
| | 0017 | 0.00 | 0.00 | 0.0 | 0.00 | 20.21 | 20.21 | ---- | 1-PH | 1112.88 |
| | 0018 | 0.00 | 0.00 | 0.0 | 0.00 | 20.44 | 20.44 | ---- | 1-PH | 1111.57 |
| | 0019 | 0.00 | 0.00 | 0.0 | 0.00 | 20.69 | 20.69 | ---- | 1-PH | 1110.69 |
| | 0020 | 0.00 | 0.00 | 0.0 | 0.00 | 20.96 | 20.96 | ---- | 1-PH | 1109.82 |
| P003 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 31.17 | 31.17 | ---- | 1-PH | 1105.66 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 32.29 | 32.29 | ---- | 1-PH | 1106.86 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 33.54 | 33.54 | ---- | 1-PH | 1108.18 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 34.95 | 34.95 | ---- | 1-PH | 1109.64 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 36.56 | 36.56 | ---- | 1-PH | 1111.19 |

# Dense-phase $CO_2$ Transportation Pipeline



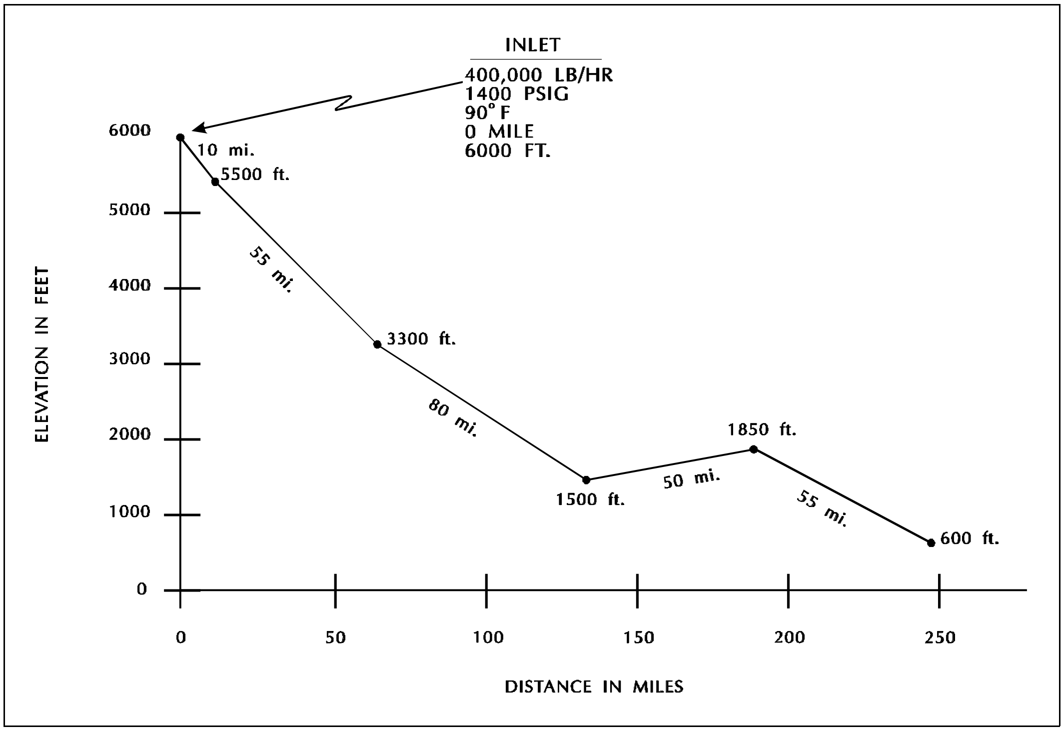
## Problem Description

High purity carbon dioxide is liquified and pumped through a 12-inch I.D., 250 miles long insulated pipeline downhill to its destination. To efficiently transport the $CO_2$, this pipeline should be operated in the dense-phase region at all times. Figure P3.1 describes this system. Table P3.1 shows the process conditions.

You are required to:

1. Determine the temperature profile for the pipeline to see if this line operates isothermally.
2. Determine if the existing insulation will keep the fluid in the dense-phase region, given that the critical pressure of the fluid is 1081 psia.
3. Determine if there is any danger of exceeding the 100°F temperature safety limit for the high pressure operation.
4. Determine the delivery pressure and temperature at the destination based on the existing set-up.

**Figure P3.1: Dense-phase CO2 Transportation Pipeline**




P3 Dense-phase CO2 Transportation Pipeline

| Table P3.1: Process Conditions | |
|---|---|
| **Heat Transfer Data** | |
| Ground Temperature | 70°F |
| Pipe Thermal Conductivity | 27.7 Btu/ft-hr-F |
| Insulation Thermal Conductivity | 0.11 Btu/ft-hr-F |
| Note: Use Default For All Other Data | |
| **Pipeline Data** | |
| Length | 250 miles |
| Inside Diameter | 11.938 inches |
| Wall Thickness | 0.406 inches |
| Pipe Roughness | 0.0007 inch |
| Burial Depth | 1 foot |
| Insulation Thickness | 10 inches |
| **Composition** | |
| **Component** | **Mole%** |
| C02 | 97.75 |
| N2 | 0.25 |
| C1 | 1.50 |
| C2 | 0.30 |
| C3 | 0.20 |

## PIPEPHASE Features Used In This Problem

- Dense-phase fluid properties can only be accurately simulated with the compositional model. Hence, compositional analysis is used for dense-phase fluid.
- The Peng-Robinson equation of state is used for all PVT to accurately predict phase behavior.
- Rigorous detail heat transfer calculation is required in order to simulate the compression heating effect.

## Results and Discussions

1. When simulating the existing system with rigorous heat transfer, the temperature is shown to vary from 90° to 75.4°F. Thus, the isothermal assumption would have been incorrect.
2. The results show that although the temperature drops, the compression heating effect helps to maintain the temperature. The pressure also increases as elevation drops. In this problem, the fluid remains as a dense-phase fluid all through the pipeline.
3. PIPEPHASE calculations based on the total energy balance show that the fluid actually gains temperature when going downhill. This can be seen in the last pipe section and its temperature plot. The highest temperature in the pipeline is approximately 93°F which is below the safety limit of 100°F.
4. It is interesting to note that this system will operate safely within a dense-phase region *without* the insulation. The temperature ranges from 90° to 71°F while the pressure rages from 1400 to 2689 psig.
5. The calculated pressure and temperature at the destination are 2495 psig and 75.4°F for the case *with* the insulation.

## Simulation Highlights

INPUT

- In order that the density calculation be consistent in the dense-phase region, the liquid density method of Peng-Robinson is specified.
- Insulation data are entered on the DEFAULT statement for detail U-value calculation.

## Input Data

The keyword input data files for the simulation case with and without insulation are given below.

### Keyword Input Data File (Case *With* Insulation)

```
TITLE   PROBLEM=PIPE3A, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP DENSEPHASE CO2 TRANSPORTATION STUDY
DIMENSI PETRO, RATE(W)=MLBHR
CALCULA SINGLE, COMPOSITIONAL
DEFAULT TAMB=70, ROUGH=0.0007, IDPIPE=11.938, SOIL, BDTOP=12, *
        CONP=27.7, THKP=0.406, THKI=10, CONI=0.11
SEGMENT DLHOR(MI)=1
PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
$
COMPONENT DATA
LIBID   CO2/N2/C1/C2/C3
$
METHODS DATA
THERMOD SYSTEM=PR, DENSITY(LIQ)=PR
$
STRUCTURE DATA
SOURCE  NAME=HILL, TEMP=90, PRES=1400, RATE(W)=400, *
             COMP=97.75/0.25/1.5/0.3/0.2
$
LINK    NAME=L001, FROM=HILL, TO=TANK
        PIPE    LENGTH(MI)=10, ECHG=-500, SOIL
        PIPE    LENGTH(MI)=55, ECHG=-2200, SOIL
        PIPE    LENGTH(MI)=80, ECHG=-1800, SOIL
        PIPE    LENGTH(MI)=50, ECHG=350, SOIL
        PIPE    LENGTH(MI)=55, ECHG=-1250, SOIL
$
SINK    NAME=TANK, PRES(ESTI)=1000, RATE(ESTI)=400
END
```

## Keyword Input Data File (Case *Without* Insulation)

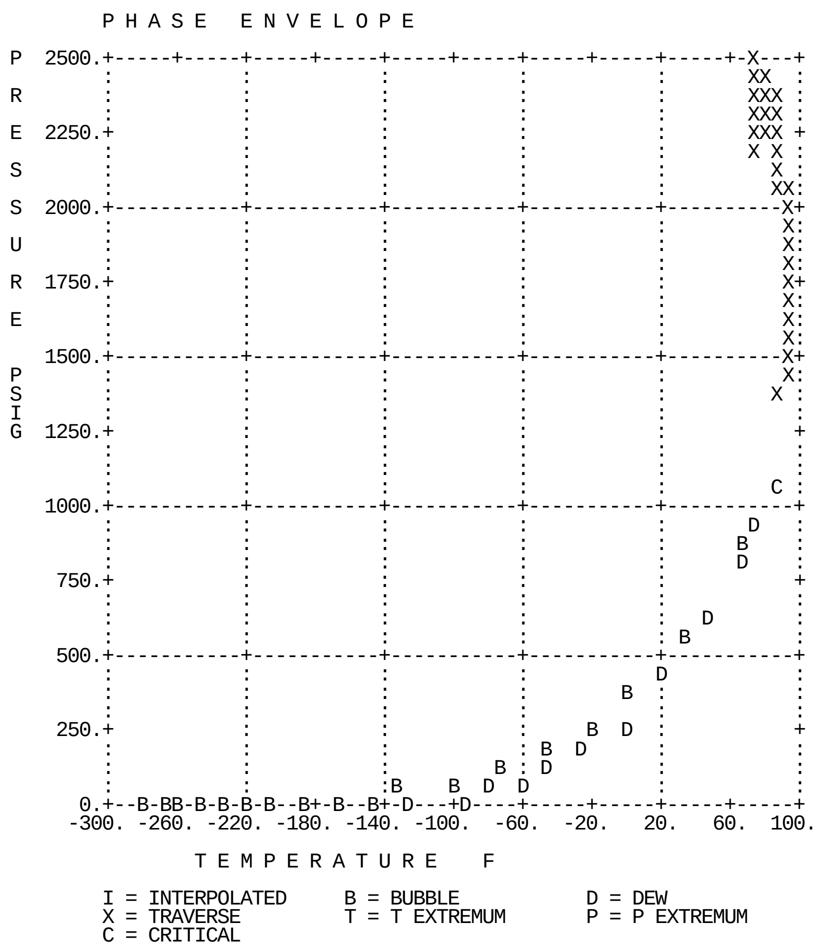
```
TITLE   PROBLEM=PIPE3B, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP DENSEPHASE CO2 TRANSPORTATION STUDY
DIMENSI PETRO, RATE(W)=MLBHR
CALCULA SINGLE, COMPOSITIONAL
DEFAULT TAMB=70, ROUGH=0.0007, IDPIPE=11.938, SOIL, BDTOP=12, *
        CONP=27.7, THKP=0.406
SEGMENT DLHOR(MI)=1
PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
$
COMPONENT DATA
LIBID   CO2/N2/C1/C2/C3
$
METHODS DATA
THERMOD SYSTEM=PR, DENSITY(LIQ)=PR
$
STRUCTURE DATA
SOURCE  NAME=HILL, TEMP=90, PRES=1400, RATE(W)=400, *
             COMP=97.75/0.25/1.5/0.3/0.2
$
LINK    NAME=L001, FROM=HILL, TO=TANK
        PIPE    LENGTH(MI)=10, ECHG=-500, SOIL
        PIPE    LENGTH(MI)=55, ECHG=-2200, SOIL
        PIPE    LENGTH(MI)=80, ECHG=-1800, SOIL
        PIPE    LENGTH(MI)=50, ECHG=350, SOIL
        PIPE    LENGTH(MI)=55, ECHG=-1250, SOIL
$
SINK    NAME=TANK, PRES(ESTI)=1000, RATE(ESTI)=400
END
```



## Output

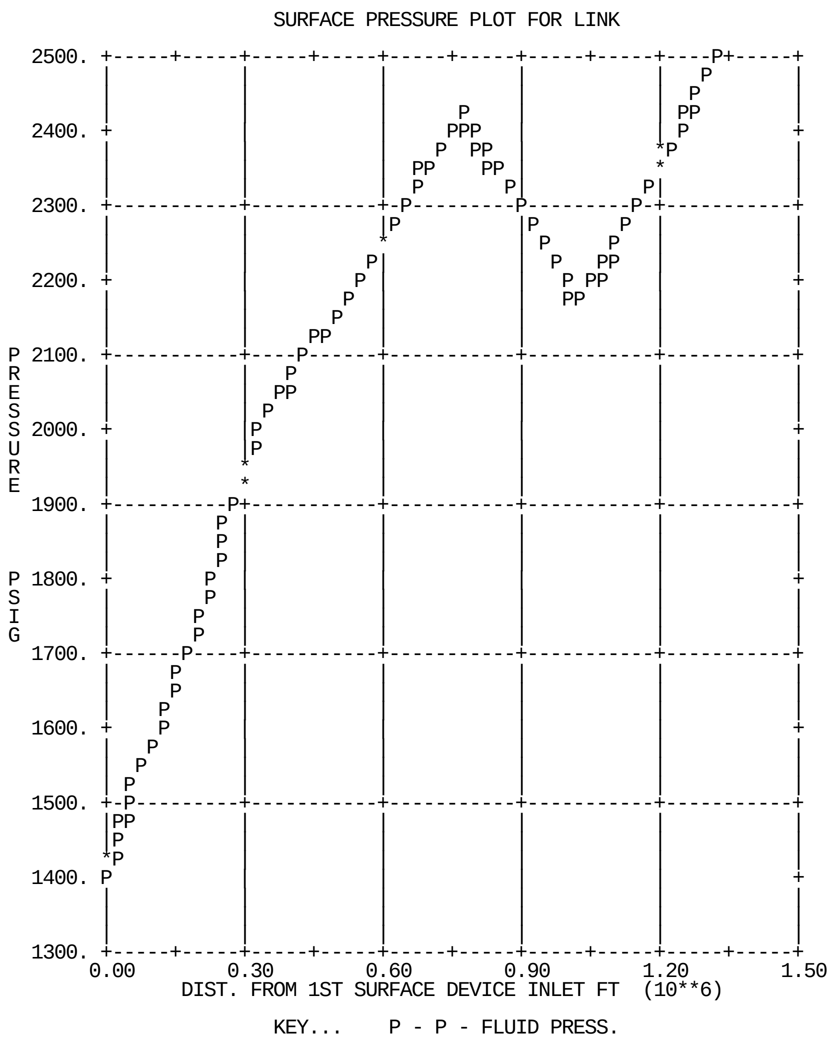
- Substantial pressure gain is realized in all downhill pipe sections due to the high density of the fluid. Total pressure gain is approximately 1100 psi for a net elevation drop of 5400 feet.
- PIPEPHASE calculates the compression heating effect due to pressure increase. This is demonstrated on the temperature plot. A few sections of the pipeline show temperature actually increasing.
- The fluid conditions along the pipeline fall outside the two-phase region (refer to the phase-envelope). Although the fluid quality is reported to be 100% (vapor) and 0% (liquid) at different sections, this is due to the logic which the program uses to label the fluid when it falls outside the two-phase region.  This does not affect the pressure drop calculations. Printing the phase densities through PROP=FULL options indicates that the fluid density is always above 40 lb/ft$^3$ irrespective of its being labelled a liquid or a gas outside the two-phase region.
- The phase envelope generated by PIPEPHASE is shown in Figure P3.2.

**Figure P3.2: Phase Envelope Generated by PIPEPHASE**



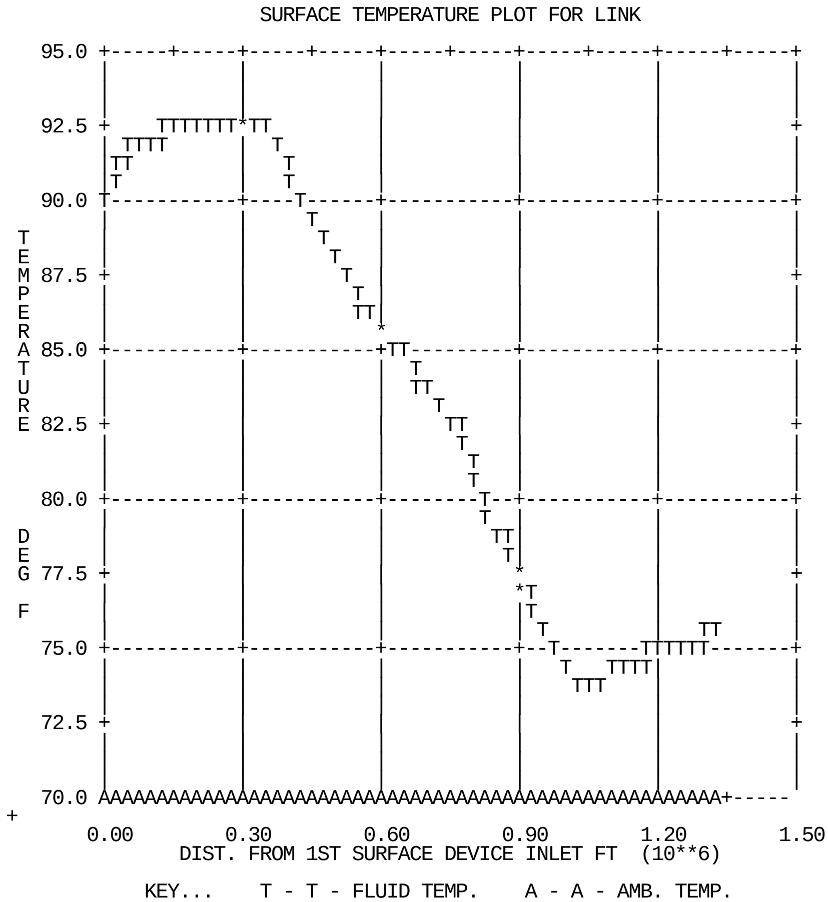
## Partial Output (Case *With* Insulation)

The pressure profile for the insulated pipe is shown below.



## Partial Output (Case *With* Insulation)

This plot shows the temperature profile for the insulated pipe.



## Partial Output (Case *With* Insulation)

The following temperature detail report shows that the temperature range is below the safety limit of 100$^{o}$F.

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 11.938 | 0.0 | I | 0.0 | 1400.0 | 90.0 | | 70.0 | 1.00 |
| (PIPE) | 0001 | | 5000.0 | | -47.3 | 1410.0 | 90.1 | 0.201 | 70.0 | 1.00 |
| | 0002 | | 10280.0 | | -50.0 | 1420.6 | 90.3 | 0.201 | 70.0 | 1.00 |
| | 0003 | | 15560.0 | | -50.0 | 1431.3 | 90.5 | 0.201 | 70.0 | 1.00 |
| | 0004 | | 20840.0 | | -50.0 | 1442.0 | 90.6 | 0.201 | 70.0 | 1.00 |
| | 0005 | | 26120.0 | | -50.0 | 1452.8 | 90.8 | 0.201 | 70.0 | 1.00 |
| | 0006 | | 31400.0 | | -50.0 | 1463.6 | 90.9 | 0.201 | 70.0 | 1.00 |
| | 0007 | | 36680.0 | | -50.0 | 1474.5 | 91.1 | 0.201 | 70.0 | 1.00 |
| | 0008 | | 41960.0 | | -50.0 | 1485.5 | 91.2 | 0.201 | 70.0 | 1.00 |
| | 0009 | | 47240.0 | | -50.0 | 1496.5 | 91.4 | 0.201 | 70.0 | 1.00 |
| | 0010 | | 52520.0 | | -50.0 | 1507.5 | 91.5 | 0.201 | 70.0 | 1.00 |
| | 0011 | | 52800.0 | O | -2.7 | 1508.1 | 91.5 | 0.201 | 70.0 | 1.00 |
| P002 | 0000 | 11.938 | 0.0 | I | 0.0 | 1508.1 | 91.5 | | 70.0 | 1.00 |
| (PIPE) | 0001 | | 5000.0 | | -37.9 | 1515.9 | 91.6 | 0.201 | 70.0 | 1.00 |
| | 0002 | | 19520.0 | | -110.0 | 1538.7 | 91.7 | 0.201 | 70.0 | 1.00 |
| | 0003 | | 34040.0 | | -110.0 | 1561.8 | 91.9 | 0.201 | 70.0 | 1.00 |
| | 0004 | | 48560.0 | | -110.0 | 1585.3 | 92.0 | 0.201 | 70.0 | 1.00 |
| | 0005 | | 63080.0 | | -110.0 | 1609.0 | 92.2 | 0.201 | 70.0 | 1.00 |
| | 0006 | | 77600.0 | | -110.0 | 1632.9 | 92.3 | 0.201 | 70.0 | 1.00 |
| | 0007 | | 92120.0 | | -110.0 | 1657.2 | 92.4 | 0.201 | 70.0 | 1.00 |
| | 0008 | | 106640.0 | | -110.0 | 1681.7 | 92.5 | 0.201 | 70.0 | 1.00 |
| | 0009 | | 121160.0 | | -110.0 | 1706.5 | 92.6 | 0.201 | 70.0 | 1.00 |
| | 0010 | | 135680.0 | | -110.0 | 1731.6 | 92.6 | 0.201 | 70.0 | 1.00 |
| | 0011 | | 150200.0 | | -110.0 | 1756.9 | 92.6 | 0.201 | 70.0 | 1.00 |
| | 0012 | | 164720.0 | | -110.0 | 1782.5 | 92.7 | 0.201 | 70.0 | 1.00 |
| | 0013 | | 179240.0 | | -110.0 | 1808.4 | 92.7 | 0.201 | 70.0 | 1.00 |
| | 0014 | | 193760.0 | | -110.0 | 1834.5 | 92.7 | 0.201 | 70.0 | 1.00 |
| | 0015 | | 208280.0 | | -110.0 | 1861.0 | 92.7 | 0.201 | 70.0 | 1.00 |
| | 0016 | | 222800.0 | | -110.0 | 1887.6 | 92.7 | 0.201 | 70.0 | 1.00 |
| | 0017 | | 237320.0 | | -110.0 | 1914.6 | 92.6 | 0.201 | 70.0 | 1.00 |
| | 0018 | | 251840.0 | | -110.0 | 1941.8 | 92.5 | 0.201 | 70.0 | 1.00 |
| | 0019 | | 266360.0 | | -110.0 | 1969.2 | 92.5 | 0.201 | 70.0 | 1.00 |
| | 0020 | | 280880.0 | | -110.0 | 1996.9 | 92.4 | 0.201 | 70.0 | 1.00 |
| | 0021 | | 290400.0 | O | -72.1 | 2015.2 | 92.4 | 0.201 | 70.0 | 1.00 |

## Partial Output (Case *With* Insulation, continued)

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| P003 | 0000 | 11.938 | 0.0 | I | 0.0 | 2015.2 | 92.4 | | 70.0 | 1.00 |
| (PIPE) | 0001 | | 5000.0 | | -21.3 | 2019.5 | 92.3 | 0.201 | 70.0 | 1.00 |
| | 0002 | | 26120.0 | | -90.0 | 2037.6 | 91.7 | 0.201 | 70.0 | 1.00 |
| | 0003 | | 47240.0 | | -90.0 | 2055.9 | 91.0 | 0.201 | 70.0 | 1.00 |
| | 0004 | | 68360.0 | | -90.0 | 2074.6 | 90.4 | 0.201 | 70.0 | 1.00 |
| | 0005 | | 89480.0 | | -90.0 | 2093.5 | 89.8 | 0.201 | 70.0 | 1.00 |
| | 0006 | | 110600.0 | | -90.0 | 2112.7 | 89.2 | 0.201 | 70.0 | 1.00 |
| | 0007 | | 131720.0 | | -90.0 | 2132.1 | 88.7 | 0.201 | 70.0 | 1.00 |
| | 0008 | | 152840.0 | | -90.0 | 2151.8 | 88.1 | 0.201 | 70.0 | 1.00 |
| | 0009 | | 173960.0 | | -90.0 | 2171.7 | 87.6 | 0.201 | 70.0 | 1.00 |
| | 0010 | | 195080.0 | | -90.0 | 2191.9 | 87.0 | 0.201 | 70.0 | 1.00 |
| | 0011 | | 216200.0 | | -90.0 | 2212.3 | 86.6 | 0.201 | 70.0 | 1.00 |
| | 0012 | | 237320.0 | | -90.0 | 2232.9 | 86.1 | 0.201 | 70.0 | 1.00 |
| | 0013 | | 258440.0 | | -90.0 | 2253.7 | 85.6 | 0.201 | 70.0 | 1.00 |
| | 0014 | | 279560.0 | | -90.0 | 2274.8 | 85.2 | 0.201 | 70.0 | 1.00 |
| | 0015 | | 300680.0 | | -90.0 | 2296.0 | 84.7 | 0.201 | 70.0 | 1.00 |
| | 0016 | | 321800.0 | | -90.0 | 2317.4 | 84.3 | 0.201 | 70.0 | 1.00 |
| | 0017 | | 342920.0 | | -90.0 | 2339.1 | 83.9 | 0.201 | 70.0 | 1.00 |
| | 0018 | | 364040.0 | | -90.0 | 2361.2 | 83.6 | 0.201 | 70.0 | 0.00 |
| | 0019 | | 385160.0 | | -90.0 | 2383.5 | 83.2 | 0.201 | 70.0 | 0.00 |
| | 0020 | | 406280.0 | | -90.0 | 2406.0 | 82.8 | 0.201 | 70.0 | 0.00 |
| | 0021 | | 422400.0 | O | -68.7 | 2423.3 | 82.5 | 0.201 | 70.0 | 0.00 |
| P004 | 0000 | 11.938 | 0.0 | I | 0.0 | 2423.3 | 82.5 | | 70.0 | 0.00 |
| (PIPE) | 0001 | | 5000.0 | | 6.6 | 2418.4 | 82.3 | 0.201 | 70.0 | 0.00 |
| | 0002 | | 18200.0 | | 17.5 | 2405.6 | 81.7 | 0.201 | 70.0 | 0.00 |
| | 0003 | | 31400.0 | | 17.5 | 2392.8 | 81.1 | 0.201 | 70.0 | 0.00 |
| | 0004 | | 44600.0 | | 17.5 | 2380.0 | 80.5 | 0.201 | 70.0 | 0.00 |
| | 0005 | | 57800.0 | | 17.5 | 2367.2 | 80.0 | 0.201 | 70.0 | 0.00 |
| | 0006 | | 71000.0 | | 17.5 | 2354.4 | 79.5 | 0.201 | 70.0 | 0.00 |
| | 0007 | | 84200.0 | | 17.5 | 2341.5 | 79.0 | 0.201 | 70.0 | 0.00 |
| | 0008 | | 97400.0 | | 17.5 | 2328.7 | 78.5 | 0.201 | 70.0 | 0.00 |
| | 0009 | | 110600.0 | | 17.5 | 2315.8 | 78.0 | 0.201 | 70.0 | 0.00 |
| | 0010 | | 123800.0 | | 17.5 | 2303.0 | 77.5 | 0.201 | 70.0 | 0.00 |
| | 0011 | | 137000.0 | | 17.5 | 2290.1 | 77.1 | 0.201 | 70.0 | 0.00 |
| | 0012 | | 150200.0 | | 17.5 | 2277.2 | 76.7 | 0.201 | 70.0 | 0.00 |
| | 0013 | | 163400.0 | | 17.5 | 2264.3 | 76.3 | 0.201 | 70.0 | 0.00 |
| | 0014 | | 176600.0 | | 17.5 | 2251.4 | 75.9 | 0.201 | 70.0 | 0.00 |
| | 0015 | | 189800.0 | | 17.5 | 2238.6 | 75.4 | 0.201 | 70.0 | 0.00 |
| | 0016 | | 203000.0 | | 17.5 | 2225.7 | 75.1 | 0.201 | 70.0 | 0.00 |
| | 0017 | | 216200.0 | | 17.5 | 2212.8 | 74.8 | 0.201 | 70.0 | 0.00 |
| | 0018 | | 229400.0 | | 17.5 | 2199.9 | 74.5 | 0.201 | 70.0 | 0.00 |
| | 0019 | | 242600.0 | | 17.5 | 2187.0 | 74.1 | 0.201 | 70.0 | 0.00 |

## Partial Output (Case *Without* Insulation)

The link device detail report is given below.

LINK "L001" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 11.938 | 0.0 | I | 0.0 | 1400.0 | 90.0 | | 70.0 | 1.00 |
| (PIPE) | 0001 | | 5000.0 | | -47.3 | 1410.1 | 89.6 | 0.930 | 70.0 | 1.00 |
| | 0002 | | 10280.0 | | -50.0 | 1420.8 | 89.3 | 0.930 | 70.0 | 1.00 |
| | 0003 | | 15560.0 | | -50.0 | 1431.8 | 88.9 | 0.930 | 70.0 | 1.00 |
| | 0004 | | 20840.0 | | -50.0 | 1442.9 | 88.5 | 0.930 | 70.0 | 1.00 |
| | 0005 | | 26120.0 | | -50.0 | 1454.2 | 88.2 | 0.930 | 70.0 | 1.00 |
| | 0006 | | 31400.0 | | -50.0 | 1465.7 | 87.8 | 0.930 | 70.0 | 1.00 |
| | 0007 | | 36680.0 | | -50.0 | 1477.2 | 87.4 | 0.930 | 70.0 | 1.00 |
| | 0008 | | 41960.0 | | -50.0 | 1489.0 | 87.0 | 0.930 | 70.0 | 1.00 |
| | 0009 | | 47240.0 | | -50.0 | 1500.9 | 86.7 | 0.930 | 70.0 | 1.00 |
| | 0010 | | 52520.0 | | -50.0 | 1512.9 | 86.3 | 0.930 | 70.0 | 1.00 |
| | 0011 | | 52800.0 | O | -2.7 | 1513.5 | 86.3 | 0.930 | 70.0 | 1.00 |
| P002 | 0000 | 11.938 | 0.0 | I | 0.0 | 1513.5 | 86.3 | | 70.0 | 1.00 |
| (PIPE) | 0001 | | 5000.0 | | -37.9 | 1522.1 | 85.8 | 0.930 | 70.0 | 1.00 |
| | 0002 | | 19520.0 | | -110.0 | 1547.7 | 84.6 | 0.930 | 70.0 | 1.00 |
| | 0003 | | 34040.0 | | -110.0 | 1574.1 | 83.5 | 0.930 | 70.0 | 1.00 |
| | 0004 | | 48560.0 | | -110.0 | 1601.2 | 82.4 | 0.933 | 70.0 | 0.00 |
| | 0005 | | 63080.0 | | -110.0 | 1628.9 | 81.5 | 0.933 | 70.0 | 0.00 |
| | 0006 | | 77600.0 | | -110.0 | 1657.2 | 80.6 | 0.933 | 70.0 | 0.00 |
| | 0007 | | 92120.0 | | -110.0 | 1686.0 | 79.7 | 0.932 | 70.0 | 0.00 |
| | 0008 | | 106640.0 | | -110.0 | 1715.3 | 79.0 | 0.932 | 70.0 | 0.00 |
| | 0009 | | 121160.0 | | -110.0 | 1745.0 | 78.3 | 0.932 | 70.0 | 0.00 |
| | 0010 | | 135680.0 | | -110.0 | 1775.1 | 77.7 | 0.932 | 70.0 | 0.00 |
| | 0011 | | 150200.0 | | -110.0 | 1805.6 | 77.1 | 0.932 | 70.0 | 0.00 |
| | 0012 | | 164720.0 | | -110.0 | 1836.5 | 76.6 | 0.932 | 70.0 | 0.00 |
| | 0013 | | 179240.0 | | -110.0 | 1867.7 | 76.1 | 0.932 | 70.0 | 0.00 |
| | 0014 | | 193760.0 | | -110.0 | 1899.2 | 75.7 | 0.932 | 70.0 | 0.00 |
| | 0015 | | 208280.0 | | -110.0 | 1931.0 | 75.3 | 0.932 | 70.0 | 0.00 |
| | 0016 | | 222800.0 | | -110.0 | 1963.1 | 75.0 | 0.932 | 70.0 | 0.00 |
| | 0017 | | 237320.0 | | -110.0 | 1995.4 | 74.7 | 0.932 | 70.0 | 0.00 |
| | 0018 | | 251840.0 | | -110.0 | 2028.0 | 74.4 | 0.932 | 70.0 | 0.00 |
| | 0019 | | 266360.0 | | -110.0 | 2060.9 | 74.2 | 0.932 | 70.0 | 0.00 |
| | 0020 | | 280880.0 | | -110.0 | 2094.0 | 74.0 | 0.932 | 70.0 | 0.00 |
| | 0021 | | 290400.0 | O | -72.1 | 2115.8 | 73.9 | 0.932 | 70.0 | 0.00 |
| P003 | 0000 | 11.938 | 0.0 | I | 0.0 | 2115.8 | 73.9 | | 70.0 | 0.00 |
| (PIPE) | 0001 | | 5000.0 | | -21.3 | 2121.2 | 73.8 | 0.932 | 70.0 | 0.00 |
| | 0002 | | 26120.0 | | -90.0 | 2144.1 | 73.3 | 0.932 | 70.0 | 0.00 |
| | 0003 | | 47240.0 | | -90.0 | 2167.2 | 72.9 | 0.932 | 70.0 | 0.00 |

# Partial Output (Case *Without* Insulation, continued)

LINK "L001" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0004 | | 68360.0 | | -90.0 | 2190.5 | 72.6 | 0.932 | 70.0 | 0.00 |
| | 0005 | | 89480.0 | | -90.0 | 2214.0 | 72.3 | 0.932 | 70.0 | 0.00 |
| | 0006 | | 110600.0 | | -90.0 | 2237.6 | 72.1 | 0.932 | 70.0 | 0.00 |
| | 0007 | | 131720.0 | | -90.0 | 2261.3 | 71.9 | 0.932 | 70.0 | 0.00 |
| | 0008 | | 152840.0 | | -90.0 | 2285.2 | 71.7 | 0.932 | 70.0 | 0.00 |
| | 0009 | | 173960.0 | | -90.0 | 2309.2 | 71.7 | 0.932 | 70.0 | 0.00 |
| | 0010 | | 195080.0 | | -90.0 | 2333.3 | 71.6 | 0.932 | 70.0 | 0.00 |
| | 0011 | | 216200.0 | | -90.0 | 2357.5 | 71.5 | 0.932 | 70.0 | 0.00 |
| | 0012 | | 237320.0 | | -90.0 | 2381.9 | 71.5 | 0.932 | 70.0 | 0.00 |
| | 0013 | | 258440.0 | | -90.0 | 2406.3 | 71.4 | 0.932 | 70.0 | 0.00 |
| | 0014 | | 279560.0 | | -90.0 | 2430.8 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0015 | | 300680.0 | | -90.0 | 2455.5 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0016 | | 321800.0 | | -90.0 | 2480.2 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0017 | | 342920.0 | | -90.0 | 2505.0 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0018 | | 364040.0 | | -90.0 | 2529.9 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0019 | | 385160.0 | | -90.0 | 2554.9 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0020 | | 406280.0 | | -90.0 | 2580.0 | 71.3 | 0.932 | 70.0 | 0.00 |
| | 0021 | | 422400.0 | O | -68.7 | 2599.2 | 71.3 | 0.932 | 70.0 | 0.00 |
| P004 | 0000 | 11.938 | 0.0 | I | 0.0 | 2599.2 | 71.3 | | 70.0 | 0.00 |
| (PIPE) | 0001 | | 5000.0 | | 6.6 | 2594.3 | 71.2 | 0.932 | 70.0 | 0.00 |
| | 0002 | | 18200.0 | | 17.5 | 2581.4 | 70.9 | 0.932 | 70.0 | 0.00 |
| | 0003 | | 31400.0 | | 17.5 | 2568.5 | 70.6 | 0.932 | 70.0 | 0.00 |
| | 0004 | | 44600.0 | | 17.5 | 2555.5 | 70.4 | 0.932 | 70.0 | 0.00 |
| | 0005 | | 57800.0 | | 17.5 | 2542.6 | 70.2 | 0.932 | 70.0 | 0.00 |
| | 0006 | | 71000.0 | | 17.5 | 2529.7 | 70.1 | 0.932 | 70.0 | 0.00 |
| | 0007 | | 84200.0 | | 17.5 | 2516.7 | 70.0 | 0.932 | 70.0 | 0.00 |
| | 0008 | | 97400.0 | | 17.5 | 2503.8 | 69.8 | 0.932 | 70.0 | 0.00 |
| | 0009 | | 110600.0 | | 17.5 | 2490.9 | 69.8 | 0.932 | 70.0 | 0.00 |
| | 0010 | | 123800.0 | | 17.5 | 2477.9 | 69.7 | 0.932 | 70.0 | 0.00 |
| | 0011 | | 137000.0 | | 17.5 | 2465.0 | 69.6 | 0.932 | 70.0 | 0.00 |
| | 0012 | | 150200.0 | | 17.5 | 2452.1 | 69.6 | 0.932 | 70.0 | 0.00 |
| | 0013 | | 163400.0 | | 17.5 | 2439.1 | 69.5 | 0.932 | 70.0 | 0.00 |
| | 0014 | | 176600.0 | | 17.5 | 2426.2 | 69.5 | 0.932 | 70.0 | 0.00 |
| | 0015 | | 189800.0 | | 17.5 | 2413.3 | 69.4 | 0.932 | 70.0 | 0.00 |
| | 0016 | | 203000.0 | | 17.5 | 2400.4 | 69.4 | 0.932 | 70.0 | 0.00 |
| | 0017 | | 216200.0 | | 17.5 | 2387.4 | 69.4 | 0.932 | 70.0 | 0.00 |
| | 0018 | | 229400.0 | | 17.5 | 2374.5 | 69.4 | 0.932 | 70.0 | 0.00 |
| | 0019 | | 242600.0 | | 17.5 | 2361.6 | 69.3 | 0.932 | 70.0 | 0.00 |

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# Heavy Oil Pipeline With Heaters

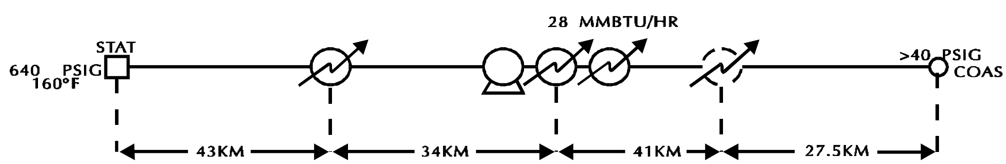
## Problem Description

A heavy oil pipeline transporting crude oil to the coast for shipping is operating far below the design capacity. The problem is due to low API gravity and extremely high viscosity of oil. In addition, the pipe is eroded and thus limited to an operating pressure of 640 psig instead of the design operating pressure of 780 psig.

Figure P4.1 illustrates this pipeline system. The project is to increase the capacity from current 45,000 bpd to 200,000 bpd. According to previous experience, one 28 MMBtu/hr heater unit at the booster station (77 kilometers from inlet) has proven to reduce the oil viscosity sufficiently to increase the capacity. In addition, due to the number of rivers and a swamp area the pipeline passes through, replacing or insulating this 30-inch line is economically infeasible at the present time.



**Figure P4.1: Crude Oil Transportation Pipeline**




Additional heater locations at 43 kilometers and 118 kilometers from the inlet are selected. Each new heating station unit provides a 28 MMBtu/hr heater.

You are required to:

1. Determine the capacities of the following four heating station combinations shown in Table P4.1 for the 12.5°API crude oil (viscosity of 8,000 cp at 85°F and 850 cp at 110°F).

**Table P4.1: Process Information**

| | Heater #1 | Heater #2* | Heater #3 |
|---|---|---|---|
| **Location** | **43 km** | **77km** | **118 km** |
| Case 1 | 1 unit | 2 units | 1 unit |
| Case 2 | 1 unit | 2 units | ---- |
| Case 3 | 1 unit | 1 unit | ---- |
| Case 4 | ---- | 1 unit | 1 unit |
| Case 5 | ---- | 1 unit | ---- |

*Include one existing heater unit

P4 Heavy Oil Pipeline With Heaters

2. Evaluate the pressure profile for the highest capacity case to ensure that the operating pressure does not exceed the 640 psig limit.

## PIPEPHASE Features Used In This Problem

- Sensitivity Analysis is used to reduce the number of runs and obtain large amounts of information in a condensed format.
- Rigorous heat transfer is required in this problem due to the sensitivity to insulation requirements.
- Two-point viscosity data entry is used for easy input of actual laboratory data.
- The non-compositional liquid model is most appropriate given the limited fluid data available.
- Heaters with duty specification are used.

## Results and Discussion

1. According to the results from the sensitivity run, both Case #1 and Case #2 provide pipeline throughput over 289,000 bpd. Case #3 provides 65,161 bpd throughput.
2. A separate simulation run reports the detail pressure results of the pipeline for Case #1. The operating pressures are below 640 psig for all pipeline sections at 200,000 bpd throughput.

## Simulation Highlights

INPUT

- Base case for sensitivity analysis is set up as a rate calculation run.
- The sensitivity analysis input is "appended" to the base case.
- Rigorous heat transfer calculation uses an overall U-factor of 1.0 Btu/ft$^2$-hr-F. Since this is the same as the default value, it is not input.
- Pipe absolute roughness of 0.0018 inches is the same as the program default and is not input.
- Single-phase liquid two-point viscosity data are input on the SET statement.
- The outflow parameter is the sink pressure of 40 psig (the minimum operating pressure allowable).
- Flowrates evaluated for the sensitivity runs range from 20,000 bpd to 300,000 bpd.

TECHNIQUE

- To determine the combined heater effect on the pipeline operation, all heaters are used as inflow parameters in the sensitivity study. The sink is selected as the solution node and the actual sink pressure is defined using the outflow parameter. Note that the source could be used as the solution node, but this selection would require iterative calculations. Refer to the results for a description of the calculation methods.



## Input Data

The keyword input data files for both simulation cases are given below.

## Keyword Input Data File (Sensitivity Analysis Run)

```
TITLE   PROBLEM=PIPE4A, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP PIPELINE HEATER VERSUS CAPACITY STUDY
DIME    PETROLEUM
CALCULA SINGLE, LIQUID
DEFAULT TAMB=84, IDPIPE=30
SEGMENT DLHOR(KM)=10
$
PVT DATA
SET     SETN=1, GRAV=12.5, VISC=85, 8000/110, 850
$
STRUCTURE DATA
        SOURCE  SETN=1, NAME=STAT, TEMP=160, PRES=640, RATE(ESTI)=200000
        PIPE    NAME=P1, LENGTH(KM)=43
        HEATER  NAME=H1, DUTY=28
        PIPE    NAME=P2, LENGTH(KM)=34
        PUMP    NAME=PUM1, POWER=300,EFF=75
        HEATER  NAME=H2, DUTY=56
        PIPE    NAME=P3, LENGTH(KM)=41
        HEATER  NAME=H3, DUTY=28
        PIPE    NAME=P4, LENGTH(KM)=27.5
        SINK    NAME=COAS, PRES=40, RATE(ESTI)=200000
$
SENSITIVITY DATA
        NODE    SINK
        FLOW    RATE=20000, 40000, 70000, 100000, 130000, 160000, *
                200000, 250000, 300000
        DESC    INFLOW=3 HEATERS,2 HEATERS,1 HEATER,1A HEATER,ORIGINAL
        INFLOW  NAME=H1, DUTY=28, 28, 28, 0, 0, *
                NAME=H2, DUTY=56, 56, 28, 28, 28,*
                NAME=H3, DUTY=28, 0, 0, 28, 0
        DESC    OUTFLOW=40 PSI
        OUTFLOW NAME=COAS, PRES=40
```

## Keyword Input Data File (Single Link Run for Case 1)

```
TITLE   PROBLEM=PIPE4B, PROJECT=PIPEAPP, USER=SIMSCI
DESCRIP PIPELINE HEATER VERSUS CAPACITY STUDY
DIME    PETROLEUM
CALCULA SINGLE, LIQUID
DEFAULT TAMB=84, IDPIPE=30
SEGMENT DLHOR(KM)=10
PRINT   DEVICE=FULL, PLOT=FULL
$
PVT DATA
SET     SETN=1, GRAV=12.5, VISC=85, 8000/110, 850
$
STRUCTURE DATA
        SOURCE  SETN=1, NAME=STAT, TEMP=160, PRES=640, RATE=200000
        PIPE    NAME=P1, LENGTH(KM)=43
        HEATER  NAME=H1, DUTY=28
        PIPE    NAME=P2, LENGTH(KM)=34
        PUMP    NAME=PUM1, POWER=300,EFF=75
        HEATER  NAME=H2, DUTY=56
        PIPE    NAME=P3, LENGTH(KM)=41
        HEATER  NAME=H3, DUTY=28
        PIPE    NAME=P4, LENGTH(KM)=27.5
        SINK    NAME=COAS, PRES(ESTI)=40, RATE(ESTI)=200000
```

## Output

- The heavy oil viscosity is greatly reduced due to the heat input. Thus, the installation of additional heaters benefits throughput.
- Comparing Case #2 to Case #3, the heater installed closer to the inlet provides a much greater throughput.
- The extreme high operating pressures for low throughput are due to fixed pump power and should be avoided if possible.
- The single link run for Case #1 at 200,000 bpd provides a detailed temperature and pressure profile of the pipeline. Results show that the operating pressure is below 640 psig and the temperature ranges from 119$^o$ to 160$^o$F.

## Partial Output

The following sensitivity analysis output shows that the heater installation increases the total throughput.

```
SOLUTION NODE IS AT OUTLET OF DEVICE P4

                            SENSITIVITY ANALYSIS

  1000. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        |           |           |           |           |           |
        |   1       |           |           |           |           |
        |   1       |           |           |           |           |
   900. +    1      |           |           |           |           +
        |    1      |           |           |           |           |
        |    1      |           |           |           |           |
        |   21      |           |           |           |           |
   800. +---*-1-----+-----------+-----------+-----------+-----------+
        |   * 1     |           |           |           |           |
        |   *21     |           |           |           |           |
        |    *1     |           |           |           |           |
   700. +    * 1    |           |           |           |           +
P       |   5* 1    |           |           |           |           |
R       |    * 1    |           |           |           |           |
E       |    *21    |           |           |           |           |
S  600. +----*2-1---+-----------+-----------+-----------+-----------+
S       |     * 11  |           |           |           |           |
U       |     *   11|           |           |           |           |
R       |     *     *1          |           |           |           |
E  500. +     *2    | 1111      |           |           |           +
        |     *2    |     111111*11111      |           |           |
        |     4*    |           |     1111  |           |           |
P       |      *    |           |         11*           |           |
S  400. +------*----+-----------+-----------+11---------+-----------+
I       |      *2   |           |           |  111      |           |
A       |      *2   |           |           |     11    |           |
        |      *2   |           |           |       11  |           |
   300. +      432  |           |           |         11|           +
        |       * 22|          2*22222222222*           *1          |
        |       *   *      2222 |           |22222      | 1         |
        |       43  |2  222     |           |     2222  |  1        |
   200. +-------43--+-22--------+-----------+---------222---1-------+
        |         3 |           |           |           |22  1      |
        |          3|           |           |           |  22 11    |
        |          3|           |           |           |    22 1   |
   100. +           *           |           |           |      2 1  +
        |           |3          |           |           |       221 |
        |   AAAAAAAA**AAAAAAAAAA*AAAAAAAAAAA*AAAAAAAAAAA*AAAAAAAAA***
        |           | 3         |           |           |           *
     0. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        0.0        60.0       120.0       180.0       240.0       300.0
                       FLOW RATE      (BBL/D)  (10**3)

          KEY...    1 - 3 HEATERS    2 - 2 HEATERS    3 - 1 HEATER
                    4 - 1A HEATER    5 - ORIGINAL     A - 40 PSI
```

## Partial Output (continued)

The following are the inflow and outflow curves for the sensitivity study. The first table gives the sink pressure calculated for each flowrate and heater configuration, assuming that the source pressure is maintained at 640 psig. Sink pressures of zero indicate that the flowrate was not obtainable. The second table shows the actual operating pressure for each flowrate. The last table gives the estimated flowrate for each case as determined from the intersection between the curves for the calculated and actual sink pressures. Solutions are not given for cases 4 and 5, because these curves do not intersect. Note that solutions can be obtained for these cases by adding low flowrate cases to the study.

SOLUTION NODE IS AT OUTLET OF DEVICE P4

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE 3 HEATERS | 2 HEATERS | 1 HEATER | 1A HEATER | ORIGINAL |
|---|---|---|---|---|---|
| 20000.00 | 939.39 | 825.86 | 799.84 | 796.84 | 683.07 |
| 40000.00 | 568.30 | 326.99 | 241.41 | 202.80 | 0.00 |
| 70000.13 | 492.22 | 212.26 | 18.79 | 0.00 | 0.00 |
| 100000.00 | 486.15 | 241.34 | 0.00 | 0.00 | 0.00 |
| 129999.88 | 472.06 | 267.25 | 0.00 | 0.00 | 0.00 |
| 160000.17 | 444.70 | 270.69 | 0.00 | 0.00 | 0.00 |
| 200000.00 | 381.86 | 244.62 | 0.00 | 0.00 | 0.00 |
| 250000.22 | 244.26 | 168.45 | 0.00 | 0.00 | 0.00 |
| 299999.97 | 30.69 | 23.79 | 0.00 | 0.00 | 0.00 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 40 PSI |
|---|---|
| 20000.00 | 54.70 |
| 40000.00 | 54.70 |
| 70000.13 | 54.70 |
| 100000.00 | 54.70 |
| 129999.88 | 54.70 |
| 160000.17 | 54.70 |
| 200000.00 | 54.70 |
| 250000.22 | 54.70 |
| 299999.97 | 54.70 |

INFLOW-OUTFLOW CURVE INTERSECTION POINTS

| INFLOW CASE | OUTFLOW CASE | RATE (BBL/D) | PRESSURE (PSIA) |
|---|---|---|---|
| 3 HEATERS | 40 PSI | 294380.22 | 54.70 |
| 2 HEATERS | 40 PSI | 289318.63 | 54.70 |
| 1 HEATER | 40 PSI | 65160.82 | 54.70 |

## Partial Output (continued)

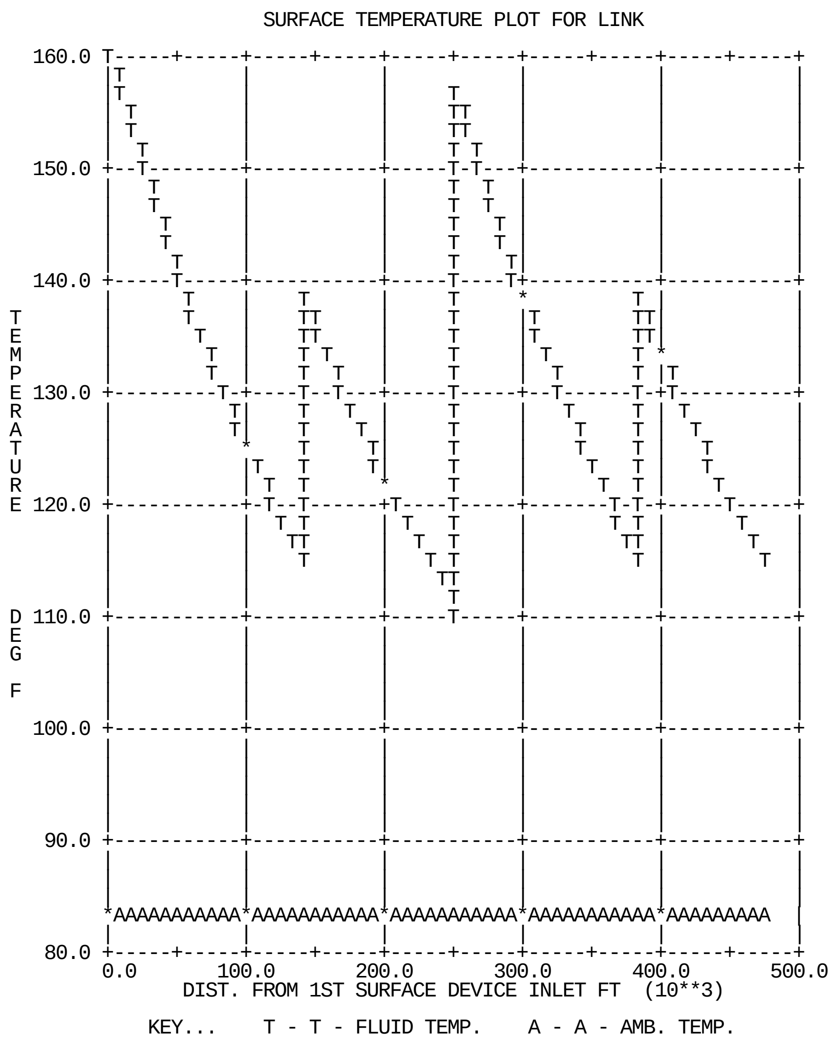
The following pressure detail report for Case 1 (run separately) shows that operating pressures are below 640 psig

```
                  LINK "LINK" DEVICE DETAIL REPORT

 PRESSURE AND TEMPERATURE REPORT
 -------------------------------
 DEVICE              MWD OR      TVD
 NAME                LENGTH   I  OR
 AND    SEGM INSIDE   FROM    &  ELEV    CALC    CALC   OVERALL AMB
 TYPE   NO   DIAM.   INLET    O  CHNG    PRESS   TEMP   U-FACT  TEMP
             (IN)     (FT)       (FT)    (PSIG)  (F)    (BTUFT- (F)
                                                        F)
 ------ ---- ------ --------- - -------- ------- ------ ------- ------
  P1    0000 30.000       0.0 I      0.0   640.0  160.0           84.0
 (PIPE) 0001          32808.0        0.0   624.6  146.0   1.000   84.0
        0002          65616.0        0.0   604.8  134.4   1.000   84.0
        0003          98424.0        0.0   579.6  124.9   1.000   84.0
        0004         131232.0        0.0   557.9  117.1   1.000   84.0
        0005         141076.0 O      0.0   548.0  115.0   1.000   84.0
  H1    0000              0.0 I      0.0   548.0  115.0 DUTY     MM BTU/HR
 (XCH1)                                                  AVAILABLE       28.
                          0.0 O      0.0   548.0  138.2 REQUIRED         28.
  P2    0000 30.000       0.0 I      0.0   548.0  138.2           84.0
 (PIPE) 0001          32808.0        0.0   524.8  128.0   1.000   84.0
        0002          65616.0        0.0   507.8  119.6   1.000   84.0
        0003          98424.0        0.0   475.3  112.8   1.000   84.0
        0004         111548.0 O      0.0   455.9  110.4   1.000   84.0
  PUM1  0000              0.0 I      0.0   455.9  110.4 AVG.POWER/STAGE HP
 (PUMP)                                                 AVAILABLE       300.0
                          0.0 O      0.0   520.8  110.6 REQUIRED        300.0
  H2    0000              0.0 I      0.0   520.8  110.6 DUTY     MM BTU/HR
 (XCH1)                                                  AVAILABLE       56.
                          0.0 O      0.0   520.8  157.3 REQUIRED         56.
  P3    0000 30.000       0.0 I      0.0   520.8  157.3           84.0
 (PIPE) 0001          32808.0        0.0   504.7  143.8   1.000   84.0
        0002          65616.0        0.0   484.0  132.6   1.000   84.0
        0003          98424.0        0.0   457.6  123.4   1.000   84.0
        0004         131232.0        0.0   433.3  115.8   1.000   84.0
        0005         134514.0 O      0.0   429.8  115.2   1.000   84.0
  H3    0000              0.0 I      0.0   429.8  115.2 DUTY     MM BTU/HR
 (XCH1)                                                  AVAILABLE       28.
                          0.0 O      0.0   429.8  138.4 REQUIRED         28.
  P4    0000 30.000       0.0 I      0.0   429.8  138.4           84.0
 (PIPE) 0001          32808.0        0.0   406.6  128.1   1.000   84.0
        0002          65616.0        0.0   389.8  119.7   1.000   84.0
        0003          90223.3 O      0.0   367.2  114.5   1.000   84.0
```

## Partial Output (continued)

The temperature profile below shows the heater locations and the temperature distribution for the pipeline.



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# Offshore Gas Condensate Gathering Network

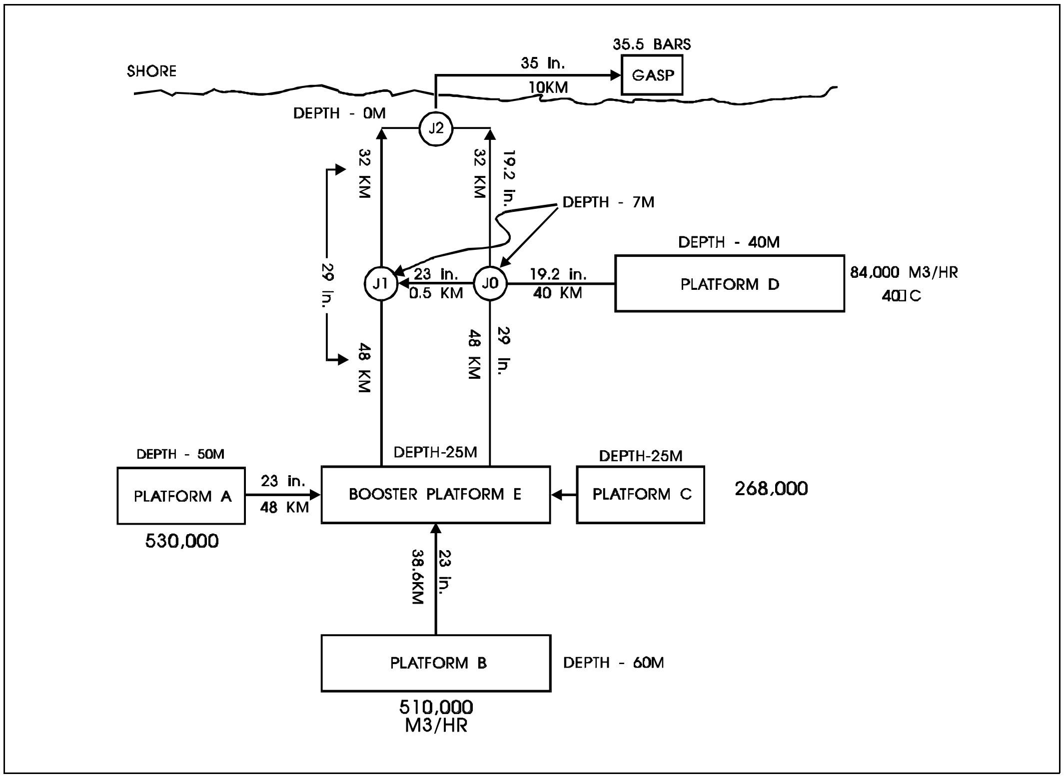
## Problem Description

A multiphase offshore gathering network collects gas condensate to be processed at an onshore facility as shown in Figure P5.1. There are four gas gathering platforms (A,B,C, and D) and one booster platform (E). A 5,000 horsepower compressor is installed on the booster platform. Gas from platforms A,B, and C pass through platform E. Two parallel pipelines connect this booster platform to the onshore facility. Gas condensate from platform D flows directly to the two parallel offshore lines, 32 kilometers from the shore. All gathering platform gas condensate rates are known and described in Table P5.1.

You are required to:

1. Determine the operating pressure required at each platform, assuming the onshore gas processing pressure is 35.5 bars.
2. Determine the liquid holdup in each segment.

**Figure P5.1: Offshore Gas Condensate Gathering Network**



| Table P5.1: Process Information | | |
|---|---|---|
| **Production Rate** | | |
| **Platform Name** | **Gas Rate $10^3$ $M^3$/HR** | **CGR $M^3$/MMSCM** |
| A | 530 | 16.8 |
| B | 510 | 11.2 |
| C | 268 | 0.0 |
| D | 84 | 33.7 |
| **Fluid Properties** | | |
| For Platform A, B, C: | | |
| Gas Specific Gravity | | 0.60 |
| Condensate Specific Gravity | | 0.85 |
| For Platform D: | | |
| Gas Specific Gravity | | 0.80 |
| Condensate Specific Gravity | | 0.75 |
| **Compressor Data** | | |
| Location | Platform "E" | |
| # of Stages | 1 | |
| Power | 5,000 HP | |
| Efficiency | 80% | |
| **Heat Transfer Data** | | |
| Water Temperature | 20°C | |
| Onshore Temperature | 30°C | |
| Overall U-Factor | 2.50 Kcal/hr-$m^2$-°C | |

## PIPEPHASE Features Used In This Problem

- Non-compositional gas condensate PVT method is used for this network analysis. If compositions are known for the sources, compositional PVT should be used for a more accurate simulation.
- A compressor with fixed power is input in the network.
- The Dukler-Eaton-Flannigan pressure drop and holdup correlations are best suited for the low condensate gas system.
- The Taitel-Dukler-Barnea flow pattern predictor is used to evaluate the flow patterns for diagnostic purposes. Note that the Dukler-Eaton-Flannigan correlation does not predict flow patterns.

## Results and Discussions

1. Gathering platform operating pressures obtained from the simulation results are listed below in Table P5.2.

**Table P5.2: Platform Operating Pressures**

| Platform | Operating pressure(bars) |
|---|---|
| A | 79.38 |
| B | 74.44 |
| C | 61.28 |
| D | 59.86 |
| E | 61.28 |

2. Liquid holdup for each segment are summarized in Table P5.3 below.

**Table P5.3: Segment Liquid Holdup**

| Segment | | | Length | Liquid holdup |
|---|---|---|---|---|
| from | | to | (km) | ($m^3$) |
| A | | E | 48.0 | 204.0 |
| B | | E | 38.6 | 152.25 |
| D | | J0 | 40.0 | 146.45 |
| E | ---J1-- | J2 | 80.0* | 485.63 |
| E | ---J0-- | J2 | 80.0* | 375.98 |
| J2 | | GASP | 10.0 | 72.3 |

*Parallel offshore lines connect booster platform to onshore facility.

P5 Offshore Gas Condensate Gathering Network

## Simulation Highlights

INPUT

- In order to obtain the pressure and liquid holdup detail report for a network run, PRINT DEVICE=PART is specified.
- Two different sets of PVT are used. The program automatically takes care of the mixing where the different fluids meet.
- A dummy node (EE), is added for the booster platform at the compressor outlet. Node E is located where nodes A,B, and C come together and the compressor is placed downstream of node E where fluid from A,B, and C are combined.
- Junction nodes J0, J1, and J2 are necessary when the links meet or a link splits. In the network setup, each junction should have at least one link flowing in and one link flowing out of it.
- Onshore temperature is different than the water temperature. The ambient water temperature is entered on the DEFAULT statement for all pipe sections. The ambient air temperature onshore is input on the pipe section in LINK 11.
- A hydraulic calculation for the segment from C to E was not performed. A regulator is used to introduce the fluid from platform C. A high pressure is given so that the pressure in the downstream link will be used in the simulation.

TECHNIQUE

- Network connectivity is based on the link FROM and TO nodes. Link input order is not important. However, it is recommended that links be input according to flow direction. Flow devices and equipment inside of each link must be entered in the flow direction. For further details on setting up networks, consult the *PIPEPHASE Input Manual*.
- The pressure drop of downcomers and risers are not to be considered, so their hydraulic calculations are not specified.

## Input Data

The keyword input data file for this simulation is given below.

### Keyword Input Data File

```
TITLE   PROBLEM=PIPE5, PROJECT=PIPEAPP, USER=SIMSCI
DESC    OFFSHORE GAS CONDENSATE GATHERING SYSTEM
DIME    METRIC, RATE(GV)=CMHR, LENGTH=M, IN
CALC    NETWORK, CONDENSATE
FCODE   PIPE=DE
DEFAULT TAMB=20, UPIPE=2.5
SEGMENT DLHOR=2000
PRINT   DEVICE=PART, INPUT=FULL, CONNECT=NONE
$
PVT DATA
        SET SETNO=1, GRAV(COND)=0.85, GRAV(GAS)=0.60, GRAV(WATER)=1.0
        SET SETNO=2, GRAV(COND)=0.75, GRAV(GAS)=0.80, GRAV(WATER)=1.0
$
STRUCTURE DATA
        SOURCE NAME=A, SETNO=1, TEMP=40, PRES(ESTI)=80, *
               RATE=0.530, CGR=16.8
        SOURCE NAME=B, SETNO=1, TEMP=40, PRES(ESTI)=80, *
               RATE=0.51, CGR=11.2
        SOURCE NAME=C, SETNO=1, TEMP=40, PRES(ESTI)=65, *
               RATE=0.268, CGR=0
        SOURCE NAME=D, SETNO=2, TEMP=40, PRES(ESTI)=80, *
               RATE=0.084, CGR=33.7
$
        JUNC NAME=E,  PRES(ESTI)=55
        JUNC NAME=EE, PRES(ESTI)=75
        JUNC NAME=JO, PRES(ESTI)=60
        JUNC NAME=J1, PRES(ESTI)=60.5
        JUNC NAME=J2, PRES(ESTI)=50
$
        LINK NAME=1, FROM=A, TO=E
             PIPE    LENGTH(KM)=48, ID=23, ECHG=25
        LINK NAME=2, FROM=B, TO=E
             PIPE    LENGTH(KM)=38.6, ID=23, ECHG=35
        LINK NAME=3, FROM=C, TO=E
             REGULAT PRES=9999
        LINK NAME=7, FROM=D, TO=JO
             PIPE    LENGTH(KM)=40, ID=19.2, ECHG=33
        LINK NAME=4, FROM=E, TO=EE
             COMPRES POWER(HP)=5000, EFF=80
        LINK NAME=5, FROM=EE, TO=JO
             PIPE    LENGTH(KM)=48, ID=29, ECHG=18
        LINK NAME=6, FROM=EE, TO=J1
             PIPE    LENGTH(KM)=48, ID=29, ECHG=18
        LINK NAME=8, FROM=JO, TO=J1
             PIPE    LENGTH(KM)=0.5, ID=23, ECHG=0
        LINK NAME=9, FROM=JO, TO=J2
             PIPE    LENGTH(KM)=32, ID=19.2, ECHG=7
        LINK NAME=10, FROM=J1, TO=J2
             PIPE    LENGTH(KM)=32, ID=29, ECHG=7
        LINK NAME=11, FROM=J2, TO=GASP
             PIPE    LENGTH(KM)=10, ID=35, ECHG=0, TAMB=30
$
        SINK NAME=GASP, PRES=35.5, RATE(ESTI)=1.4
```

## Output

- Network link and node reports summarize each node pressure, flowrate, and temperature, as well as total pressure drop for each link. These are used to describe the network operating conditions in a condensed format.
- The Taitel-Dukler-Barnea method predicts that all pipe segments are in stratified flow.
- The device summary shows the effect of fluid mixing on junction temperatures. This explains why the temperature of the fluid just before mixing is different from the outflow junction temperature (after mixing).

## Partial Output

The following node and link reports summarize the node operating conditions.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | | ----ACTUAL FLOW RATES***-- GAS (MMCMHR) | OIL (CMHR) | WATER (CMHR) | PRESS: (BAR) | PRESS: DROP (BAR) | TEMP: (C) | ----HOLDUP**--- GAS (MM SCM) | LIQ (SCM) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | (F) | 0.006715 | 8406.600 | 0.000 | 79.38 | | 40.0 | | |
| | E | (T) | 0.008802 | 7939.999 | 0.000 | 61.28 | 18.10 | 38.4 | 0.88592 | 204.18 |
| 10 | J1 | (F) | 0.017326 | 15.392 | 0.000 | 57.41 | | 24.4 | | |
| | J2 | (T) | 0.025215 | 12.416 | 0.000 | 40.08 | 17.33 | 22.0 | 0.68690 | 179.07 |
| 11 | J2 | (F) | 0.033755 | 17.224 | 0.000 | 40.08 | | 21.8 | | |
| | GASP | (T) | 0.038635 | 15.577 | 0.000 | 35.50* | 4.58 | 23.4 | 0.23721 | 72.36 |
| 2 | B | (F) | 0.006924 | 5330.865 | 0.000 | 74.44 | | 40.0 | | |
| | E | (T) | 0.008458 | 5112.665 | 0.000 | 61.28 | 13.16 | 38.1 | 0.68498 | 152.39 |
| 3 | C | (F) | 0.004481 | 0.000 | 0.000 | 61.28 | | 40.0 | | |
| | E | (T) | 0.004481 | 0.000 | 0.000 | 61.28 | 1.69E-3 | 40.0 | 0.00000 | 0.00 |
| 4 | E | (F) | 0.021712 | 16.092 | 0.000 | 61.28 | | 38.3 | | |
| | EE | (T) | 0.020004 | 16.460 | 0.000 | 66.37 | -5.09 | 39.0 | 0.00000 | 0.00 |
| 5 | EE | (F) | 0.009969 | 8.203 | 0.000 | 66.37 | | 39.0 | | |
| | JO | (T) | 0.010812 | 9.019 | 0.000 | 57.53 | 8.84 | 23.0 | 1.28304 | 307.40 |
| 6 | EE | (F) | 0.010036 | 8.258 | 0.000 | 66.37 | | 39.0 | | |
| | J1 | (T) | 0.010911 | 9.067 | 0.000 | 57.41 | 8.96 | 23.0 | 1.28154 | 306.99 |
| 7 | D | (F) | 0.001353 | 2783.094 | 0.000 | 59.86 | | 40.0 | | |
| | JO | (T) | 0.001392 | 2830.865 | 0.000 | 57.53 | 2.34 | 36.8 | 0.44889 | 146.58 |
| 8 | JO | (F) | 0.006392 | 6.321 | 0.000 | 57.53 | | 26.4 | | |
| | J1 | (T) | 0.006402 | 6.323 | 0.000 | 57.41 | 0.12 | 26.2 | 0.00789 | 2.06 |
| 9 | JO | (F) | 0.005916 | 5.849 | 0.000 | 57.53 | | 26.4 | | |
| | J2 | (T) | 0.008542 | 4.808 | 0.000 | 40.08 | 17.45 | 21.5 | 0.30172 | 83.50 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

NODE SUMMARY

| NODE | PRES. (BAR) | ---STANDARD FLOW RATES ---** GAS (MMCMHR) | OIL (CMHR) | WATER (CMHR) | TEMP. (C) |
|---|---|---|---|---|---|
| A | 79.38 | 0.530000* | 8.904 | 0.000 | 40.0 |
| J1 | 57.41 | 0.000000* | 0.000 | 0.000 | 24.4 |
| J2 | 40.08 | 0.000000* | 0.000 | 0.000 | 21.8 |
| B | 74.44 | 0.510000* | 5.712 | 0.000 | 40.0 |
| C | 61.28 | 0.268000* | 0.000 | 0.000 | 40.0 |
| E | 61.28 | 0.000000* | 0.000 | 0.000 | 38.3 |
| EE | 66.37 | 0.000000* | 0.000 | 0.000 | 39.0 |
| D | 59.86 | 0.084000* | 2.831 | 0.000 | 40.0 |
| JO | 57.53 | 0.000000* | 0.000 | 0.000 | 26.4 |
| GASP | 35.50* | -1.392E0 | -17.447 | 0.000 | 23.4 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

## Partial Output (continued)

Note that temperatures prior to mixing (link outlet temperatures) are different from junction temperature that reflects temperatures after mixing.

```
                                DEVICE SUMMARY

                 C
                 O                                 ------- OUTLET ------ AVG.
LINK DEVI DEVI   R   INSIDE   MEAS      ELEV                       INSITU  LIQ
NAME NAME TYPE   R   DIAM     LENGTH    CHNG       PRESS:  TEMP:   LGR    HOLDUP
                     (IN)     (M)       (M)       (BAR)   (C)     (M3MMM-
                                                                   3)
---- ---- ---- ---- -------- --------- ------- ------- ------ ------- ------
1      ***SOURCE*** RATE= 0.53000 (MMCMHR)        79.38   40.0 CGR =    16.8
     A                                            79.38   40.0
     P001 PIPE ED     23.000  47999.88   25.00   61.28   38.4 2.888E5   0.02
         **JUNCTION**  PRES=   61.28 (BAR)   TEMP=   38.3 (C)

10    **JUNCTION**  RATE= 1.03834 (MMCMHR)        57.41   24.4 CGR =    12.1
     J1                                           57.41   24.4
     P010 PIPE ED     29.000  32000.02    7.00   40.08   22.0 1.263E5   0.01
         **JUNCTION**  PRES=   40.08 (BAR)   TEMP=   21.8 (C)

11    **JUNCTION**  RATE= 1.39200 (MMCMHR)        40.08   21.8 CGR =    12.5
     J2                                           40.08   21.8
     P011 PIPE ED     35.000  10000.00    0.00   35.43   23.4 1.031E5   0.01
          *** SINK *** PRES=   35.50 (BAR)   TEMP=   23.4 (C)

2      ***SOURCE*** RATE= 0.51000 (MMCMHR)        74.44   40.0 CGR =    11.2
     B                                            74.44   40.0
     P002 PIPE ED     23.000  38600.16   35.00   61.21   38.1 1.914E5   0.01
         **JUNCTION**  PRES=   61.28 (BAR)   TEMP=   38.3 (C)

3      ***SOURCE*** RATE= 0.26800 (MMCMHR)        61.28   40.0 CGR =     0.0
     C                                            61.28   40.0
     R003 DREG DN      0.000      0.00    0.00   61.28   40.0     0.0   0.00
         **JUNCTION**  PRES=   61.28 (BAR)   TEMP=   38.3 (C)

4     **JUNCTION**  RATE= 1.30800 (MMCMHR)        61.28   38.3 CGR =    11.2
     E                                            61.28   38.3
     C005 COMP XX      0.000      0.00    0.00   66.37   39.0     0.0   0.00
         **JUNCTION**  PRES=   66.37 (BAR)   TEMP=   39.0 (C)

5     **JUNCTION**  RATE= 0.65182 (MMCMHR)        66.37   39.0 CGR =    11.2
     EE                                           66.37   39.0
     P006 PIPE ED     29.000  47999.88   18.00   57.53   23.0 2.150E5   0.02
         **JUNCTION**  PRES=   57.53 (BAR)   TEMP=   26.4 (C)

6     **JUNCTION**  RATE= 0.65618 (MMCMHR)        66.37   39.0 CGR =    11.2
     EE                                           66.37   39.0
     P007 PIPE ED     29.000  47999.88   18.00   57.41   23.0 2.142E5   0.01
         **JUNCTION**  PRES=   57.41 (BAR)   TEMP=   24.4 (C)

7      ***SOURCE*** RATE= 0.08400 (MMCMHR)        59.86   40.0 CGR =    33.7
     D                                            59.86   40.0
     P004 PIPE ED     19.200  39999.80   33.00   57.45   36.8 5.671E5   0.02
         **JUNCTION**  PRES=   57.53 (BAR)   TEMP=   26.4 (C)
8     **JUNCTION**  RATE= 0.38215 (MMCMHR)        57.53   26.4 CGR =    13.7
     JO                                           57.53   26.4
     P008 PIPE ED     23.000    500.00    0.00   57.41   26.2 2.535E5   0.02
         **JUNCTION**  PRES=   57.41 (BAR)   TEMP=   24.4 (C)

9     **JUNCTION**  RATE= 0.35366 (MMCMHR)        57.53   26.4 CGR =    13.7
     JO                                           57.53   26.4
     P009 PIPE ED     19.200  32000.02    7.00   40.04   21.5 1.442E5   0.01
         **JUNCTION**  PRES=   40.08 (BAR)   TEMP=   21.8 (C)
```

## Partial Output (continued)

Total liquid holdup for each link is reported on the pressure detail report. The following selected link (from Platform A to booster Platform E) pressure and holdup reports show that the total liquid holdup is 204.0 cubic meters for this link.

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (M) | I & O | TVD OR ELEV CHNG (M) | CALC PRESS (BAR) | CALC TEMP (C) | OVERALL U-FACT (KCMC) | AMB TEMP (C) |
|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 23.000 | 0.00 | I | 0.00 | 79.38 | 40.0 | | 20.0 |
| (PIPE) | 0001 | | 2399.99 | | 1.25 | 78.56 | 39.9 | 2.50 | 20.0 |
| | 0002 | | 4799.99 | | 1.25 | 77.73 | 39.8 | 2.50 | 20.0 |
| | 0003 | | 7199.98 | | 1.25 | 76.89 | 39.8 | 2.50 | 20.0 |
| | 0004 | | 9599.98 | | 1.25 | 76.05 | 39.7 | 2.50 | 20.0 |
| | 0005 | | 11999.97 | | 1.25 | 75.20 | 39.6 | 2.50 | 20.0 |
| | 0006 | | 14399.96 | | 1.25 | 74.34 | 39.5 | 2.50 | 20.0 |
| | 0007 | | 16799.96 | | 1.25 | 73.47 | 39.4 | 2.50 | 20.0 |
| | 0008 | | 19199.95 | | 1.25 | 72.59 | 39.4 | 2.50 | 20.0 |
| | 0009 | | 21599.95 | | 1.25 | 71.71 | 39.3 | 2.50 | 20.0 |
| | 0010 | | 23999.94 | | 1.25 | 70.81 | 39.2 | 2.50 | 20.0 |
| | 0011 | | 26399.93 | | 1.25 | 69.91 | 39.1 | 2.50 | 20.0 |
| | 0012 | | 28799.93 | | 1.25 | 68.99 | 39.0 | 2.50 | 20.0 |
| | 0013 | | 31199.92 | | 1.25 | 68.07 | 39.0 | 2.50 | 20.0 |
| | 0014 | | 33599.92 | | 1.25 | 67.13 | 38.9 | 2.50 | 20.0 |
| | 0015 | | 35999.91 | | 1.25 | 66.19 | 38.8 | 2.50 | 20.0 |
| | 0016 | | 38399.91 | | 1.25 | 65.23 | 38.7 | 2.50 | 20.0 |
| | 0017 | | 40799.90 | | 1.25 | 64.26 | 38.6 | 2.50 | 20.0 |
| | 0018 | | 43199.89 | | 1.25 | 63.28 | 38.6 | 2.50 | 20.0 |
| | 0019 | | 45599.89 | | 1.25 | 62.29 | 38.5 | 2.50 | 20.0 |
| | 0020 | | 47999.88 | O | 1.25 | 61.28 | 38.4 | 2.50 | 20.0 |

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ACM) | LIQ VEL (MPS) | ACTUAL GAS VEL (MPS) | MIX . VEL (MPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (MPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 2.E-3 | 0.02 | 10.58 | 0.65 | 7.11 | 7.01 | ---- | STRT | 367.89 |
| | 0002 | 2.E-3 | 0.02 | 21.13 | 0.65 | 7.19 | 7.08 | ---- | STRT | 367.36 |
| | 0003 | 1.E-3 | 0.02 | 31.65 | 0.66 | 7.27 | 7.16 | ---- | STRT | 366.82 |
| | 0004 | 1.E-3 | 0.02 | 42.13 | 0.66 | 7.35 | 7.25 | ---- | STRT | 366.28 |
| | 0005 | 1.E-3 | 0.02 | 52.57 | 0.66 | 7.44 | 7.33 | ---- | STRT | 365.71 |
| | 0006 | 1.E-3 | 0.02 | 62.97 | 0.66 | 7.53 | 7.42 | ---- | STRT | 365.14 |
| | 0007 | 1.E-3 | 0.02 | 73.34 | 0.66 | 7.62 | 7.51 | ---- | STRT | 364.55 |
| | 0008 | 1.E-3 | 0.02 | 83.67 | 0.66 | 7.72 | 7.60 | ---- | STRT | 363.95 |
| | 0009 | 1.E-3 | 0.02 | 93.96 | 0.66 | 7.81 | 7.70 | ---- | STRT | 363.33 |
| | 0010 | 1.E-3 | 0.02 | 104.20 | 0.67 | 7.92 | 7.80 | ---- | STRT | 362.70 |
| | 0011 | 1.E-3 | 0.02 | 114.40 | 0.67 | 8.02 | 7.91 | ---- | STRT | 362.05 |
| | 0012 | 1.E-3 | 0.02 | 124.56 | 0.67 | 8.13 | 8.01 | ---- | STRT | 361.40 |
| | 0013 | 1.E-3 | 0.02 | 134.67 | 0.67 | 8.25 | 8.13 | ---- | STRT | 360.72 |
| | 0014 | 1.E-3 | 0.02 | 144.73 | 0.67 | 8.36 | 8.24 | ---- | STRT | 360.03 |
| | 0015 | 1.E-3 | 0.02 | 154.74 | 0.67 | 8.49 | 8.37 | ---- | STRT | 359.32 |
| | 0016 | 1.E-3 | 0.02 | 164.70 | 0.67 | 8.61 | 8.49 | ---- | STRT | 358.60 |
| | 0017 | 1.E-3 | 0.02 | 174.61 | 0.67 | 8.75 | 8.62 | ---- | STRT | 357.86 |
| | 0018 | 1.E-3 | 0.02 | 184.46 | 0.67 | 8.89 | 8.76 | ---- | STRT | 357.10 |
| | 0019 | 1.E-3 | 0.02 | 194.26 | 0.67 | 9.03 | 8.90 | ---- | STRT | 356.32 |
| | 0020 | 1.E-3 | 0.02 | **204.00** | 0.67 | 9.18 | 9.05 | ---- | STRT | 355.53 |

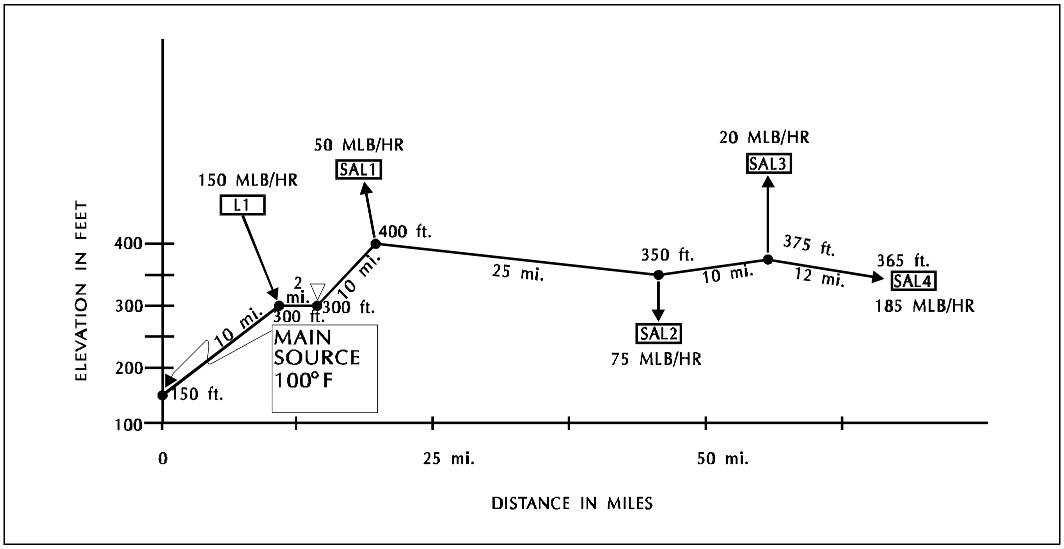
# Gas Gathering Distribution System

## Problem Description

Natural gas is collected from two different fields ten miles apart and sold to four customers along a main pipeline. There is a booster compressor which provides 1100 psig outlet pressure to meet the minimum delivery pressure of 650 psig imposed by all the customers. Based on the data provided in Figure P6.1and Table P6.1, determine the following:

1. Compressor power requirement.
2. Delivery pressures at each sales point.

**Figure P6.1: Gas Gathering Distribution System**




P6 Gas Gathering Distribution System

**Table P6.1: ProcessInformation**

| **Fluid Compositions** | | |
|---|---|---|
| **Components** | **Main Source** | **L1** |
| C1 | 0.664 | 0.700 |
| C2 | 0.186 | 0.176 |
| C3 | 0.091 | 0.078 |
| IC4 | 0.028 | 0.022 |
| NC4 | 0.020 | 0.019 |
| IC5 | 0.007 | 0.002 |
| NC5 | 0.003 | 0.002 |
| NC6 | 0.001 | 0.001 |

| **Compressor Data** | |
|---|---|
| Outlet Pressure | 1,100 psig |
| Adiabatic Efficiency | 75% |
| **Heat Transfer Data** | |
| Ambient Temperature | 80°F |
| Overall U-Factor | 1 Btu/hr-ft$^2$-F |
| **Pipeline Data** | |
| Inside Diameter | 14.75 inch |
| Roughness | 0.0018 inch |

P6 Gas Gathering Distribution System

## PIPEPHASE Features Used In This Problem

- Lateral source and lateral sales devices are used to simplify the network since the hydraulics for lateral sources or sinks are not to be considered here.
- Compositional modeling is used for a more accurate PVT prediction.
- Rigorous heat transfer is specified for more accurate heat balance and physical property calculations.
- Compositional compressor calculations with outlet pressure specifications are used.

## Results and Discussions

1. Compressor power required is 827 horsepower.

2. Sales point pressures:

   Sales #1- 1037 psig

   Sales #2- 862 psig

   Sales #3- 812 psig

   Sales #4- 761 psig

## Simulation Highlights

INPUT

- The main source must appear as the first source on the input. Lateral source temperature and pressure are not given and will be set at the same values as the injection mainline conditions. If the temperature and pressure are given for the lateral source, the program does not check if the injection pressure is higher than the mainline pressure. This data is used for enthalpy balance calculations only.
- The pipe heat transfer coefficient of 1.0 Btu/hr-$ft^2$-F and pipe roughness of 0.0018 inches are the same as the program default values and are not entered in the input.

TECHNIQUE

- Lateral source and sales options are used for this problem. Lateral source and sales options cannot be used for non-compositional fluids. For non-compositional fluid cases, the network model must be used.
- A one mile calculation segment is used for each pipeline section. In general, more segments improve the accuracy. However, this also increases the run time.

## Input Data

The keyword input data file for this simulation is given below.

### Keyword Input Data File

```
TITLE   PROBLEM=PIPE6, PROJECT=PIPEAPP, USER=SIMSCI
DESC    LATERAL SOURCE AND SALES STUDY OF WET GAS LINE
DIME    PETROLEUM, RATE(W)=MLBHR
CALC    SINGLE, COMPOSITIONAL
DEFAULT IDPIPE=14.75
PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
FCODE   PIPE=DE
SEGMENT DLHOR(MI)=1, MAXS=50
$
COMPONENT DATA
        LIBID   C1/C2/C3/IC4/NC4/IC5/NC5/NC6
$
METHOD DATA
        THERMOD SYSTEM=SRK
$
STRUCTURE DATA
        SOURCE  NAME=MAIN, TEMP=100, PRES=1010, RATE(W)=180, *
                COMP=0.664/0.186/0.091/0.028/0.02/0.007/0.003/0.001
        SOURCE  NAME=L1, RATE(W)=150, *
                COMP=0.70/0.176/0.078/0.022/0.019/0.002/0.002/0.001
$
        LINK    NAME=L1, FROM=MAIN, TO=SNK
                PIPE    LENGTH(MI)=10, ECHG=150
                INJECT  FROM=L1
                PIPE    LENGTH(MI)=2
                COMPRES PRES=1100, EFF=75
                PIPE    LENGTH(MI)=10, ECHG=100
                SALES   NAME=SAL1, RATE(W)=50
                PIPE    LENGTH(MI)=25, ECHG=-50
                SALES   NAME=SAL2, RATE(W)=75
                PIPE    LENGTH(MI)=10, ECHG=25
                SALES   NAME=SAL3, RATE(W)=20
                PIPE    LENGTH(MI)=12, ECHG=-10
$
        SINK    NAME=SNK, PRES(ESTI)=500, RATE(ESTI)=185
END
```

## Output

- The mainline flowrate in and out of the injection or sales points are reported in the pressure detail printout shown on the following pages.
- The device detail report shows the calculated power for the compressor is 827 horsepower for an outlet pressure of 1100 psig.
- The sales fluid composition is shown on a flash report. This is the weighted combination of the two sources.

## Partial Output

Selected parts of the device detail output shows the temperature, pressure, and quality. The flowrates for sales and injection devices are also given.

```
                 LINK "L1  " DEVICE DETAIL REPORT

 PRESSURE AND TEMPERATURE REPORT
 -------------------------------
 DEVICE              MWD OR        TVD
 NAME                LENGTH    I   OR
 AND    SEGM INSIDE   FROM     &   ELEV     CALC    CALC   OVERALL AMB
 TYPE   NO   DIAM.   INLET     O   CHNG     PRESS   TEMP   U-FACT  TEMP    QUAL
             (IN)     (FT)         (FT)     (PSIG)  (F)    (BTUFT- (F)     (FRAC)
                                                           F)
 ------ ---- ------ --------- - -------- ------- ------ ------- ------ -------
  P001  0000 14.750       0.0 I      0.0  1010.0  100.0           80.0    1.00
 (PIPE) 0001           5000.0       14.2  1007.7   97.1   1.000   80.0    1.00
        0002          10280.0       15.0  1005.2   94.6   1.000   80.0    1.00
        0003          15560.0       15.0  1002.8   92.5   1.000   80.0    1.00
        0004          20840.0       15.0   999.4   91.1   1.000   80.0    0.99
        0005          26120.0       15.0   995.7   89.8   1.000   80.0    0.99
        0006          31400.0       15.0   991.8   88.6   1.000   80.0    0.98
        0007          36680.0       15.0   987.9   87.6   1.000   80.0    0.97
        0008          41960.0       15.0   983.9   86.6   1.000   80.0    0.97
        0009          47240.0       15.0   979.9   85.8   1.000   80.0    0.96
        0010          52520.0       15.0   975.9   85.0   1.000   80.0    0.95
        0011          52800.0 O      0.8   975.7   85.0   1.000   80.0    0.95
  I002  0000              0.0 I      0.0   975.7   85.0 RATE IN 180.000 M LB/HR
 (INJ )                                       INJ.  PRESSURE     975.7 PSIG
                                          INJ.  TEMPERATURE      85.0 DEG F
                                                       RATE OUT 330.000 M LB/HR
                          0.0 O      0.0   975.7   85.0
  P003  0000 14.750       0.0 I      0.0   975.7   85.0           80.0    1.00
 (PIPE) 0001           5000.0        0.0   961.2   83.9   1.000   80.0    1.00
        0002          10280.0        0.0   952.2   83.2   1.000   80.0    0.99
        0003          10560.0 O      0.0   951.7   83.2   1.000   80.0    0.99
  C004  0000              0.0 I      0.0   951.7   83.2 AVG.POWER/STAGE HP
 (COMP)                                                    AVAILABLE          0.0
                          0.0 O      0.0  1100.0  101.9 REQUIRED            826.8
  P005  0000 14.750       0.0 I      0.0  1100.0  101.9           80.0    0.99
 (PIPE) 0001           5000.0        9.5  1094.0   99.9   1.000   80.0    1.00
        0002          10280.0       10.0  1087.7   97.9   1.000   80.0    1.00
        0003          15560.0       10.0  1081.4   96.1   1.000   80.0    1.00
        0004          20840.0       10.0  1075.1   94.4   1.000   80.0    1.00
        0005          26120.0       10.0  1068.9   92.8   1.000   80.0    1.00
        0006          31400.0       10.0  1062.6   91.4   1.000   80.0    1.00
        0007          36680.0       10.0  1056.3   90.1   1.000   80.0    1.00
        0008          41960.0       10.0  1050.0   88.8   1.000   80.0    1.00
        0009          47240.0       10.0  1043.7   87.7   1.000   80.0    1.00
        0010          52520.0       10.0  1037.3   86.6   1.000   80.0    1.00
        0011          52800.0 O      0.5  1037.0   86.6   1.000   80.0    1.00
  SAL1  0000              0.0 I      0.0  1037.0   86.6 RATE     M LB/HR
 (SALE)                                                  IN    330.000
                                                        OUT    280.000
        0001              0.0 O      0.0  1037.0   86.6
  P007  0000 14.750       0.0 I      0.0  1037.0   86.6           80.0    1.00
 (PIPE) 0001           5000.0       -1.9  1033.0   85.7   1.000   80.0    1.00
        0002          10280.0       -2.0  1028.8   84.9   1.000   80.0    1.00
        0003          15560.0       -2.0  1024.6   84.3   1.000   80.0    1.00
          :
          :
          :
        0009          47240.0        2.5   817.4   76.6   1.000   80.0    0.96
        0010          52520.0        2.5   812.3   76.6   1.000   80.0    0.96
        0011          52800.0 O      0.1   812.0   76.6   1.000   80.0    0.96
  SAL3  0000              0.0 I      0.0   812.0   76.6 RATE     M LB/HR
 (SALE)                                                  IN    205.000
                                                        OUT    185.000
        0001              0.0 O      0.0   812.0   76.6
  P011  0000 14.750       0.0 I      0.0   812.0   76.6           80.0    0.96
 (PIPE) 0001           5000.0       -0.8   808.1   76.7   1.000   80.0    0.96
        0002          10280.0       -0.8   804.0   76.8   1.000   80.0    0.96
        0003          15560.0       -0.8   799.8   76.9   1.000   80.0    0.97
          :
          :
```

## Partial Output (continued)

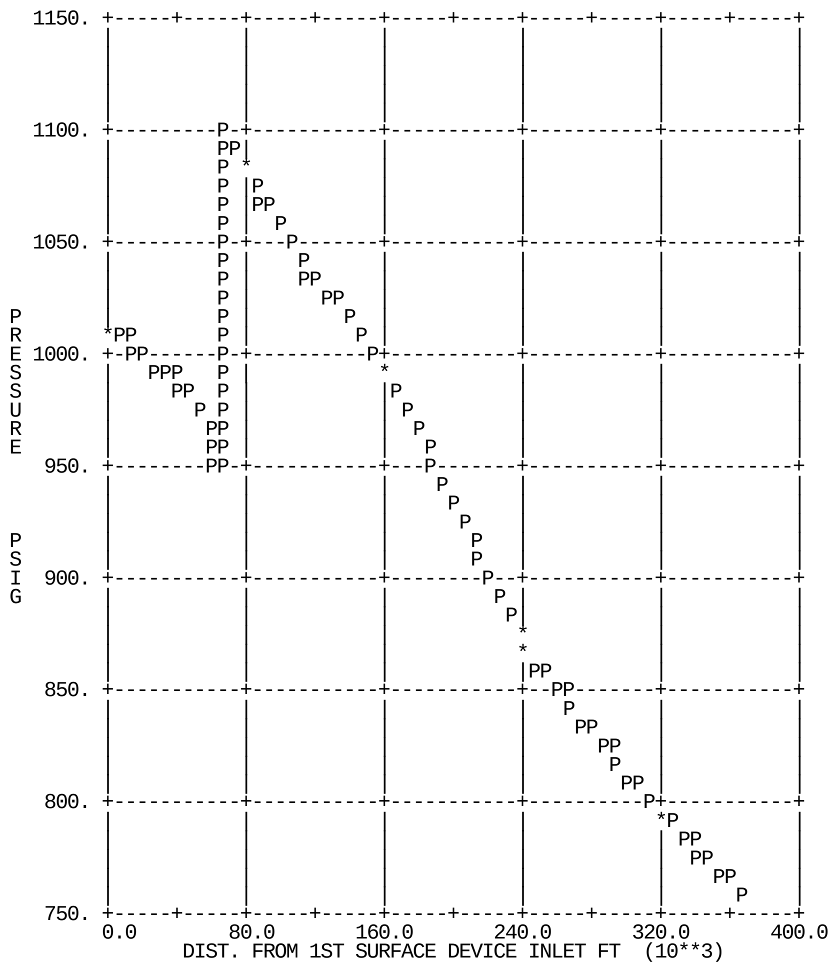
The following is a flash report generated for the sink.

```
 NODE SNK  AT     77.3 DEG F           AND     761.4 PSIG

                     --------------------MOLE FRACTION-------------------

                     ----HYDROCARBON----   COMBINED             TOTAL
COMPONENT            VAPOR      LIQUID1    VAP+LIQ1   LIQUID2   STREAM
-----------------    --------   --------   --------   --------  --------
C1                   0.687543   0.242544   0.680800   0.000000  0.680800
C2                   0.180980   0.204321   0.181333   0.000000  0.181333
C3                   0.082795   0.223890   0.084933   0.000000  0.084933
IC4                  0.023793   0.116651   0.025200   0.000000  0.025200
NC4                  0.018089   0.113402   0.019533   0.000000  0.019533
IC5                  0.004009   0.047419   0.004667   0.000000  0.004667
NC5                  0.002109   0.030089   0.002533   0.000000  0.002533
NC6                  0.000682   0.021685   0.001000   0.000000  0.001000

TOTAL RATE (INLET TO NODE IF JUNCTION)
          M LB/HR     180.104      4.896    185.000      0.000   185.000
          MOLE/HR      7.8109     0.1202     7.9311     0.0000    7.9311
WT FRAC LIQ                                0.026465             0.026465

PHASE PROPERTIES
----------------
MASS FRACTION        0.973535   0.026465   1.000000   0.000000  1.000000
VOLUME FRAC          0.996391   0.003609   1.000000   0.000000  1.000000
DENSITY LB/FT3           4.00      30.03                  0.00
SPECIFIC GRAV        0.795868   0.481570              0.000000
VISCOSITY CP           0.0124     0.0660                0.0000
ENTHALPY  BTU/LB       69.024     18.200                 0.000    67.679
SURF TENS DYNES/CM                 3.014                 0.000
MOLECULAR WT          23.0579    40.7405    23.3258     0.0000   23.3258
```

## Partial Output (continued)

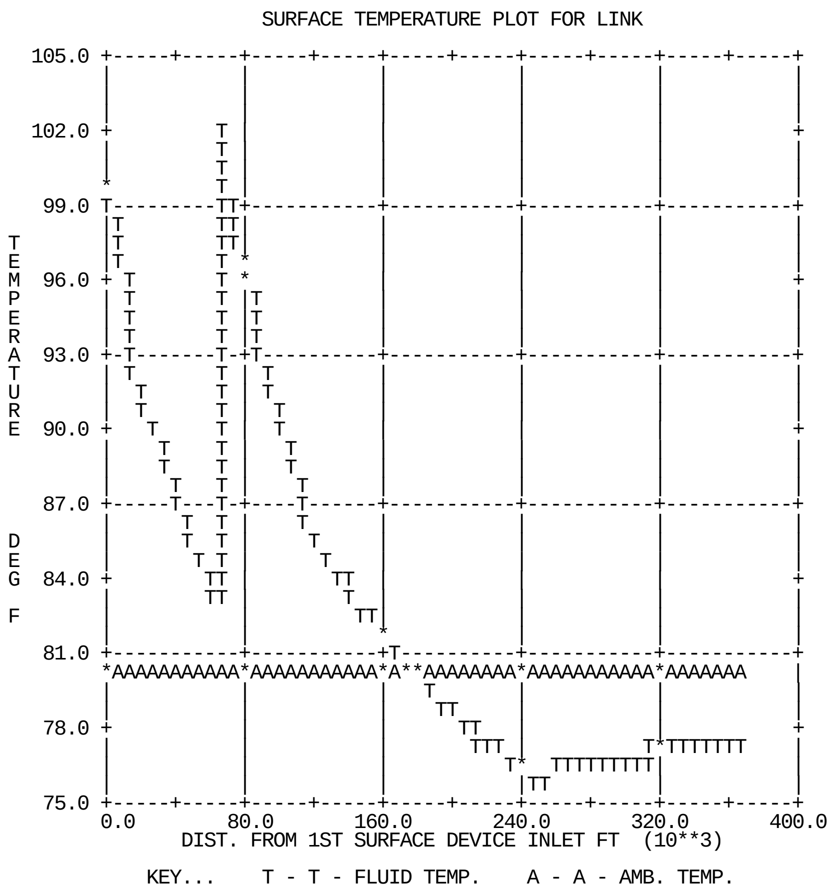
The PLOT=FULL option generates plots of pressure and temperature versus distance.

SURFACE PRESSURE PLOT FOR LINK




KEY... P - P - FLUID PRESS.

## Partial Output (continued)



# Multiphase Gas Condensate Pipeline

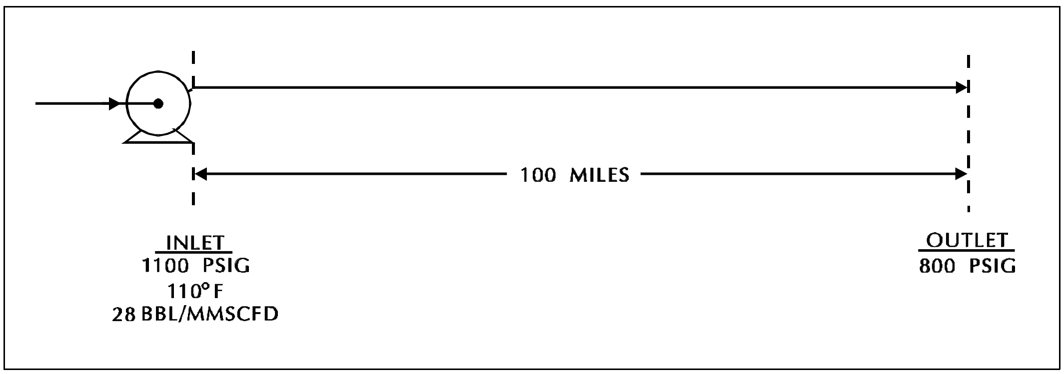
## Problem Description

A multiphase pipeline is to be installed for a new condensate field. The initial production rate is to be 100 MMscfd. The production is expected to increase linearly over the next three years to a maximum of 350 MMscfd. The sales contract requires a minimum delivery pressure of 800 psig. The pipeline inlet pressure is 1,100 psig. Refer to Figure P7.1 and Table P7.1 for process information.

You are required to:

1. Determine the hydraulically feasible combination of compressor horsepower and pipeline sizes which are able to transport 100 MMscfd to 350 MMscfd of gas condensate with a minimum delivery pressure of 800 psig.
2. Determine the production rate at which a compressor will need to be installed for the chosen pipe diameter. Also find the required compressor size.

**Figure P7.1: Multiphase Gas Condensate Pipeline**



| Table P7.1: Process Information | |
|---|---|
| **Fluid Properties** | |
| Gas Specific Gravity | 0.8 |
| Condensate Specific Gravity | 0.7 |
| Water Specific Gravity | 1.002 |
| **Heat Transfer Data** | |
| Overall U-factor | 1.0 Btu/hr-ft$^2$-F |
| Abient Temperature | 80°F |
| **CompressorData** | |
| Adiabatic Efficiency | 75% |
| Available Power | 1,000, 2,000, 4,000 HP |
| **Fixed Elevation Pipeline Data** | |
| Smooth Pipe Roughness | 0.0018 inches |
| Available Inside Diameters | 18, 22, 24, 28, 32 inches |

## PIPEPHASE Features Used In This Problem

- Sensitivity analysis is used to obtain all necessary information in one run.
- Non-compositional gas condensate analysis is used since only limited fluid properties are required for the analysis.
- The Mukherjee & Brill-Eaton hybrid correlation is used.
- Rigorous heat transfer calculation is used to incorporate the heat effect on total energy balance.

## Results and Discussion

1. The following results are obtained using the Sensitivity Analysis option.

**Table P7.2: Throughput in MMscfd**

| INFLOW (compressor hp) | OUTFLOW (pipe diameter) | | | | |
|---|---|---|---|---|---|
| | 18-inch | 22-inch | 24-inch | 28-inch | 32-inch |
| 4,000 | 219.4 | 321.0 | 367.7 | 491.0 | >500.0 |
| 2,000 | 180.8 | 273.1 | 320.0 | 446.1 | >500.0 |
| 1,000 | 156.3 | 244.8 | 289.6 | 420.9 | >500.0 |
| 0 | 122.7 | 213.5 | 254.4 | 390.2 | >500.0 |

Even with maximum compressor power, the 18 and 22-inch line sizes are too small to handle 350 MMscfd of gas condensate. The line sizes that will deliver throughput up to 350 MMscfd are: 24-inch (4,000 hp compressor required), 28 and 32-inch (no compressor required).

2. If a 24-inch line size is chosen, the compressor should be online at a throughput of about 260 MMscfd. The required size for a rate of 350 MMscfd is 4,000 horsepower. Both options of a 28-inch line without a compressor and a 24-inch line with 4,000 horsepower compressor are hydraulically feasible given the throughput and delivery pressure constraints. A choice between these two options can then be made based on economics not discussed here.

## Simulation Highlights

INPUT

- Base input is the same as that for a single link run with end pressures fixed.
- Overall heat transfer coefficient and pipe roughness use the program default values.
- The pipe inlet pressure is chosen as the solution node.
- Compressor power and pipeline ID are the inflow and outflow parameters respectively, since these are the two main variables in the decision.

TECHNIQUE

- The use of Sensitivity Analysis in this problem produces the same results as with manual studies, but in less time and at a reduced cost. PIPEPHASE allows compounding of parameters in much the same manner as other sensitivity programs.

## Input Data

The keyword input data file for this simulation is given below.

### Keyword Input Data File

```
TITLE   PROBLEM=PIPE7, PROJECT=PIPEAPP, USER=SIMSCI
DESC    STUDY COMPRESSOR POWER VERSUS PIPE ID
DIME    PETROLEUM, GRAV=SPGR, LENGTH=MI,IN
CALC    SINGLE, CONDENSATE
FCODE   PIPE=MBE
SEGMENT DLHOR=10
PRINT   INPUT=NONE
$
PVT DATA
        SET     SETN=1, GRAV(GAS)=0.8, GRAV(COND)=0.7, *
                GRAV(WATER)=1.002
$
STRUCTURE DATA
        SOURCE  SETN=1, NAME=3, TEMP=110, PRES=1100, *
                RATE(ESTI)=30, CGR=28
$
        LINK    NAME=L1, FROM=3, TO=1
                COMPRES NAME=C1, POWER=4000, EFF=75
                PIPE    NAME=P1, LENGTH=100, ID=18
$
        SINK    NAME=1, PRES=800, RATE(ESTI)=30
$
SENSITIVITY DATA
        NODE    NAME=P1
        FLOW    RATE=100, 200, 400, 500
        DESC    INFLOW=4000 HP, 2000 HP, 1000 HP, NO COMP
        INFLOW  NAME=C1, POWER=4000, 2000, 1000, 0
        DESC    OUTFLOW=18 INCH, 22 INCH, 24 INCH, *
                28 INCH, 32 INCH
        OUTFLOW NAME=P1, ID=18, 22, 24, 28, 32
```

## Output

- A node pressure vs. flowrate plot gives the general trend of the inflow and outflow parameters.

## Partial Output

The node pressure sensitivity plot below shows the geneal trend for the different paramenter values.

```
                            SENSITIVITY ANALYSIS

  3000. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        |           |           |           |           |           |
        |           |           |           |           |          A*
        |           |           |           |           |        AA |
  2700. +           |           |           |           |      AA   +
        |           |           |           |           |    AA     |
        |           |           |           |           |  AA       |
        |           |           |           |           |AA         |
  2400. +-----------+-----------+-----------+----------AA-----------+
        |           |           |           |        AA |           |
        |           |           |           |      AA   |           |
        |           *           |           |    AA     |           |
  2100. +           |11         |           |  AA       |           +
P       |           |  1        |           |AA         |           |
R       |           |   11      |          A*           |          B*
E       |           |     1     |        AA |           |       BBB |
S 1800. +-----------+------11---+------AA---+-----------+----BBB----+
S       |           |        1  |    AA     |           | BBB       |
U       |           |         11|  AA       |          B*B       CC*
R       |           *22         ***11       |       BBB |     CCCC  |
E 1500. +           |  2222     *    1111111*    BBB    | CCCC      +
        |           |      222*A|           |1***1111 CC*C          |
        |           *333    AA 2*222222    B*B    CCC*11*111111     |
P       |           |   33**33  |      2***2*2****2     |      11****
S 1200. +-----------+----A----3333333***33****33333**************2222
I       |           *44**4444444*4***4****44*4444444*******4444******
A       |           |AA      BBB*BCCCC      *DDDDDDD    |     EEEEEE*
        |           *  BBB***CCC*C  DDDDDDDD|     EEEEEE*EEEEE      |
   900. +           ***CCCDDDDDD*DDD  EEEEEE*EEEEE      |           +
        |           ******EEEEEE*EEEEE      |           |           |
        |           |           |           |           |           |
        |           |           |           |           |           |
   600. +-----------+-----------+-----------+-----------+-----------+
        |           |           |           |           |           |
        |           |           |           |           |           |
        |           |           |           |           |           |
   300. +           |           |           |           |           +
        |           |           |           |           |           |
        |           |           |           |           |           |
        |           |           |           |           |           |
     0. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        0.0       100.0       200.0       300.0       400.0       500.0
                       FLOW RATE      (MCFD)  (10**3)

             KEY...    1 - 4000 HP    2 - 2000 HP    3 - 1000 HP
                       4 - NO COMP    A - 18 INCH    B - 22 INCH
                       C - 24 INCH    D - 28 INCH    E - 32 INCH
```

## Partial Output (continued)

The following are the inflow and outflow curves for the sensitivity study. The inflow curves are given in the first table. The pipe inlet pressure is calculated for each flowrate and compressor horsepower based on the source pressure of 1110 psig. The outflow curves are given in the second table. The pipe inlet pressure is calculated for each flowrate and pipe diameter based on the sink pressure of 800 psig. The last table gives the estimated flowrate for each combination of compressor horsepower and pipe diameter as determined from the intersection between the inflow and outflow curves. Solutions are not given for combinations where these curves do not intersect. All flowrates for the 32 inch pipe fall outside the boundaries of the simulation and will be greater than 500 MMDCFD.

SOLUTION NODE IS AT INLET OF DEVICE P1

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE | INFLOW VARIABLE | | | |
|---|---|---|---|---|
| (MCFD) | 4000 HP | 2000 HP | 1000 HP | NO COMP |
| 100000.00 | 2197.46 | 1585.80 | 1332.21 | 1114.70 |
| 200000.00 | 1585.80 | 1332.21 | 1218.97 | 1114.70 |
| 400000.50 | 1332.21 | 1218.97 | 1165.72 | 1114.70 |
| 500001.22 | 1285.82 | 1197.40 | 1155.34 | 1114.70 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE | OUTFLOW VARIABLE | | | | |
|---|---|---|---|---|---|
| (MCFD) | 18 INCH | 22 INCH | 24 INCH | 28 INCH | 32 INCH |
| 100000.00 | 1010.90 | 891.80 | 865.48 | 838.72 | 827.21 |
| 200000.00 | 1468.66 | 1074.62 | 990.81 | 900.57 | 859.89 |
| 400000.50 | 2421.89 | 1666.30 | 1446.67 | 1125.79 | 973.08 |
| 500001.22 | 2876.03 | 1938.02 | 1661.74 | 1306.31 | 1060.99 |

| RATE | INFLOW VARIABLE | | | |
|---|---|---|---|---|
| (MCFD) | 4000 HP | 2000 HP | 1000 HP | NO COMP |
| 100000.00 | 187.09 | 148.95 | 129.45 | 110.00 |
| 200000.00 | 148.95 | 129.45 | 119.70 | 110.00 |
| 400000.50 | 129.45 | 119.70 | 114.84 | 110.00 |
| 500001.22 | 125.54 | 117.75 | 113.87 | 110.00 |

INFLOW-OUTFLOW CURVE INTERSECTION POINTS

| INFLOW CASE | OUTFLOW CASE | RATE (MCFD) | PRESSURE (PSIA) |
|---|---|---|---|
| 4000 HP | 18 INCH | 219412.83 | 1561.19 |
| | 22 INCH | 320951.56 | 1432.44 |
| | 24 INCH | 367733.94 | 1373.12 |
| | 28 INCH | 490971.88 | 1290.01 |
| 2000 HP | 18 INCH | 180818.05 | 1380.85 |
| | 22 INCH | 273083.84 | 1290.83 |
| | 24 INCH | 319978.63 | 1264.28 |
| | 28 INCH | 446109.50 | 1209.02 |
| 1000 HP | 18 INCH | 156270.84 | 1268.49 |
| | 22 INCH | 244764.05 | 1207.05 |
| | 24 INCH | 289629.91 | 1195.10 |
| | 28 INCH | 420917.53 | 1163.55 |
| NO COMP | 18 INCH | 122675.16 | 1114.70 |
| | 22 INCH | 213548.09 | 1114.70 |
| | 24 INCH | 254353.53 | 1114.70 |
| | 28 INCH | 390152.50 | 1114.70 |

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# Pipeline Capacity Study

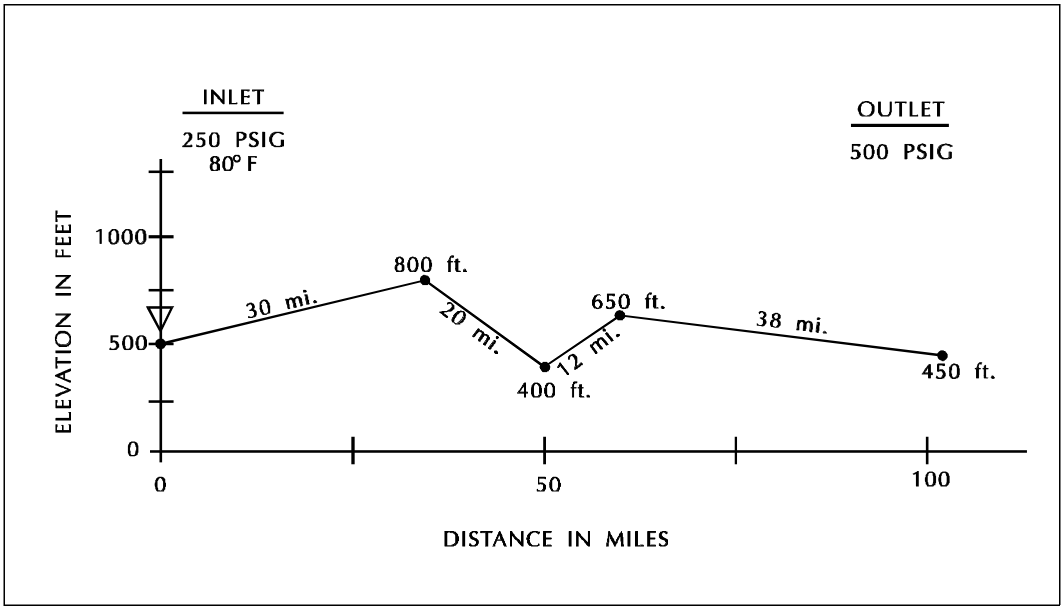
## Problem Description

It is desired to evaluate the possibility of using an existing dry gas pipeline to transport two-phase gas condensate across 100 miles of terrain. The gas is compressed and cooled to 100°F. It then flows through the 100 mile buried pipeline. The terminal pressure required is 500 psig for downstream processing. The pipeline profile is described in Figure P8.1 and process information is given in Table P8.1.

You are required to:

1. Determine the capacity of the pipeline for two-phase gas condensate fluid, assuming that inlet compressor capacity is fixed.
2. Determine the additional equipment required for switching this pipeline from a single-phase to a multiphase operation.

**Figure P8.1: Gas Condensate Pipeline**



| Table P8.1: Process Information | |
|---|---|
| **Fluid Properties** | |
| Gas Gravity | 0.79 |
| Condensate Gravity | 0.645 |
| Condensate Gas Rate | 5 BBL/MMscfd |
| Water Gas Rate | 5 BBL/MMscfd |
| **Pipeline Data** | |
| Inside Diameter | 14.75 inches |
| Pipe Roughness | 0.005 inch |
| **Heat Transfer Data** | |
| Ground Temperature | 70°F |
| U-factor | 0.55 Btu/hr-ft$^2$-F |

**CompressorData**

| Rate (MMscfd) | Head (ft) | Eficiency (%) |
|---|---|---|
| 0 | 3,600 | 85 |
| 10 | 3,200 | 81 |
| 15 | 2,880 | 75 |
| 25 | 2,000 | 70 |
| 50 | 0 | 70 |

| | |
|---|---|
| Maximum Power Per Stage | 350 Hp |
| # of Stages | 10 |

## PIPEPHASE Features Used In This Problem

- Single link rate calculation easily finds the maximum throughput in a single run.
- Non-compositional gas condensate analysis for multiphase fluid behavior.
- A compressor curve is supplied and can be easily input into the program.
- The velocity report output requested for slip holdup and *in situ* (actual) velocities along the pipeline.
- The Taitel-Dukler-Barnea flow regime prediction for accurate flow pattern prediction.
- The Dukler-Eaton-Flannigan pressure drop correlation is used.

## Results and Discussion

1. The total flow capacity calculated is 34.5 MMscfd when using the Dukler-Eaton-Flannigan pressure drop and holdup correlation. This correlation predicts a conservatively lower capacity, because pressure gains for downhill sections are considered neglible. This assumption is valid for downhill stratified flow. Taitel-Dukler-Barnea predicts stratified flow in both downhill pipe sections, but predicts annular and intermittent flow for the uphill sections. Based on these results, terrain induced slug flow may occur in certain sections of pipeline.
2. The downstream process must include a vapor and liquid separation facility in order to handle the steady flow of 350 barrels per day of liquid. Additionally, pigging equipment and a slug catcher that can handle 3,200 barrels may also be required.

## Simulation Highlights

INPUT

- Rigorous heat transfer calculations are based on an overall U-factor of 0.55 Btu/hr-ft$^2$-F for shallow buried pipe.
- Pipe roughness is specified as 0.005 inches on the DEFAULT card and applies to all pipe sections.
- A performance curve is supplied for the ten compressor stages.

TECHNIQUE

- Rate calculation in the program will be automatically invoked when source and sink pressures are specified. Source rate estimation is required for initial iteration calculation.

## Input Data

The keyword input data file for this simulation is given below.

### Keyword Input Data File

```
TITLE   PROBLEM=PIPE8, PROJECT=PIPEAPP, USER=SIMSCI
DESC    PIPELINE CAPACITY DETERMINATION
DIME    PETROLEUM, GRAV=SPGR, LENGTH=MI,IN
CALC    SINGLE, CONDENSATE
FCODE   PIPE=DE
DEFAULT TAMB=70, ROUGH=0.005, IDPIPE=14.75, UPIPE=0.55
SEGMENT DLHOR(MI)=1
PRINT   INPUT=FULL, DEVICE=PART, PLOTS=FULL, MAP=TAITEL
$
PVT DATA
        SET     SETN0=1, GRAV(GAS)=0.79, GRAV(COND)=0.645, *
                GRAV(WATER)=1.0
$
STRUCTURE DATA
        SOURCE  SETNO=1, NAME=1, TEMP=80, PRES=250,*
                RATE(ESTI)=10, CGR=5, WGR=5
$
                COMPRES STAGES=10, POWER(MAX)=350, CURVE=0,3600,85/*
                10,3200,81/15,2880,75/25,2000,70/50,0,70
                COOLER  TOUT=100
                PIPE    LENGTH=30, ECHG(FT)=300
                PIPE    LENGTH=20, ECHG(FT)=-400
                PIPE    LENGTH=12, ECHG(FT)=250
                PIPE    LENGTH=38, ECHG(FT)=-200
$
        SINK    NAME=2, PRES=500, RATE(ESTI)=10
END
```

## Output

- A compressor discharge pressure of 708 psig is calculated. The available power limit for each stage is 350 horsepower, and the calculated power is 199 horsepower.
- A compressor discharge temperature of 186$^{o}$F is calculated. An aftercooler is required to cool the temperature to 100$^{o}$F.
- The two downhill pipe sections are in stratified flow based on the Taitel-Dukler-Barnea flow regime map.

## Partial Output

The link, node and device summaries are shown below.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | ----ACTUAL FLOW RATES***-- GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | ----HOLDUP**--- GAS (MM SCF) | LIQ (STB) |
|---|---|---|---|---|---|---|---|---|---|
| LINK | SORS(F) | 1.8482 | 93.0 | 172.5 | 250.0* | | 80.0 | | |
| | SNK (T) | 0.8633 | 166.1 | 172.1 | 500.7* | -250.7 | 70.0 | 29.7499 | 3175.7 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

NODE SUMMARY

| NODE | PRES. (PSIG) | ---STANDARD FLOW RATES ---** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | TEMP. (F) |
|---|---|---|---|---|---|
| SORS | 250.0* | 34.4680 | 172.3 | 172.3 | 80.0 |
| SNK | 500.7* | 34.4680 | 172.3 | 172.3 | 70.0 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

NODE CONTAMINANT AND GAS SUMMARY

| NODE | N2(%) | CO2(%) | H2S(%) |
|---|---|---|---|
| SORS | 0.0000 | 0.0000 | 0.0000 |
| SNK | 0.0000 | 0.0000 | 0.0000 |

DEVICE SUMMARY

| LINK NAME | DEVI NAME | DEVI TYPE | COR | INSIDE DIAM (IN) | MEAS LENGTH (MI) | ELEV CHNG (MI) | ------- OUTLET PRESS: (PSIG) | TEMP: (F) | ------ INSITU LGR (BBLMM-CF) | AVG. LIQ HOLDUP |
|---|---|---|---|---|---|---|---|---|---|---|
| LINK | ***SOURCE*** RATE= 34.4680 (MMCFD) | | | | | | 250.0 | 80.0 | CGR = | 5.00 |
| | SORS | | | | | | 250.0 | 80.0 | | |
| | C001 | COMP | XX | 0.000 | 0.00000 | 0.00000 | **707.9** | 185.6 | 0.00 | 0.00 |
| | C002 | XCH1 | TC | 0.000 | 0.00000 | 0.00000 | 707.9 | 100.0 | 0.00 | 0.00 |
| | P003 | PIPE | ED | 14.750 | 30.00000 | 0.05682 | 633.9 | 70.0 | 1.402E5 | 0.04 |
| | P004 | PIPE | ED | 14.750 | 20.00000 | -7.6E-2 | 605.6 | 70.0 | 1.303E5 | 0.03 |
| | P005 | PIPE | ED | 14.750 | 12.00000 | 0.04735 | 562.2 | 70.0 | 1.166E5 | 0.03 |
| | P006 | PIPE | ED | 14.750 | 38.00000 | -3.8E-2 | 500.7 | 70.0 | 9.780E4 | 0.02 |
| | *** SINK *** PRES= 500.7 (PSIG) TEMP= 70.0 (F) | | | | | | | | | |

## Partial Output (continued)

The link device detail report below indicates that the calculated pressure and temperature for compressor C001 is about 708 psig and 186 degrees F respectively.

```
                  LINK "LINK" DEVICE DETAIL REPORT

 PRESSURE AND TEMPERATURE REPORT
 -------------------------------
 DEVICE              MWD OR       TVD
 NAME                LENGTH    I  OR
 AND    SEGM INSIDE   FROM     &  ELEV     CALC    CALC   OVERALL AMB
 TYPE   NO   DIAM.   INLET     O  CHNG     PRESS   TEMP   U-FACT  TEMP
             (IN)     (MI)        (MI)     (PSIG)  (F)    (BTUFT- (F)
                                                          F)
 ------ ---- ------ --------- - -------- ------- ------ ------- ------
  C001  0000          0.00000 I  0.00000   250.0   80.0 AVG.POWER/STAGE HP
 (COMP)                                                 AVAILABLE        350.0
                      0.00000 O  0.00000   707.9  185.6 REQUIRED         199.2
  C002  0000          0.00000 I  0.00000   707.9  185.6 DUTY      MM BTU/HR
 (XCH1)                                                  AVAILABLE        0.
                      0.00000 O  0.00000   707.9  100.0 REQUIRED         -4.
  P003  0000 14.750   0.00000 I  0.00000   707.9  100.0           70.0
 (PIPE) 0001          1.50000    0.00284   704.2   89.0   0.550   70.0
        0002          3.00000    0.00284   700.5   82.1   0.550   70.0
        0003          4.50000    0.00284   696.8   77.6   0.550   70.0
        0004          6.00000    0.00284   693.1   74.7   0.550   70.0
        0005          7.50000    0.00284   689.4   73.0   0.550   70.0
        0006          9.00000    0.00284   685.7   71.8   0.550   70.0
        0007         10.50000    0.00284   682.0   71.1   0.550   70.0
        0008         12.00000    0.00284   678.4   70.7   0.550   70.0
        0009         13.50000    0.00284   674.7   70.4   0.550   70.0
        0010         15.00000    0.00284   671.0   70.3   0.550   70.0
        0011         16.50000    0.00284   667.3   70.2   0.550   70.0
        0012         18.00000    0.00284   663.6   70.1   0.550   70.0
        0013         19.50000    0.00284   659.9   70.1   0.550   70.0
        0014         21.00000    0.00284   656.2   70.0   0.550   70.0
        0015         22.50000    0.00284   652.5   70.0   0.550   70.0
        0016         24.00000    0.00284   648.8   70.0   0.550   70.0
        0017         25.50000    0.00284   645.1   70.0   0.550   70.0
        0018         27.00000    0.00284   641.4   70.0   0.550   70.0
        0019         28.50000    0.00284   637.6   70.0   0.550   70.0
        0020         30.00000 O  0.00284   633.9   70.0   0.550   70.0
          :
          :
          :
  P006  0000 14.750   0.00000 I  0.00000   562.2   70.0           70.0
 (PIPE) 0001          1.90000   -0.00189   559.3   70.0   0.550   70.0
        0002          3.80000   -0.00189   556.4   70.0   0.550   70.0
        0003          5.70000   -0.00189   553.4   70.0   0.550   70.0
        0004          7.60000   -0.00189   550.4   70.0   0.550   70.0
        0005          9.50000   -0.00189   547.4   70.0   0.550   70.0
        0006         11.40000   -0.00189   544.4   70.0   0.550   70.0
        0007         13.30000   -0.00189   541.4   70.0   0.550   70.0
        0008         15.20000   -0.00189   538.4   70.0   0.550   70.0
        0009         17.10000   -0.00189   535.3   70.0   0.550   70.0
        0010         19.00000   -0.00189   532.3   70.0   0.550   70.0
        0011         20.90000   -0.00189   529.2   70.0   0.550   70.0
        0012         22.80000   -0.00189   526.1   70.0   0.550   70.0
        0013         24.70000   -0.00189   523.0   70.0   0.550   70.0
        0014         26.60000   -0.00189   519.9   70.0   0.550   70.0
        0015         28.50000   -0.00189   516.7   70.0   0.550   70.0
        0016         30.40000   -0.00189   513.5   70.0   0.550   70.0
        0017         32.30000   -0.00189   510.4   70.0   0.550   70.0
        0018         34.20000   -0.00189   507.2   70.0   0.550   70.0
        0019         36.10000   -0.00189   504.0   70.0   0.550   70.0
        0020         38.00000 O -0.00189   500.7   70.0   0.550   70.0
```

## Partial Output (continued)

The surface pressure plot for the link is given below.

```
                       SURFACE PRESSURE PLOT FOR LINK
  750.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        |           |           |           |           |           |
        |           |           |           |           |           |
        *           |           |           |           |           |
  700.0 PPPP        |           |           |           |           +
        *   PPP     |           |           |           |           |
        *      PPP  |           |           |           |           |
        *         PP*           |           |           |           |
  650.0 P-----------+PPP--------+-----------+-----------+-----------+
        *           |   PPPP    |           |           |           |
        *           |      PPPPP*           |           |           |
        *           |           |PPPPP      |           |           |
P 600.0 P           |           |     PPP   |           |           +
R       *           |           |       PPP |           |           |
E       *           |           |         PP*           |           |
S       *           |           |           |PPPP       |           |
S 550.0 P-----------+-----------+-----------+----PPPP---+-----------+
U       *           |           |           |        PPP*P          |
R       *           |           |           |           | PPPP      |
E       *           |           |           |           |     PPPPP |
  500.0 P           |           |           |           |          PP
        *           |           |           |           |           |
        *           |           |           |           |           |
        *           |           |           |           |           |
P 450.0 P-----------+-----------+-----------+-----------+-----------+
S       *           |           |           |           |           |
I       *           |           |           |           |           |
G       *           |           |           |           |           |
  400.0 P           |           |           |           |           +
        *           |           |           |           |           |
        *           |           |           |           |           |
        *           |           |           |           |           |
  350.0 P-----------+-----------+-----------+-----------+-----------+
        *           |           |           |           |           |
        *           |           |           |           |           |
        *           |           |           |           |           |
  300.0 P           |           |           |           |           +
        *           |           |           |           |           |
        *           |           |           |           |           |
        *           |           |           |           |           |
  250.0 P-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        0.0        20.0        40.0        60.0        80.0       100.0
                   DIST. FROM 1ST SURFACE DEVICE INLET MI

                       KEY...    P - P - FLUID PRESS.
```

## Partial Output (continued)

The surface temperature plot for the link is given below.

```
                        SURFACE TEMPERATURE PLOT FOR LINK

   200.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
         |           |           |           |           |           |
         |           |           |           |           |           |
         |           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
   180.0 T-----------+-----------+-----------+-----------+-----------+
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
   160.0 T-----------+-----------+-----------+-----------+-----------+
         *           |           |           |           |           |
 T       *           |           |           |           |           |
 E       *           |           |           |           |           |
 M       *           |           |           |           |           |
 P       *           |           |           |           |           |
 E 140.0 T-----------+-----------+-----------+-----------+-----------+
 R       *           |           |           |           |           |
 A       *           |           |           |           |           |
 T       *           |           |           |           |           |
 U       *           |           |           |           |           |
 R       *           |           |           |           |           |
 E 120.0 T-----------+-----------+-----------+-----------+-----------+
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
         *           |           |           |           |           |
 D 100.0 T-----------+-----------+-----------+-----------+-----------+
 E       *           |           |           |           |           |
 G       *T          |           |           |           |           |
         *T          |           |           |           |           |
 F       * T         |           |           |           |           |
         * T         |           |           |           |           |
    80.0 *--T--------+-----------+-----------+-----------+-----------+
         *  T        |           |           |           |           |
         |A  TT      |           |           |           |           |
         |AAAAA*******************************************************
         |           |           |           |           |           |
         |           |           |           |           |           |
    60.0 +-----------+-----------+-----------+-----------+-----------+
         |           |           |           |           |           |
         |           |           |           |           |           |
         |           |           |           |           |           |
         |           |           |           |           |           |
         |           |           |           |           |           |
    40.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
         0.0        20.0        40.0        60.0        80.0       100.0
                    DIST. FROM 1ST SURFACE DEVICE INLET MI

             KEY...    T - T - FLUID TEMP.    A - A - AMB. TEMP.
```

## Partial Output (continued)

The holdup and velocity detail report given below indicates that the downhill pipe sections P004 and P006 are operating under stratified flow conditions.

```
                         LINK "LINK"  DEVICE DETAIL REPORT


 HOLDUP AND VELOCITY DETAIL REPORT
 ---------------------------------
 DEVICE
 NAME         ---LIQUID HOLDUP---            ACTUAL                       T-D
 AND    SEG. NO                      LIQ      GAS     MIX .  FLOW FLOW   SONIC
 TYPE   NO.  SLIP  SLIP    TOTAL     VEL      VEL     VEL    REGM REGM    VEL
                          (ABBL)    (FPS)    (FPS)   (FPS)               (FPS)
 ------ ---- ----- ----- -------- ------- ------- ------- ---- ---- -------
 (COMP) 0000
  C001  0001
 (XCH1) 0000
  C002  0001
         :
         :
         :
  P004  0000
 (PIPE) 0001 3.E-3  0.03   1295.3    0.58    6.63    6.43 ---- STRT 1201.71
        0002 3.E-3  0.03   1332.5    0.59    6.65    6.45 ---- STRT 1201.33
        0003 3.E-3  0.03   1369.5    0.59    6.66    6.46 ---- STRT 1200.95
        0004 3.E-3  0.03   1406.3    0.59    6.68    6.48 ---- STRT 1200.57
        0005 3.E-3  0.03   1442.8    0.60    6.70    6.50 ---- STRT 1200.19
        0006 3.E-3  0.03   1479.1    0.60    6.71    6.51 ---- STRT 1199.80
        0007 3.E-3  0.03   1515.1    0.60    6.73    6.53 ---- STRT 1199.42
        0008 3.E-3  0.03   1551.0    0.61    6.75    6.55 ---- STRT 1199.03
        0009 3.E-3  0.03   1586.6    0.61    6.76    6.57 ---- STRT 1198.64
        0010 3.E-3  0.03   1622.0    0.61    6.78    6.58 ---- STRT 1198.25
        0011 3.E-3  0.03   1657.1    0.62    6.80    6.60 ---- STRT 1197.86
        0012 3.E-3  0.03   1692.1    0.62    6.81    6.62 ---- STRT 1197.47
        0013 3.E-3  0.03   1726.8    0.62    6.83    6.64 ---- STRT 1197.08
        0014 3.E-3  0.03   1761.2    0.63    6.85    6.66 ---- STRT 1196.68
        0015 3.E-3  0.03   1795.4    0.63    6.87    6.67 ---- STRT 1196.29
        0016 3.E-3  0.03   1829.4    0.63    6.88    6.69 ---- STRT 1195.89
        0017 3.E-3  0.03   1863.2    0.64    6.90    6.71 ---- STRT 1195.49
        0018 3.E-3  0.03   1896.7    0.64    6.92    6.73 ---- STRT 1195.09
        0019 3.E-3  0.03   1930.0    0.65    6.94    6.75 ---- STRT 1194.69
        0020 3.E-3  0.03   1963.0    0.65    6.95    6.77 ---- STRT 1194.29
  P005  0000
 (PIPE) 0001 3.E-3  0.03   1995.7    0.66    6.99    6.80 ---- INTR 1193.40
        0002 3.E-3  0.03   2027.7    0.67    7.03    6.85 ---- INTR 1192.38
        0003 3.E-3  0.03   2059.1    0.68    7.08    6.90 ---- INTR 1191.36
        0004 3.E-3  0.03   2089.9    0.69    7.13    6.95 ---- INTR 1190.33
        0005 3.E-3  0.03   2120.0    0.70    7.17    7.00 ---- INTR 1189.30
        0006 3.E-3  0.03   2149.6    0.72    7.22    7.05 ---- INTR 1188.27
        0007 3.E-3  0.03   2178.5    0.73    7.27    7.10 ---- INTR 1187.23
        0008 3.E-3  0.03   2206.9    0.75    7.32    7.15 ---- INTR 1186.19
        0009 3.E-3  0.02   2234.6    0.76    7.37    7.20 ---- INTR 1185.15
        0010 3.E-3  0.02   2261.6    0.78    7.42    7.26 ---- INTR 1184.10
        0011 3.E-3  0.02   2288.1    0.79    7.47    7.31 ---- INTR 1183.05
        0012 3.E-3  0.02   2313.9    0.81    7.52    7.36 ---- INTR 1182.00
  P006  0000
 (PIPE) 0001 3.E-3  0.02   2361.8    0.83    7.57    7.41 ---- STRT 1181.10
        0002 3.E-3  0.02   2408.8    0.84    7.61    7.46 ---- STRT 1180.24
        0003 2.E-3  0.02   2454.7    0.86    7.65    7.50 ---- STRT 1179.36
        0004 2.E-3  0.02   2499.7    0.88    7.70    7.55 ---- STRT 1178.49
        0005 2.E-3  0.02   2543.6    0.90    7.74    7.60 ---- STRT 1177.60
        0006 2.E-3  0.02   2586.5    0.91    7.78    7.65 ---- STRT 1176.71
        0007 2.E-3  0.02   2628.9    0.92    7.83    7.69 ---- STRT 1175.81
        0008 2.E-3  0.02   2671.2    0.92    7.88    7.74 ---- STRT 1174.91
        0009 2.E-3  0.02   2713.4    0.92    7.93    7.79 ---- STRT 1173.99
        0010 2.E-3  0.02   2755.5    0.92    7.99    7.85 ---- STRT 1173.07
        0011 2.E-3  0.02   2797.6    0.92    8.04    7.90 ---- STRT 1172.15
        0012 2.E-3  0.02   2839.6    0.92    8.09    7.95 ---- STRT 1171.21
        0013 2.E-3  0.02   2881.5    0.92    8.15    8.00 ---- STRT 1170.27
        0014 2.E-3  0.02   2923.4    0.92    8.20    8.06 ---- STRT 1169.32
        0015 2.E-3  0.02   2965.2    0.92    8.26    8.11 ---- STRT 1168.34
        0016 2.E-3  0.02   3006.9    0.92    8.32    8.17 ---- STRT 1167.37
        0017 2.E-3  0.02   3048.5    0.92    8.37    8.23 ---- STRT 1166.40
        0018 2.E-3  0.02   3090.0    0.92    8.43    8.29 ---- STRT 1165.41
        0019 2.E-3  0.02   3131.5    0.92    8.49    8.35 ---- STRT 1164.42
        0020 2.E-3  0.02   3172.9    0.92    8.56    8.41 ---- STRT 1163.42
```

## Partial Output (continued)

The Taitel-Dukler-Barnea flow regime map is given below.

```
         !+--------------+--------------+---------------+-------------+!
    75.00+ DDDDDDDDDDDDDDDDDDDDDDDDDDD IIIIIIIIIIIIIIIIIIIIIIII AAAAAAA+
         ! DDDDDDDDDDDDDDDDDDDD IIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAA!
         ! DDDDDDDDDDDDD IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAA!
         ! DDDDDDD IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAA!
         ! D IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAA!
    10.00+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSS WWWWWWWWWWWWWWW IIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSS WWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSS WWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSS WWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
     1.00+ SSSSSSSSSSS WWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAA+
         ! SSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAA!
VSL      ! SSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAA!
     0.10+ SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAA+
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSSS WWWWWWWWW+WWWWWWWWWWWW AAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAA!
     0.01+ SSSSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAA+
         !+--------------+--------------+---------------+-------------+!
         0.1            1.0           10.0           100.0         900.0

                                        VSG
VSL = SUPERFICIAL LIQUID VELOCITY (FPS)
VSG = SUPERFICIAL GAS VELOCITY (FPS)
+   = OPERATING POINT
   PRESSURE=      500.7184(PSIG)
   TEMP:   =       70.0000(F)
   ANGLE   =       -0.0573(DEG)
```

# Retrograde Gas Pipeline

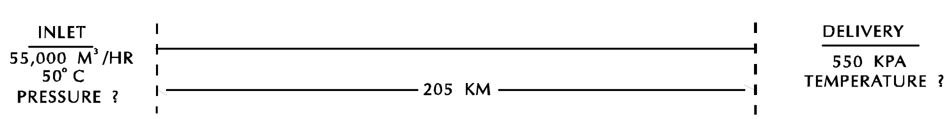
## Problem Description

A 205-kilometer long gas pipeline is transporting 55,000 cubic meters per hour of gas to a distribution station. The contract delivery pressure at the terminal point is 550 kPa. A schematic of this pipeline is shown in Figure P9.1 and process information is given in Table P9.1.

You are required to:

1. Determine the inlet pressure required to satisfy the delivery pressure of 550 kilopascals.
2. Determine the fluid temperature at the terminal point.
3. Based on an outlet temperature of 8°C (ambient temperature), the phase envelope shows the fluid to be a single-phase gas. Determine if the entire pipeline can be simulated as a non-compositional gas.

**Figure P9.1: Retrograde Gas Pipeline System**



| Table P9.1: Process Information | |
|---|---|
| **Composition Data** | |
| **Component** | **Mole %** |
| N2 | 10.53 |
| C1 | 70.53 |
| C2 | 12.04 |
| C3 | 4.21 |
| IC4 | 0.50 |
| NC4 | 1.25 |
| IC4 | 0.35 |
| NC5 | 0.43 |
| NC6 | 0.13 |
| NC7 | 0.03 |
| Specific Gravity | 0.74 |
| **Fixed Elevation Pipeline Data** | |
| Inside Diameter | 12.0 inches |
| Wall Thickness | 0.375 inches |
| Roughness | 0.0018 inch |
| **Heat Transfer Data** | |
| Ground Temperature | 8°C |
| Pipe Buried Depth | 1 meter |

## PIPEPHASE Features Used In This Problem

- Compositional analysis using library components is done to provide accurate phase behavior such as retrograde condensation.
- The Peng-Robinson equation of state is used for the PVTcalculations.
- Rigorous detailed heat transfer calculations are performed for buried pipes.
- Gas volume output from compositional analysis is specified in order to have direct comparison with the non-compositional gas model.

## Results and Discussion

1. The calculated inlet pressure is 6033 kPa if a full compositional analysis is used. When using the non-compositional gas model, the inlet pressure is calculated to be 5138 kPa. A difference of 896 kPa (130 psi) is attributed to the different fluid properties calculated. Using the results of a non-compositional model could cause the underdesign of the compressor at the inlet to the pipeline.
2. The fluid temperature reaches $8^oC$ at about 47 kilometers from the inlet using the compositional model. A fluid outlet temperature of $3.2^oC$ is much lower than the ambient temperature of $8^oC$. This is due to the Joule-Thomson effect calculated in compositional analysis. The non-compositional gas model reported the fluid temperature reaches $8^oC$ at 38 kilometers from the inlet and stays at $8^oC$, thereafter.
3. Although the compositional model shows the fluid at the inlet and outlet of the pipeline is single-phase gas, the BBM correlation predicts a region of segregated fluid flow within the pipeline. Retrograde condensation exists between 23 and 174 kilometers from the inlet. The non-compositional gas model will not predict any liquid holdup in the line due to the nature of the model. Thus, the accurate phase behavior and associated liquid holdup can only be predicted by using compositional modeling.

P9 Retrograde Gas Pipeline

## Simulation Highlights

INPUT

- Separate runs are made, the first with compositional and the second with non-compositional calculation option.
- When the inlet temperature and outlet pressure are known, the iterative network model can be used.
- The default absolute roughness of the pipe is 0.0018 inches.
- The Beggs and Brill-Moody (BBM), pressure drop and holdup correlation is used with the compositional analysis. The Moody pressure drop pressure correlation is automatically used in the non-compositional gas model since the BBM correlation degenerates to Moody when the fluid becomes single-phase.

TECHNIQUE

- Thirty calculation segments were specified to model the pipeline. In general more segments are required to improve the accuracy, but this will also increase run time.
- Point-by-point PVT calculation is used in this problem, although a PVT table may be generated to save run time.

## Input Data

The keyword input data files for both simulation cases are given below.

### Keyword Input Data File (Compositional Analysis)

```
TITLE   PROBLEM=PIPE9A, PROJECT=PIPEAPP, USER=SIMSCI
DESC    ASSESSMENT OF GAS LINE INLET PRESSURE - COMPOSITIONAL
DIME    SI, RATE(GV)=CMHR, TEMP=C, LENGTH=M, IN
CALC    COMP, NETWORK
DEFAULT TAMB=8, SOIL, BDTOP(M)=1, THKPIPE=0.375
SEGMENT NHOR=30
PRINT   INPUT=FULL, DEVICE=FULL, PLOTS=FULL
$
COMPONENT DATA
LIBID   N2/C1/C2/C3/IC4/NC4/IC5/NC5/NC6/NC7
$
METHOD DATA
THERMO  SYSTEM=PR
$
STRUCTURE DATA
        SOURCE  NAME=SUPP, TEMP=50, PRES(ESTI)=6000, RATE(GV)=0.055, *
        COMP=10.53/70.53/12.04/4.21/0.5/1.25/0.35/0.43/0.13/0.03
$
        LINK    NAME=1, FROM=SUPP, TO=DELI
                PIPE    ID=12, LENGTH(KM)=205, SOIL
$
        SINK    NAME=DELI, PRES=550, RATE(ESTI)=16000
END
```

### Keyword Input Data File (Non-compositional Analysis)

```
TITLE   PROBLEM=PIPE9, PROJECT=PIPEAPP, USER=SIMSCI
DESC    ASSESSMENT OF GAS LINE INLET PRESSURE - NON-COMPOSITIONAL
DIME    SI, RATE(GV)=CMHR, TEMP=C, LENGTH=M, IN
CALC    GAS, NETWORK
DEFAULT TAMB=8, SOIL, BDTOP(M)=1, THKPIPE=0.375
SEGMENT NHOR=30
PRINT   INPUT=FULL, DEVICE=PART, PLOTS=FULL
$
PVT DATA
        SET     SETNO=1, GRAV(GAS)=0.74
$
STRUCTURE DATA
        SOURCE  SETNO=1, NAME=SUPP, TEMP=50, *
                PRES(ESTI)=6000, RATE(GV)=0.055
$
        LINK    NAME=1, FROM=SUPP, TO=DELI
                PIPE    ID=12, LENGTH(KM)=205, SOIL
$
        SINK    NAME=DELI, PRES=550, RATE(ESTI)=16000
END
```

## Output

- Partial outputs of both compositionaland non-compositional runs are presented for comparison purposes.
- A rigorous detailed heat transfer coefficient of 3.4 kcal/hr-$m^2$-$^oC$ is calculated by the program.
- The program automatically increases the number of calculation segments in compositional analysis when a large temperature (or pressure) change is recognized. This is illustrated at the first 50 kilometers of the pipeline.
- Although the heat transfer coefficients calculated from the two runs are very close together (3.4 kcal/hr-$m^2$-$^oC$), the temperature profiles shown are different due to the accuracy of the phase split and fluid properties in the different fluid models.

## Partial Output

Portions of the PIPEPHASE output report are given in this section. Among the reports featured are link device reports, link surface temperature and pressure plots, and a phase envelope generated by PIPEPHASE.

Detailed reports for the compositional analysis are shown below.

LINK "1 " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (M) | I & O | TVD OR ELEV CHNG (M) | CALC PRESS (KPA) | CALC TEMP (C) | OVERALL U-FACT (WMC) | AMB TEMP (C) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 12.000 | 0.00 | I | 0.00 | 6033. | 50.0 | | 8.0 | 1.00 |
| (PIPE) | 0001 | | 1524.00 | | 0.00 | 6012. | 44.0 | 3.40 | 8.0 | 1.00 |
| | 0002 | | 4061.18 | | 0.00 | 5978. | 35.9 | 3.40 | 8.0 | 1.00 |
| | 0003 | | 7162.98 | | 0.00 | 5937. | 28.5 | 3.40 | 8.0 | 1.00 |
| | 0004 | | 11270.59 | | 0.00 | 5886. | 21.5 | 3.39 | 8.0 | 1.00 |
| | 0005 | | 17135.47 | | 0.00 | 5814. | 15.3 | 3.39 | 8.0 | 1.00 |
| | 0006 | | 23968.81 | | 0.00 | 5717. | 11.8 | 3.39 | 8.0 | 1.00 |
| | 0007 | | 30802.15 | | 0.00 | 5632. | 10.0 | 3.39 | 8.0 | 0.99 |
| | 0008 | | 37635.48 | | 0.00 | 5543. | 8.8 | 3.39 | 8.0 | 0.98 |
| | 0009 | | 44468.82 | | 0.00 | 5452. | 8.2 | 3.39 | 8.0 | 0.98 |
| | 0010 | | 51302.16 | | 0.00 | 5357. | 7.7 | 3.39 | 8.0 | 0.98 |
| | 0011 | | 58135.49 | | 0.00 | 5259. | 7.5 | 3.39 | 8.0 | 0.98 |
| | 0012 | | 64968.83 | | 0.00 | 5157. | 7.3 | 3.39 | 8.0 | 0.98 |
| | 0013 | | 71802.17 | | 0.00 | 5052. | 7.2 | 3.39 | 8.0 | 0.98 |
| | 0014 | | 78635.50 | | 0.00 | 4941. | 7.1 | 3.39 | 8.0 | 0.98 |
| | 0015 | | 85468.84 | | 0.00 | 4826. | 7.0 | 3.39 | 8.0 | 0.98 |
| | 0016 | | 92302.18 | | 0.00 | 4706. | 6.9 | 3.39 | 8.0 | 0.98 |
| | 0017 | | 99135.52 | | 0.00 | 4579. | 6.8 | 3.39 | 8.0 | 0.98 |
| | 0018 | | 105968.85 | | 0.00 | 4446. | 6.8 | 3.39 | 8.0 | 0.98 |
| | 0019 | | 112802.18 | | 0.00 | 4305. | 6.7 | 3.39 | 8.0 | 0.98 |
| | 0020 | | 119635.52 | | 0.00 | 4154. | 6.6 | 3.39 | 8.0 | 0.98 |
| | 0021 | | 126468.86 | | 0.00 | 3994. | 6.5 | 3.39 | 8.0 | 0.98 |
| | 0022 | | 133302.19 | | 0.00 | 3821. | 6.4 | 3.39 | 8.0 | 0.98 |
| | 0023 | | 140135.53 | | 0.00 | 3634. | 6.2 | 3.39 | 8.0 | 0.99 |
| | 0024 | | 146968.88 | | 0.00 | 3432. | 6.1 | 3.39 | 8.0 | 0.99 |
| | 0025 | | 153802.20 | | 0.00 | 3216. | 5.9 | 3.39 | 8.0 | 0.99 |
| | 0026 | | 160635.55 | | 0.00 | 2982. | 5.7 | 3.39 | 8.0 | 0.99 |
| | 0027 | | 167468.89 | | 0.00 | 2726. | 5.5 | 3.39 | 8.0 | 0.99 |
| | 0028 | | 174302.23 | | 0.00 | 2439. | 5.2 | 3.39 | 8.0 | 0.99 |
| | 0029 | | 181135.58 | | 0.00 | 2019. | 4.3 | 3.39 | 8.0 | 1.00 |
| | 0030 | | 187399.06 | | 0.00 | 1763. | 4.8 | 3.39 | 8.0 | 1.00 |
| | 0031 | | 194232.41 | | 0.00 | 1426. | 5.0 | 3.39 | 8.0 | 1.00 |
| | 0032 | | 197528.77 | | 0.00 | 1229. | 4.8 | 3.39 | 8.0 | 1.00 |
| | 0033 | | 200825.11 | | 0.00 | 990. | 4.4 | 3.39 | 8.0 | 1.00 |
| | 0034 | | 202386.16 | | 0.00 | 853. | 4.1 | 3.39 | 8.0 | 1.00 |
| | 0035 | | 203947.22 | | 0.00 | 689. | 3.7 | 3.39 | 8.0 | 1.00 |
| | 0036 | | 204578.97 | | 0.00 | 609. | 3.4 | 3.39 | 8.0 | 1.00 |
| | 0037 | | 205000.16 | O | 0.00 | 549. | 3.2 | 3.39 | 8.0 | 1.00 |

# Partial Output (continued)

Pressure detail report for non-compositional gas analysis is shown below.

LINK "1 " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (M) | I & O | TVD OR ELEV CHNG (M) | CALC PRESS (KPA) | CALC TEMP (C) | OVERALL U-FACT (WMC) | AMB TEMP (C) |
|---|---|---|---|---|---|---|---|---|---|
| P001 | 0000 | 12.000 | 0.00 | I | 0.00 | 5138. | 50.0 | | 8.0 |
| (PIPE) | 0001 | | 6833.34 | | 0.00 | 5046. | 20.5 | 3.38 | 8.0 |
| | 0002 | | 13666.68 | | 0.00 | 4959. | 11.4 | 3.38 | 8.0 |
| | 0003 | | 20500.01 | | 0.00 | 4874. | 8.9 | 3.38 | 8.0 |
| | 0004 | | 27333.35 | | 0.00 | 4788. | 8.2 | 3.38 | 8.0 |
| | 0005 | | 34166.69 | | 0.00 | 4700. | 8.1 | 3.38 | 8.0 |
| | 0006 | | 41000.03 | | 0.00 | 4610. | 8.0 | 3.38 | 8.0 |
| | 0007 | | 47833.36 | | 0.00 | 4518. | 8.0 | 3.38 | 8.0 |
| | 0008 | | 54666.70 | | 0.00 | 4424. | 8.0 | 3.38 | 8.0 |
| | 0009 | | 61500.04 | | 0.00 | 4328. | 8.0 | 3.38 | 8.0 |
| | 0010 | | 68333.37 | | 0.00 | 4230. | 8.0 | 3.38 | 8.0 |
| | 0011 | | 75166.71 | | 0.00 | 4128. | 8.0 | 3.38 | 8.0 |
| | 0012 | | 82000.05 | | 0.00 | 4024. | 8.0 | 3.38 | 8.0 |
| | 0013 | | 88833.38 | | 0.00 | 3917. | 8.0 | 3.38 | 8.0 |
| | 0014 | | 95666.72 | | 0.00 | 3806. | 8.0 | 3.38 | 8.0 |
| | 0015 | | 102500.05 | | 0.00 | 3692. | 8.0 | 3.38 | 8.0 |
| | 0016 | | 109333.40 | | 0.00 | 3573. | 8.0 | 3.38 | 8.0 |
| | 0017 | | 116166.73 | | 0.00 | 3451. | 8.0 | 3.38 | 8.0 |
| | 0018 | | 123000.06 | | 0.00 | 3323. | 8.0 | 3.38 | 8.0 |
| | 0019 | | 129833.41 | | 0.00 | 3189. | 8.0 | 3.38 | 8.0 |
| | 0020 | | 136666.73 | | 0.00 | 3049. | 8.0 | 3.38 | 8.0 |
| | 0021 | | 143500.08 | | 0.00 | 2902. | 8.0 | 3.38 | 8.0 |
| | 0022 | | 150333.41 | | 0.00 | 2746. | 8.0 | 3.38 | 8.0 |
| | 0023 | | 157166.73 | | 0.00 | 2580. | 8.0 | 3.38 | 8.0 |
| | 0024 | | 164000.09 | | 0.00 | 2402. | 8.0 | 3.38 | 8.0 |
| | 0025 | | 170833.44 | | 0.00 | 2208. | 8.0 | 3.38 | 8.0 |
| | 0026 | | 177666.80 | | 0.00 | 1994. | 8.0 | 3.39 | 8.0 |
| | 0027 | | 184500.13 | | 0.00 | 1753. | 8.0 | 3.39 | 8.0 |
| | 0028 | | 191333.48 | | 0.00 | 1470. | 8.0 | 3.39 | 8.0 |
| | 0029 | | 198166.81 | | 0.00 | 1114. | 8.0 | 3.39 | 8.0 |
| | 0030 | | 205000.16 | O | 0.00 | 553. | 8.0 | 3.39 | 8.0 |

## Partial Output (continued)

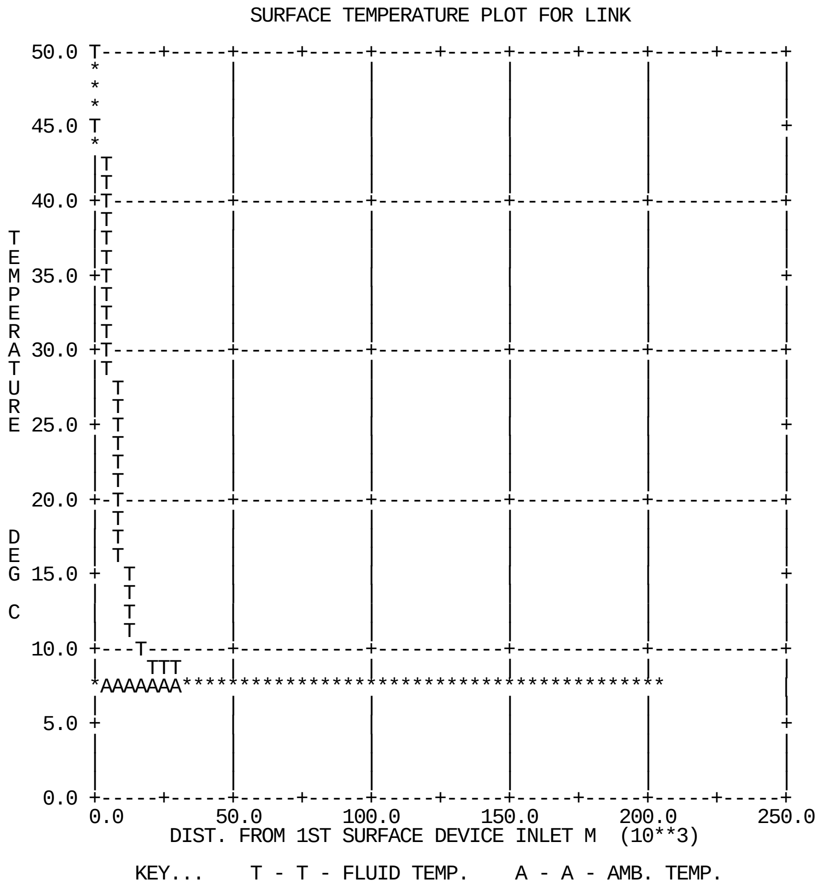
The temperature plot below shows the Joule-Thomson cooling from the composition analysis.

```
                     SURFACE TEMPERATURE PLOT FOR LINK

  50.0 T-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
       *           |           |           |           |           |
       *           |           |           |           |           |
       *           |           |           |           |           |
  45.0 T           |           |           |           |           +
       *           |           |           |           |           |
       *           |           |           |           |           |
       *           |           |           |           |           |
  40.0 +T----------+-----------+-----------+-----------+-----------+
       |T          |           |           |           |           |
T      |T          |           |           |           |           |
E      |T          |           |           |           |           |
M 35.0 +T          |           |           |           |           +
P      |T          |           |           |           |           |
E      | T         |           |           |           |           |
R      | T         |           |           |           |           |
A 30.0 +-T---------+-----------+-----------+-----------+-----------+
T      | T         |           |           |           |           |
U      | T         |           |           |           |           |
R      | T         |           |           |           |           |
E 25.0 +  T        |           |           |           |           +
       |  T        |           |           |           |           |
       |  T        |           |           |           |           |
       |  T        |           |           |           |           |
  20.0 +--T--------+-----------+-----------+-----------+-----------+
       |  T        |           |           |           |           |
D      |   T       |           |           |           |           |
E      |   T       |           |           |           |           |
G 15.0 +   T       |           |           |           |           +
       |    T      |           |           |           |           |
C      |    T      |           |           |           |           |
       |     T     |           |           |           |           |
  10.0 +------TT---+-----------+-----------+-----------+-----------+
       |        TTT|           |           |           |           |
       *AAAAAAAAAAA**********AA*AAAAAAAAAAA*AAAAAAAAAAA*A          |
       |           |         TT*TTTTTTTTTTT*TTT        |           |
   5.0 +           |           |           |   TTT TTTT*           +
       |           |           |           |      T    |T          |
       |           |           |           |           |           |
       |           |           |           |           |           |
   0.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
       0.0       50.0       100.0       150.0       200.0       250.0
              DIST. FROM 1ST SURFACE DEVICE INLET M  (10**3)

           KEY...    T - T - FLUID TEMP.    A - A - AMB. TEMP.
```

P9 Retrograde Gas Pipeline

## Partial Output (continued)

The non-compositional gas simulation temperature plot does not show Joule-Thomson cooling.



## Partial Output (continued)

PIPEPHASE can generate phase envelopes for the SRK and PR compositional methods. The phase envelope generated in this case is shown below. The path of fluid traverse is marked by ‘X’.

```
        P H A S E   E N V E L O P E

P 12500.+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        :           :           :           :           :           :
R       :           :           :           :           :           :
        :           :           :           :           :           :
E 11250.+           :           :           :           :           +
S       :           :           :           :           :           :
        :           :           :           D PD        :           :
        :           :           :           :           :           :
S 10000.+-----------+-----------+----------D+----D------+-----------+
        :           :           :         C :           :           :
U       :           :           :        B  :      I    :           :
        :           :           :           :           :           :
R  8750.+           :           :       B   :      D    :           +
        :           :           :           :           :           :
E       :           :           :      B    :           :           :
        :           :           :           :           :           :
   7500.+-----------+-----------+-----B-----+-----------+-----------+
K       :           :           :           :           :           :
P       :           :           :    B      :        D  :           :
A       :           :           :           :           :           :
   6250.+           :           :   B       :           :           +
        :           :           :  B        :        XX XX XX       :
        :           :           :           :       XD  :           :
        :           :           : B         :      XXT  :           :
   5000.+-----------+-----------+B----------+------X----+-----------+
        :           :           :           :      X    :           :
        :           :           B           :      X    :           :
        :           :          B:           :      X    :           :
   3750.+           :          B:           :      X D  :           +
        :           :           :           :      X    :           :
        :           :         B :           :      X    :           :
        :           :        B  :           :      X    :           :
   2500.+-----------+-------B---+-----------+------XD---+-----------+
        :           :      B    :           :           :           :
        :           :     B     :           :      X    :           :
        :           :   BB      :           :     DX    :           :
   1250.+           :   B       :           :    D X    :           +
        :           : BB        :           :      X    :           :
        :          BBB          :           :  DD  X    :           :
        :       BBBB:           :           DD          :           :
      0.BBBBBBBB----+-----+-----+--DDDDDDDDD+-----+-----+-----+-----+
     -210. -180. -150. -120.  -90.  -60.  -30.    0.   30.   60.   90.

                T E M P E R A T U R E   C

        I = INTERPOLATED     B = BUBBLE           D = DEW
        X = TRAVERSE         T = T EXTREMUM       P = P EXTREMUM
        C = CRITICAL
```

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# Blackoil Looped Network

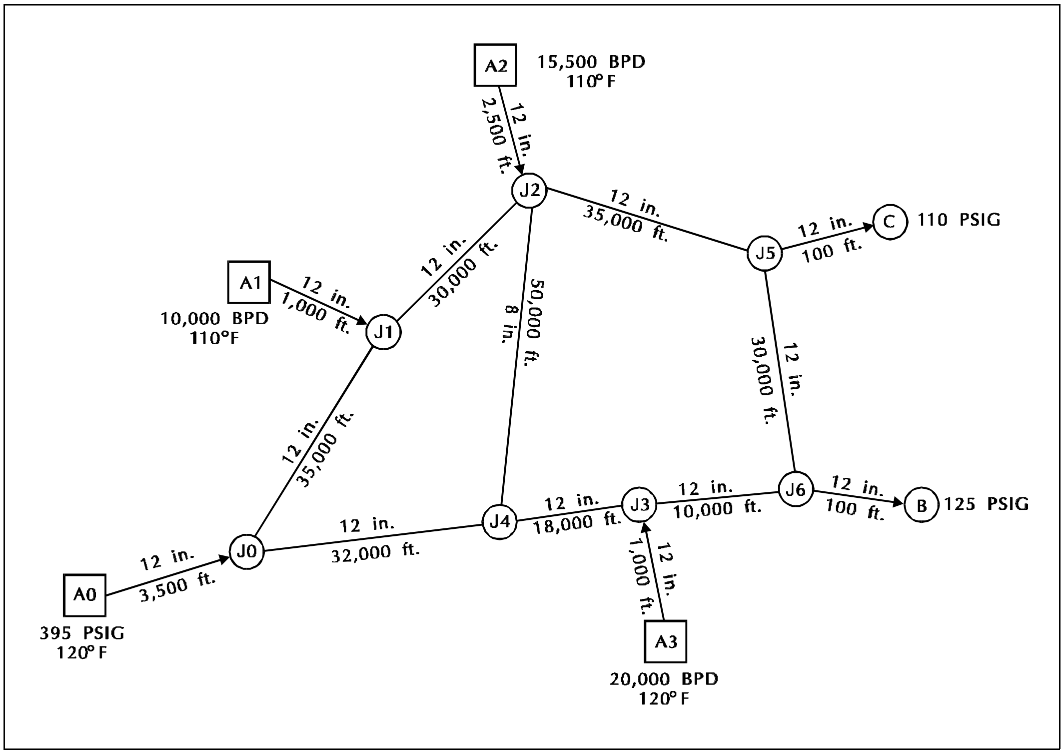
## Problem Description

In a blackoil gathering and distribution facility, oil is collected from four different fields and then transported to two terminal points (B and C). This system consists of loops and crossover lines. A schematic of this system, along with a set of operating data is shown in Figure P10.1 and process information is given in Table P10.1.

You are required to:

1. Determine the unknown boundary flows and pressures, along with the flow distribution in the loops and crossovers.
2. Determine the location of potential bottlenecks, identifying problem links for corrective action.
3. Determine individual delivery rates for the terminal points, as well as the total system capacity.

**Figure P10.1: Blackoil Looped Network**




P10 Blackoil Looped Network

| Table P10.1: Process Information | | |
|---|---|---|
| **Node Data** | | |
| **Source** | **Flowrate, bpd** | **Gas-Oil Ratio (GOR), $ft^3$/Bbl** |
| A0 | 8,000 (Estimated) | 400 |
| A1 | 10,000 (Fixed) | 300 |
| A2 | 15,500 (Fixed) | 350 |
| A3 | 20,000 (Fixed) | 230 |
| **Blackoil Properties** | | |
| Oil Specific Gravity | | 0.54 |
| Gas Specific Gravity | | 0.765 |
| **Pipeline Data** | | |
| Inside Diameter | | 12 inches |
| Roughness | | 0.0018 inch |
| **Heat Transfer Data** | | |
| Overall U-factor | | 2.0 Btu/hr - ft 2 -F |
| Ambient Temperature | | 80° F |



## PIPEPHASE Features Used In This Problem

- The network option with mixed boundary conditions is used to solve for unknown pressures and flowrates.
- The Blackoil Vazquez PVT equation, best suited for moderate gravity blackoil fluids, is used.
- Rigorous heat transfer uses an overall U-factor to obtain more accurate fluid properties and energy balance.
- A velocity detail report is requested in order to determine if there are erosion problems in any of the pipeline segments.

## Results and Discussion

1. The link and node reports in the OUTPUT section show the pressure distribution and flowrate in each link. Table P10.2 below summarizes the boundary conditions.

| Table P10.2: Node Pressure and Flowrate Results | | |
|---|---|---|
| **Node Name** | **Pressure(psig)** | **Flowrate(bpd)** |
| AO (source) | 395.0* | 147,209 |
| A1 (source) | 299.5 | 10,000* |
| A2 (source) | 233.6 | 15,500* |
| A3 (source) | 176.1 | 20,000* |
| B (sink) | 125.0* | 71,828 |
| C (sink) | 110.0* | 120,800 |

*Denotes user-specified values.

P10 Blackoil Looped Network

2. The results show that the following pipe sections have the highest pressure drops:

| Link Name | Pressure Gradient (psi/ft) | Pressure Drop (psi) |
|---|---|---|
| 3 | 0.0038 | 121.3 |
| 8 | 0.0035 | 122.1 |

   Some links have a higher pressure gradient but are short enough that their pressure drops are relatively small. The 50,000 ft. long crossover line from J2 to J4 has a flowrate of 5,695 bbl/day and a total pressure drop of 3.8 psi. This crossover link is insignificant in transporting the fluid. It may be shut down without substantially affecting the whole network throughput.

3. The total system delivers 192,628 bbl/day of oil. Terminal B receives 71,828 bpd and Terminal C receives 120,800.

## Simulation Highlights

INPUT

- The Beggs and Brill-Moody correlation (DEFAULT) is chosen for pressure drop and holdup calculations. Thus, there is no entry required for FCODE.
- An ambient temperature of 80$^{o}$F, which is the same as the program default value, is also not input into the data file.
- Although water is not present in this problem, water gravity must be input for the Blackoil model. A specific gravity of 1.0 is used in the input.
- The Vazquez correlation for blackoil properties calculation is the default method in the program. There is no need to specify this correlation.

TECHNIQUE

- For looped networks, the direction of flow in the link should be consistent with the pressure estimates of the nodes. The more complicated the network, the more important junction pressure estimates become.

# Input Data

The keyword input data file for this simulation is given below.

## Keyword Input Data File

```
TITLE   PROBLEM=PIPE10, PROJECT=PIPEAPP, USER=SIMSCI
DESC    LOOPED NETWORK
DIME    PETROLEUM, GRAV=SPGR
CALC    NETWORK, BLACKOIL
DEFAULT IDPIPE=12, UPIPE=2.0
SEGMENT DLHOR=1000
PRINT   INPUT=FULL, DEVICE=FULL
$
PVT DATA
        SET     SETN=1, GRAV(GAS)=0.765, GRAV(OIL)=0.54, *
                GRAV(WATER)=1.0
$
STRUCTURE DATA
        SOURCE  SETNO=1, NAME=A0, TEMP=120, PRES=395, *
                RATE(ESTI)=100000, GOR=400
        SOURCE  SETNO=1, NAME=A1, TEMP=110, PRES(ESTI)=300, *
                RATE=10000, GOR=300
        SOURCE  SETNO=1, NAME=A2, TEMP=110, PRES(ESTI)=250, *
                RATE=15500, GOR=100
        SOURCE  SETNO=1, NAME=A3, TEMP=120, PRES(ESTI)=200, *
        RATE=20000, GOR=230
$
        JUNCTIO NAME=J0
        JUNCTIO NAME=J1
        JUNCTIO NAME=J2
        JUNCTIO NAME=J3
        JUNCTIO NAME=J4
        JUNCTIO NAME=J5
        JUNCTIO NAME=J6
$
        LINK    NAME=1, FROM=A0, TO=J0
                PIPE    LENGTH=3500
        LINK    NAME=2, FROM=J0, TO=J1
                PIPE    LENGTH=35000
        LINK    NAME=3, FROM=J0, TO=J4
                PIPE    LENGTH=32000
        LINK    NAME=4, FROM=A1, TO=J1
                PIPE    LENGTH=1000
        LINK    NAME=5, FROM=J1, TO=J2
                PIPE    LENGTH=30000
        LINK    NAME=6, FROM=A2, TO=J2
                PIPE    LENGTH=2500
        LINK    NAME=7, FROM=J2, TO=J4
                PIPE    LENGTH=50000, ID=8
        LINK    NAME=8, FROM=J2, TO=J5
                PIPE    LENGTH=35000
        LINK    NAME=9, FROM=J4, TO=J3
                PIPE    LENGTH=18000
        LINK    NAME=10, FROM=A3, TO=J3
                PIPE    LENGTH=1000
        LINK    NAME=11, FROM=J3,  TO=J6
                PIPE    LENGTH=10000
        LINK    NAME=12, FROM=J5,  TO=J6
                PIPE    LENGTH=30000
        LINK    NAME=13, FROM=J6,  TO=B
                PIPE    LENGTH=100
        LINK    NAME=14, FROM=J5,  TO=C
                PIPE    LENGTH=100
$
        SINK    NAME=B, PRES=125, RATE(ESTI)=14000
        SINK    NAME=C, PRES=110, RATE(ESTI)=14000
END
```

P10 Blackoil Looped Network

## Output

- If the link flow direction is different than that specified by the user, a negative flowrate is printed for this link in all reports. For example, Link 7 has negative flowrate which means that the flow direction is from Junction 4 to Junction 2.

## Partial Output

The following link and node reports show the flow distribution and flowrates for each link. Negative flowrates mean the link direction is reversed from that given by the user.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | | ----ACTUAL FLOW RATES***-- GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | ----HOLDUP**--- GAS (MM SCF) | LIQ (STB) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A0 | (F) | 0.0000 | 198313.5 | 0.0 | 395.0* | | 120.0 | | |
| | J0 | (T) | 0.0000 | 198036.4 | 0.0 | 357.9 | 37.1 | 119.0 | 0.0000 | 408.7 |
| 10 | A3 | (F) | 0.0000 | 25556.5 | 0.0 | 176.1 | | 120.0 | | |
| | J3 | (T) | 0.0000 | 25422.5 | 0.0 | 175.9 | 0.2 | 117.9 | 0.0000 | 117.6 |
| 11 | J3 | (F) | 0.0000 | 134613.8 | 0.0 | 175.9 | | 104.4 | | |
| | J6 | (T) | 0.0000 | 134465.8 | 0.0 | 125.2 | 50.6 | 102.1 | 0.0000 | 1205.4 |
| 12 | J6 | (F) | 0.0000 | -41664.1 | 0.0 | 125.2 | | 102.1 | | |
| | J5 | (T) | 0.0000 | -41754.2 | 0.0 | 110.7 | -14.6 | 102.1 | 0.0000 | 3702.1 |
| 13 | J6 | (F) | 0.0000 | 92801.7 | 0.0 | 125.2 | | 102.1 | | |
| | B | (T) | 0.0000 | 92796.7 | 0.0 | 125.0* | 0.2 | 102.0 | 0.0000 | 12.1 |
| 14 | J5 | (F) | 0.0000 | 151678.0 | 0.0 | 110.7 | | 93.7 | | |
| | C | (T) | 0.0000 | 151686.5 | 0.0 | 110.0* | 0.7 | 93.7 | 0.0000 | 12.3 |
| 2 | J0 | (F) | 0.0000 | 79089.5 | 0.0 | 357.9 | | 119.0 | | |
| | J1 | (T) | 0.0000 | 75817.1 | 0.0 | 299.4 | 58.4 | 100.9 | 0.0000 | 4185.9 |
| 3 | J0 | (F) | 0.0000 | 118946.9 | 0.0 | 357.9 | | 119.0 | | |
| | J4 | (T) | 0.0000 | 115964.6 | 0.0 | 236.6 | 121.3 | 106.7 | 0.0000 | 3790.9 |
| 4 | A1 | (F) | 0.0000 | 12735.6 | 0.0 | 299.5 | | 110.0 | | |
| | J1 | (T) | 0.0000 | 12639.7 | 0.0 | 299.4 | 7.23E-2 | 106.9 | 0.0000 | 120.5 |
| 5 | J1 | (F) | 0.0000 | 88454.7 | 0.0 | 299.4 | | 101.8 | | |
| | J2 | (T) | 0.0000 | 86872.4 | 0.0 | 232.7 | 66.7 | 93.7 | 0.0000 | 3688.9 |
| 6 | A2 | (F) | 0.0000 | 18371.3 | 0.0 | 233.6 | | 110.0 | | |
| | J2 | (T) | 0.0000 | 18135.4 | 0.0 | 232.7 | 0.9 | 104.9 | 0.0000 | 306.2 |
| 7 | J4 | (F) | 0.0000 | -5694.3 | 0.0 | 236.6 | | 106.7 | | |
| | J2 | (T) | 0.0000 | -5695.4 | 0.0 | 232.7 | -3.8 | 106.7 | 0.0000 | 2842.8 |
| 8 | J2 | (F) | 0.0000 | 110671.5 | 0.0 | 232.7 | | 96.2 | | |
| | J5 | (T) | 0.0000 | 109927.8 | 0.0 | 110.7 | 122.1 | 90.6 | 0.0000 | 4348.8 |
| 9 | J4 | (F) | 0.0000 | 110270.3 | 0.0 | 236.6 | | 106.7 | | |
| | J3 | (T) | 0.0000 | 109199.4 | 0.0 | 175.9 | 60.7 | 101.3 | 0.0000 | 2168.7 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

NODE SUMMARY

| NODE | PRES. (PSIG) | ---STANDARD FLOW RATES ---** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | TEMP. (F) |
|---|---|---|---|---|---|
| A0 | 395.0* | 58.8834 | 147208.5 | 0.0 | 120.0 |
| A3 | 176.1 | 4.6000 | 20000.0* | 0.0 | 120.0 |
| J3 | 175.9 | 0.0000 | 0.0* | 0.0 | 104.4 |
| J5 | 110.7 | 0.0000 | 0.0* | 0.0 | 93.7 |
| J6 | 125.2 | 0.0000 | 0.0* | 0.0 | 102.1 |
| J0 | 357.9 | 0.0000 | 0.0* | 0.0 | 119.0 |
| A1 | 299.5 | 3.0000 | 10000.0* | 0.0 | 110.0 |
| J1 | 299.4 | 0.0000 | 0.0* | 0.0 | 101.8 |
| A2 | 233.6 | 1.5500 | 15500.0* | 0.0 | 110.0 |
| J2 | 232.7 | 0.0000 | 0.0* | 0.0 | 96.2 |
| J4 | 236.6 | 0.0000 | 0.0* | 0.0 | 106.7 |
| B | 125.0* | -26.3849 | -71828.4 | 0.0 | 102.0 |
| C | 110.0* | -41.6485 | -1.208E5 | 0.0 | 93.7 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

## Partial Output (continued)

The following pressure, holdup and pressure gradient reports for the crossover Link 7 (from J2 to J4) show a very low velocity and low pressure gradient for this link.

```
                LINK "7   " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT
-------------------------------
DEVICE              MWD OR      TVD
NAME                LENGTH   I  OR
AND    SEGM INSIDE   FROM    &  ELEV     CALC    CALC   OVERALL AMB
TYPE   NO   DIAM.   INLET    O  CHNG     PRESS   TEMP   U-FACT  TEMP
            (IN)     (FT)       (FT)     (PSIG)  (F)    (BTUFT- (F)
                                                        F)
------ ---- ------ --------- - -------- ------- ------ ------- ------
 P007  0000  8.000       0.0 I      0.0   236.6  106.7           80.0
(PIPE) 0001           2500.0        0.0   236.4   97.7   2.000   80.0
       0002           5000.0        0.0   236.2   91.7   2.000   80.0
       0003           7500.0        0.0   236.0   87.8   2.000   80.0
       0004          10000.0        0.0   235.8   85.1   2.000   80.0
       0005          12500.0        0.0   235.6   83.4   2.000   80.0
       0006          15000.0        0.0   235.4   82.2   2.000   80.0
       0007          17500.0        0.0   235.3   81.5   2.000   80.0
       0008          20000.0        0.0   235.1   81.0   2.000   80.0
       0009          22500.0        0.0   234.9   80.6   2.000   80.0
       0010          25000.0        0.0   234.7   80.4   2.000   80.0
        :
        :
        :

HOLDUP AND VELOCITY DETAIL REPORT
---------------------------------
DEVICE
NAME        ---LIQUID HOLDUP---          ACTUAL                  T-D
AND    SEG. NO                    LIQ     GAS     MIX .  FLOW FLOW   SONIC
TYPE   NO.  SLIP  SLIP   TOTAL    VEL     VEL     VEL    REGM REGM   VEL
                         (ABBL)  (FPS)   (FPS)   (FPS)              (FPS)
------ ---- ----- ----- -------- ------- ------- ------- ---- ---- -------
 P007  0000
(PIPE) 0001  1.00  1.00    155.4    1.02    0.00    1.02 1-PH 1-PH    0.00
       0002  1.00  1.00    310.8    1.01    0.00    1.01 1-PH 1-PH    0.00
       0003  1.00  1.00    466.3    0.99    0.00    0.99 1-PH 1-PH    0.00
       0004  1.00  1.00    621.7    0.98    0.00    0.98 1-PH 1-PH    0.00
       0005  1.00  1.00    777.1    0.98    0.00    0.98 1-PH 1-PH    0.00
       0006  1.00  1.00    932.5    0.97    0.00    0.97 1-PH 1-PH    0.00
       0007  1.00  1.00   1087.9    0.97    0.00    0.97 1-PH 1-PH    0.00
       0008  1.00  1.00   1243.3    0.97    0.00    0.97 1-PH 1-PH    0.00
       0009  1.00  1.00   1398.8    0.97    0.00    0.97 1-PH 1-PH    0.00
       0010  1.00  1.00   1554.2    0.97    0.00    0.97 1-PH 1-PH    0.00
        :
        :
        :

PRESSURE GRADIENT DETAIL REPORT
-------------------------------
DEVICE
NAME
AND   SEGM.  --PRESSURE GRADIENT---- ---PRESSURE DROP---
TYPE  NO:     FRIC    ELEV    TOTAL    FRIC     ELEV
            (PSIFT)  (PSIFT)  (PSIFT)  (PSIG)   (PSIG)
------ ---- -------- -------- -------- -------- --------
 P007  0000
(PIPE) 0001 -7.59E-5   0.0000 -7.59E-5     -0.2      0.0
       0002 -7.47E-5   0.0000 -7.47E-5     -0.2      0.0
       0003 -7.40E-5   0.0000 -7.40E-5     -0.2      0.0
       0004 -7.35E-5   0.0000 -7.35E-5     -0.2      0.0
       0005 -7.32E-5   0.0000 -7.32E-5     -0.2      0.0
       0006 -7.30E-5   0.0000 -7.30E-5     -0.2      0.0
       0007 -7.29E-5   0.0000 -7.29E-5     -0.2      0.0
       0008 -7.28E-5   0.0000 -7.28E-5     -0.2      0.0
       0009 -7.28E-5   0.0000 -7.28E-5     -0.2      0.0
       0010 -7.27E-5   0.0000 -7.27E-5     -0.2      0.0
        :
        :
```

## Partial Output (continued)

The device summary is shown below.

```
                                   DEVICE SUMMARY

                 C
                 O                                      ------- OUTLET ------ AVG.
LINK DEVI DEVI   R   INSIDE    MEAS      ELEV                        INSITU  LIQ
NAME NAME TYPE   R   DIAM      LENGTH    CHNG     PRESS:  TEMP:        GLR  HOLDUP
                     (IN)      (FT)      (FT)    (PSIG)  (F)     (CFBBL)
---- ---- ---- ---- -------- --------- ------- ------- ------ ------- ------
1      ***SOURCE*** RATE= 1.472E5 (BPD)           395.0  120.0  GLR=     400.
     A0                                           395.0  120.0
     P001 PIPE BM     12.000    3500.0     0.0   357.9  119.0       0.   1.00
         **JUNCTION**  PRES=   357.9 (PSIG)  TEMP=  119.0 (F)

10     ***SOURCE*** RATE= 20000.0 (BPD)           176.1  120.0  GLR=     230.
     A3                                           176.1  120.0
     P010 PIPE BM     12.000    1000.0     0.0   175.9  117.9       0.   1.00
         **JUNCTION**  PRES=   175.9 (PSIG)  TEMP=  104.4 (F)

11    **JUNCTION**  RATE= 1.040E5 (BPD)           175.9  104.4  GLR=     367.
     J3                                           175.9  104.4
     P011 PIPE BM     12.000   10000.0     0.0   125.2  102.1       0.   1.00
         **JUNCTION**  PRES=   125.2 (PSIG)  TEMP=  102.1 (F)

12    **JUNCTION**  RATE= -3.22E4 (BPD)           125.2  102.1  GLR=     367.
     J5                                           125.2  102.1
     P012 PIPE BM     12.000   30000.0     0.0   110.9   88.1       0.   1.00
         **JUNCTION**  PRES=   110.7 (PSIG)  TEMP=   93.7 (F)

13    **JUNCTION**  RATE= 71828.4 (BPD)           125.2  102.1  GLR=     367.
     J6                                           125.2  102.1
     P013 PIPE BM     12.000     100.0     0.0   125.0  102.0       0.   1.00
          *** SINK *** PRES=   125.0 (PSIG)  TEMP=  102.0 (F)

14    **JUNCTION**  RATE= 1.208E5 (BPD)           110.7   93.7  GLR=     345.
     J5                                           110.7   93.7
     P014 PIPE BM     12.000     100.0     0.0   110.0   93.7       0.   1.00
          *** SINK *** PRES=   110.0 (PSIG)  TEMP=   93.7 (F)

2     **JUNCTION**  RATE= 58790.4 (BPD)           357.9  119.0  GLR=     400.
     J0                                           357.9  119.0
     P002 PIPE BM     12.000   35000.0     0.0   299.4  100.9       0.   1.00
         **JUNCTION**  PRES=   299.4 (PSIG)  TEMP=  101.8 (F)

3     **JUNCTION**  RATE= 88418.0 (BPD)           357.9  119.0  GLR=     400.
     J0                                           357.9  119.0
     P003 PIPE BM     12.000   32000.0     0.0   236.6  106.7       0.   1.00
         **JUNCTION**  PRES=   236.6 (PSIG)  TEMP=  106.7 (F)

4      ***SOURCE*** RATE= 10000.0 (BPD)           299.5  110.0  GLR=     300.
     A1                                           299.5  110.0
     P004 PIPE BM     12.000    1000.0     0.0   299.5  106.9       0.   1.00
         **JUNCTION**  PRES=   299.4 (PSIG)  TEMP=  101.8 (F)
5     **JUNCTION**  RATE= 68790.4 (BPD)           299.4  101.8  GLR=     385.
     J1                                           299.4  101.8
     P005 PIPE BM     12.000   30000.0     0.0   233.4   93.7       0.   1.00
         **JUNCTION**  PRES=   232.7 (PSIG)  TEMP=   96.2 (F)

6      ***SOURCE*** RATE= 15500.0 (BPD)           233.6  110.0  GLR=     100.
     A2                                           233.6  110.0
     P006 PIPE BM     12.000    2500.0     0.0   233.4  104.9       0.   1.00
         **JUNCTION**  PRES=   232.7 (PSIG)  TEMP=   96.2 (F)

7     **JUNCTION**  RATE= -4341.7 (BPD)           236.6  106.7  GLR=     400.
     J2                                           236.6  106.7
     P007 PIPE BM      8.000   50000.0     0.0   232.9   80.0       0.   1.00
         **JUNCTION**  PRES=   232.7 (PSIG)  TEMP=   96.2 (F)

8     **JUNCTION**  RATE= 88632.1 (BPD)           232.7   96.2  GLR=     336.
     J2                                           232.7   96.2
     P008 PIPE BM     12.000   35000.0     0.0   109.9   90.6       0.   1.00
         **JUNCTION**  PRES=   110.7 (PSIG)  TEMP=   93.7 (F)

9     **JUNCTION**  RATE= 84076.4 (BPD)           236.6  106.7  GLR=     400.
     J4                                           236.6  106.7
     P009 PIPE BM     12.000   18000.0     0.0   175.8  101.3       0.   1.00
         **JUNCTION**  PRES=   175.9 (PSIG)  TEMP=  104.4 (F)
```

# Condensate Well Tubing Design

## Problem Description

A gas well completed in a sandstone reservoir produces some sand. From erosional velocity considerations the well can be safely produced at a gas velocity of up to 24 ft/sec. The maximum production rate will be 10 MMscfd. The minimum bottomhole pressure is expected to be 2000 psig (abandonment pressure.) A schematic of the well is shown in Figure P11.1. Other process data for the well are given in Table P11.1.

You are required to:

1. Determine the minimum size of the inner tubings TUB2, TUB3 and TUB4 in order that the erosion velocity is not exceeded for the maximum allowable rate. Note that the outermost tubing TUB1 is not sized.
2. Determine the maximum velocity in the tubing string.
3. Determine where the maximum velocity occurs.

**Figure P11.1: Condensate Well**

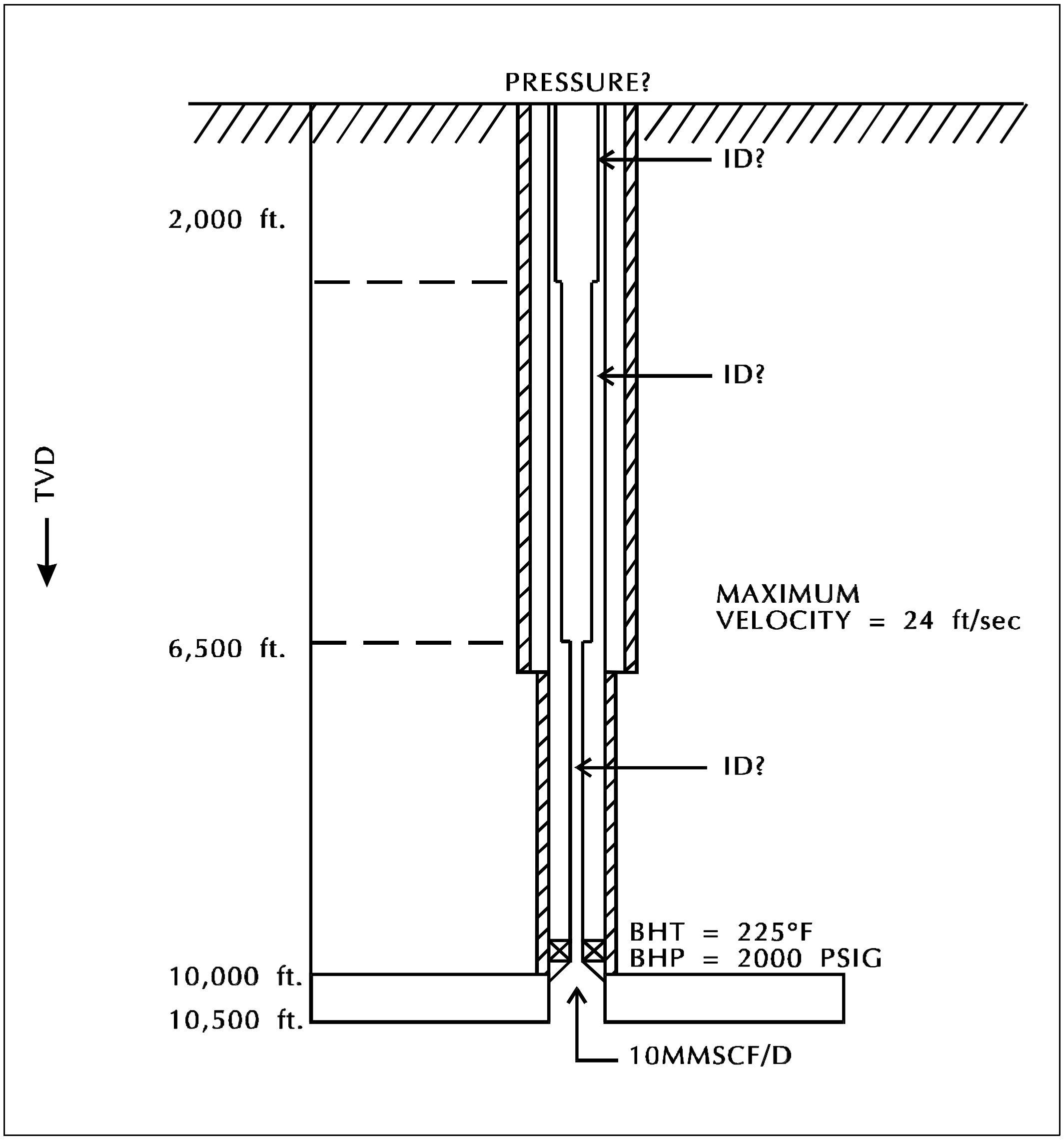


**Table P11.1: Process Information**

**Fluid Compositions**

| Components | Mole % |
|---|---|
| N2 | 11.21 |
| H2S | 0.05 |
| CO2 | 6.49 |
| H2 | 0.3 |
| C1 | 80.12 |
| C2 | 1.37 |
| C3 | 0.28 |
| IC4 | 0.05 |
| NC4 | 0.08 |
| IC5 | 0.03 |
| NC5 | 0.02 |

**Compressor Data**

| MWD (ft) | ID (in) |
|---|---|
| 10500 | 5.5 |
| 10000 | 2.441 |
| 6500 | 2.992 |
| 2000 | 3.958 |

**Heat Transfer Data**

U = 2.5 Btu/hr-ft$^2$-F

Temp. Gradient = 1.4°F/100 ft

## PIPEPHASE Features Used In This Problem

- The automatic line sizer with velocity criteria option is used to size selected piping devices. This eliminates the need for manual trial runs to achieve the design criteria.
- The compositional model is used which treats heat transfer and temperature effects accurately.
- Rigorous enthalpy and heat transfer calculations are performed. This is important especially if parameters such as velocity are of primary interest as in this problem.

## Results and Discussion

A partial output listing is given. The following results were obtained:

1. The tubing sizes calculated were 3.548 in., 3.548 in. and 2.992 in., starting at the surface. These are shown in the device summary of the output.
2. The maximum velocity is 23.7 ft/sec as shown in the velocity report of link detail output. Without the sizing constraint, the maximum velocity would be 38.4 ft/sec.
3. This maximum velocity occurs at a depth of about 6500 ft.



## Simulation Highlights

INPUT

- The compositional gas option was used since it was known beforehand there will be no liquid phase over the range of pressures and temperatures in the system. This option bypasses the unnecessary flash calculations. The effects of non-hydrocarbon gases ($N_2$, $CO_2$, $H_2S$) were taken into account rigorously through the use of the SRK equation of state.
- The default (BEGGS-BRILL-MOODY) correlation was used. For single phase, this degenerates to MOODY and considers acceleration effects rigorously.

TECHNIQUE

- Segment sizes of 400 ft. were used.
- A constant maximum velocity (24 ft/sec) curve was used for the velocity criteria in line sizing.
- Multiple tubings were used. The greater the number of tubings, the closer the design to the theoretical minimum size combination.

## Input Data

Petroleum units of measure are used throughout the simulation. The keyword input file for this simulation is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL1, PROJ=WELLAPP, USER=SIMSCI
DESC    CONDENSATE WELL TUBING DESIGN
DIME    PETROLEUM
CALC    SINGLE, COMP(GAS)
PRINT   DEVICE=PART, PLOT=FULL, INPUT=NONE
DEFAULT UTUBE=2.5, TGRAD=1.4
SEGMENT DLVERT=400
$
COMP DATA
        LIBID   CO2/H2S/N2/H2/C1/C2/C3/IC4/NC4/IC5/NC5
$
METHOD DATA
        THERMO  SYSTEM=SRK
$
STRUCTURE DATA
        SOURCE  NAME=S1, PRES=2000, TEMP=225, RATE(GV)=10,*
        COMP=6.49/0.05/11.21/0.3/80.12/1.37/0.28/0.05/0.08/0.03/0.02
$
        TUBING  NAME=TUB1, LENGTH=10500, ID=5.5
        TUBING  NAME=TUB2, LENGTH=10000, ID=2.441
        TUBING  NAME=TUB3, LENGTH=6500, ID=2.992
        TUBING  NAME=TUB4, LENGTH=2000, ID=3.958
$
        SINK    NAME=S2, PRES(ESTI)=500, RATE(ESTI)=10
$
SIZING DATA
        DEVICE  NAME=TUB2,TUB3,TUB4
        LINE    ID=1.995,2.441,2.992,3.548,3.958
        MAXV    VELO(FPS)=24/24, ID=1/6
END
```



## Output

- The maximum velocity does not occur at the surface (lowest pressure point) because of the tapered tubing where the tubing size increases as it nears the surface.
- The velocities in the wellbore are printed in the link device detail report (holdup and velocity detail section).
- The linesizing option in PIPEPHASE checks if the conduit diameter is large enough to satisfy a maximum velocity criteria. If the maximum velocity is exceeded, the next larger diameter is tried. However, if the maximum velocity is not exceeded, calculations are not tried with a smaller diameter.

## Partial Output

The pressure and velocity reports are given below and on the following page. The results show that the maximum velocity of 23.7 ft/sec occurs at a depth of 6500 ft.

LINK "LINK" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| TUB1 | 0000 | 5.500 | 10500.0 | I | 10500.0 | 2000.0 | 225.0 | | 225.0 | 1.00 |
| (TBNG) | 0001 | | 10250.0 | | 10250.0 | 1990.3 | 224.2 | 2.500 | 221.5 | 1.00 |
| | 0002 | | 10000.0 | O | 10000.0 | 1980.6 | 223.1 | 2.500 | 218.0 | 1.00 |
| TUB2 | 0000 | 2.992 | 10000.0 | I | 10000.0 | 1980.6 | 223.1 | | 218.0 | 1.00 |
| (TBNG) | 0001 | | 9600.0 | | 9600.0 | 1957.1 | 221.3 | 2.500 | 212.4 | 1.00 |
| | 0002 | | 9200.0 | | 9200.0 | 1933.8 | 219.3 | 2.500 | 206.8 | 1.00 |
| | 0003 | | 8800.0 | | 8800.0 | 1910.5 | 217.0 | 2.500 | 201.2 | 1.00 |
| | 0004 | | 8400.0 | | 8400.0 | 1887.2 | 214.5 | 2.500 | 195.6 | 1.00 |
| | 0005 | | 8000.0 | | 8000.0 | 1864.0 | 211.8 | 2.500 | 190.0 | 1.00 |
| | 0006 | | 7600.0 | | 7600.0 | 1840.8 | 208.9 | 2.500 | 184.4 | 1.00 |
| | 0007 | | 7200.0 | | 7200.0 | 1817.6 | 205.8 | 2.500 | 178.8 | 1.00 |
| | 0008 | | 6800.0 | | 6800.0 | 1794.5 | 202.6 | 2.500 | 173.2 | 1.00 |
| | **0009** | | **6500.0** | **O** | **6500.0** | 1777.2 | 200.1 | 2.500 | 169.0 | 1.00 |
| TUB3 | 0000 | 3.548 | 6500.0 | I | 6500.0 | 1777.2 | 200.1 | | 169.0 | 1.00 |
| (TBNG) | 0001 | | 6100.0 | | 6100.0 | 1759.3 | 196.3 | 2.500 | 163.4 | 1.00 |
| | 0002 | | 5700.0 | | 5700.0 | 1741.5 | 192.4 | 2.500 | 157.8 | 1.00 |
| | 0003 | | 5300.0 | | 5300.0 | 1723.6 | 188.4 | 2.500 | 152.2 | 1.00 |
| | 0004 | | 4900.0 | | 4900.0 | 1705.8 | 184.2 | 2.500 | 146.6 | 1.00 |
| | 0005 | | 4500.0 | | 4500.0 | 1688.0 | 179.9 | 2.500 | 141.0 | 1.00 |
| | 0006 | | 4100.0 | | 4100.0 | 1670.2 | 175.5 | 2.500 | 135.4 | 1.00 |
| | 0007 | | 3700.0 | | 3700.0 | 1652.4 | 171.1 | 2.500 | 129.8 | 1.00 |
| | 0008 | | 3300.0 | | 3300.0 | 1634.6 | 166.5 | 2.500 | 124.2 | 1.00 |
| | 0009 | | 2900.0 | | 2900.0 | 1616.8 | 161.9 | 2.500 | 118.6 | 1.00 |
| | 0010 | | 2500.0 | | 2500.0 | 1599.0 | 157.2 | 2.500 | 113.0 | 1.00 |
| | 0011 | | 2100.0 | | 2100.0 | 1581.3 | 152.4 | 2.500 | 107.4 | 1.00 |
| | 0012 | | 2000.0 | O | 2000.0 | 1576.8 | 151.2 | 2.500 | 106.0 | 1.00 |
| TUB4 | 0000 | 3.548 | 2000.0 | I | 2000.0 | 1576.8 | 151.2 | | 106.0 | 1.00 |
| (TBNG) | 0001 | | 1600.0 | | 1600.0 | 1559.1 | 146.3 | 2.500 | 100.4 | 1.00 |
| | 0002 | | 1200.0 | | 1200.0 | 1541.3 | 141.4 | 2.500 | 94.8 | 1.00 |
| | 0003 | | 800.0 | | 800.0 | 1523.5 | 136.4 | 2.500 | 89.2 | 1.00 |
| | 0004 | | 400.0 | | 400.0 | 1505.7 | 131.4 | 2.500 | 83.6 | 1.00 |
| | 0005 | | 0.0 | O | 0.0 | 1487.9 | 126.2 | 2.500 | 78.0 | 1.00 |

## Partial Output (continued)

The velocities in the well are given in the output below.

LINK "LINK" DEVICE DETAIL REPORT

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| TUB1 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 6.58 | 6.58 | 1-PH | 1-PH | 1540.30 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 6.60 | 6.60 | 1-PH | 1-PH | 1538.82 |
| TUB2 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 22.41 | 22.41 | 1-PH | 1-PH | 1533.88 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 22.59 | 22.59 | 1-PH | 1-PH | 1530.79 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 22.76 | 22.76 | 1-PH | 1-PH | 1527.36 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 22.92 | 22.92 | 1-PH | 1-PH | 1523.59 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 23.08 | 23.08 | 1-PH | 1-PH | 1519.51 |
| | 0006 | 0.00 | 0.00 | 0.0 | 0.00 | 23.23 | 23.23 | 1-PH | 1-PH | 1515.08 |
| | 0007 | 0.00 | 0.00 | 0.0 | 0.00 | 23.38 | 23.38 | 1-PH | 1-PH | 1510.42 |
| | 0008 | 0.00 | 0.00 | 0.0 | 0.00 | 23.53 | 23.53 | 1-PH | 1-PH | 1505.49 |
| | **0009** | 0.00 | 0.00 | 0.0 | 0.00 | **23.65** | **23.65** | 1-PH | 1-PH | 1502.16 |
| TUB3 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 16.87 | 16.87 | 1-PH | 1-PH | 1497.12 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 16.91 | 16.91 | 1-PH | 1-PH | 1491.13 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 16.94 | 16.94 | 1-PH | 1-PH | 1484.89 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 16.97 | 16.97 | 1-PH | 1-PH | 1478.42 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 16.99 | 16.99 | 1-PH | 1-PH | 1471.73 |
| | 0006 | 0.00 | 0.00 | 0.0 | 0.00 | 17.01 | 17.01 | 1-PH | 1-PH | 1464.82 |
| | 0007 | 0.00 | 0.00 | 0.0 | 0.00 | 17.02 | 17.02 | 1-PH | 1-PH | 1457.72 |
| | 0008 | 0.00 | 0.00 | 0.0 | 0.00 | 17.04 | 17.04 | 1-PH | 1-PH | 1450.42 |
| | 0009 | 0.00 | 0.00 | 0.0 | 0.00 | 17.05 | 17.05 | 1-PH | 1-PH | 1443.01 |
| | 0010 | 0.00 | 0.00 | 0.0 | 0.00 | 17.05 | 17.05 | 1-PH | 1-PH | 1435.40 |
| | 0011 | 0.00 | 0.00 | 0.0 | 0.00 | 17.06 | 17.06 | 1-PH | 1-PH | 1427.61 |
| | 0012 | 0.00 | 0.00 | 0.0 | 0.00 | 17.06 | 17.06 | 1-PH | 1-PH | 1425.68 |
| TUB4 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 17.06 | 17.06 | 1-PH | 1-PH | 1417.65 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 17.05 | 17.05 | 1-PH | 1-PH | 1409.48 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 17.05 | 17.05 | 1-PH | 1-PH | 1401.13 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 17.04 | 17.04 | 1-PH | 1-PH | 1392.62 |
| | 0005 | 0.00 | 0.00 | 0.0 | 0.00 | 17.02 | 17.02 | 1-PH | 1-PH | 1383.95 |

## Partial Output (continued)

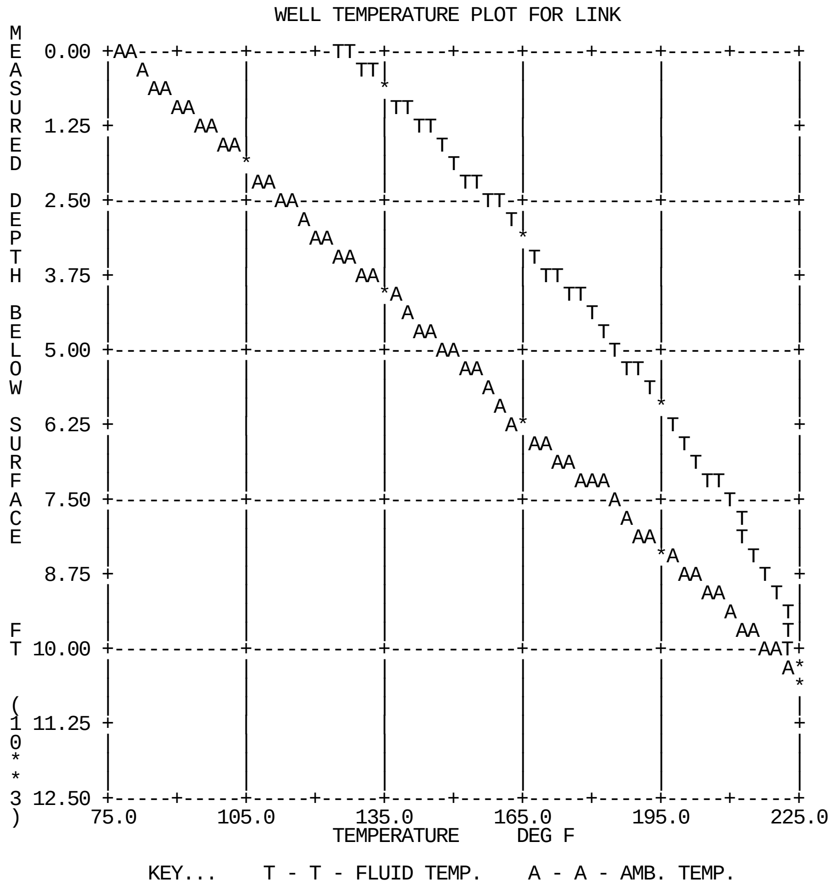
The pressure profile in the well is shown below.

```
                         WELL PRESSURE PLOT FOR LINK
M
E  0.00 +----PP-----+-----+-----+-----+-----+-----+-----+-----+-----+
A       |      P     |           |           |           |           |
S       |       P    |           |           |           |           |
U       |       PP   |           |           |           |           |
R  1.25 +         PP|           |           |           |           +
E       |           *P          |           |           |           |
D       |           | P         |           |           |           |
        |           | PP        |           |           |           |
D  2.50 +-----------+---PP------+-----------+-----------+-----------+
E       |           |     P     |           |           |           |
P       |           |      P    |           |           |           |
T       |           |      PP   |           |           |           |
H  3.75 +           |        PP |           |           |           +
        |           |         P*           |           |           |
B       |           |           |P          |           |           |
E       |           |           | P         |           |           |
L  5.00 +-----------+-----------+--P--------+-----------+-----------+
O       |           |           |   PP      |           |           |
W       |           |           |     P     |           |           |
        |           |           |      P    |           |           |
S  6.25 +           |           |       PP  |           |           +
U       |           |           |         P |           |           |
R       |           |           |          P*           |           |
F       |           |           |           |PPP        |           |
A  7.50 +-----------+-----------+-----------+---P-------+-----------+
C       |           |           |           |    P      |           |
E       |           |           |           |     PP    |           |
        |           |           |           |       PPP |           |
   8.75 +           |           |           |          P*           +
        |           |           |           |           |P          |
        |           |           |           |           | PP        |
F       |           |           |           |           |   PP      |
T 10.00 +-----------+-----------+-----------+-----------+-----P-----+
        |           |           |           |           |      P    |
        |           |           |           |           |       P   |
(       |           |           |           |           |           |
1 11.25 +           |           |           |           |           +
0       |           |           |           |           |           |
*       |           |           |           |           |           |
*       |           |           |           |           |           |
3 12.50 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
)     1440.       1560.       1680.       1800.       1920.       2040.
                              PRESSURE    PSIG

                       KEY...    P - P - FLUID PRESS.
```

P11 Condensate Well Tubing Design

## Partial Output (continued)

The temperature profile in the well is shown below.



## Partial Output (continued)

The traverse of the fluid (marked by ‘X’ on the phase envelope below) shows that the initial assumption of a gas-only phase at the process conditions was correct.

```
        P H A S E   E N V E L O P E

P 25000.+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        :           :           :           :           :           :
R       :B          :           :           :           :           :
        :           :           :           :           :           :
E 22500.+           :           :           :           :           +
        :           :           :           :           :           :
S       :           :           :           :           :           :
        :           :           :           :           :           :
S 20000.+-----------+-----------+-----------+-----------+-----------+
        :           :           :           :           :           :
U       :           :           :           :           :           :
        :           :           :           :           :           :
R 17500.+           :           :           :           :           +
        :           :           :           :           :           :
E       :B          :           :           :           :           :
        :           :           :           :           :           :
  15000.+-----------+-----------+-----------+-----------+-----------+
P       :           :           :           :           :           :
S       :           :           :           :           :           :
I       :           :           :           :           :           :
G 12500.+           :           :           :           :           +
        :           :           :           :           :           :
        :           :           :           :           :           :
        : B         :           :           :           :           :
  10000.+-----------+-----------+-----------+-----------+-----------+
        :           :           :           :           :           :
        :           :           :           :           :           :
        :           :           :           :           :           :
   7500.+ B         :           :           :           :           +
        :           :           :           :           :           :
        :           :           :           :           :           :
        :           :           :           :           :           :
   5000.+-B---------+-----------+-----------+-----------+-----------+
        :           :           :           :           :           :
        : B         :           :           :           :           :
        :           :           :           :           :           :
   2500.+ B         :           :           :           :           +
        : B         :           :           :       XXXXXXX         :
        : B         :           :           :     XXX   :           :
        :  BB       :     BBBBBBCPDT        :           :           :
      0.+---BBBBBBPBBBBBBB+---D-DDDD--+-----+-----+-----+-----+-----+
     -400. -325. -250. -175. -100.  -25.   50.  125.  200.  275.  350.

                T E M P E R A T U R E   F

        I = INTERPOLATED     B = BUBBLE           D = DEW
        X = TRAVERSE         T = T EXTREMUM       P = P EXTREMUM
        C = CRITICAL
```

P11 Condensate Well Tubing Design

# Retrograde Gas Condensate Well

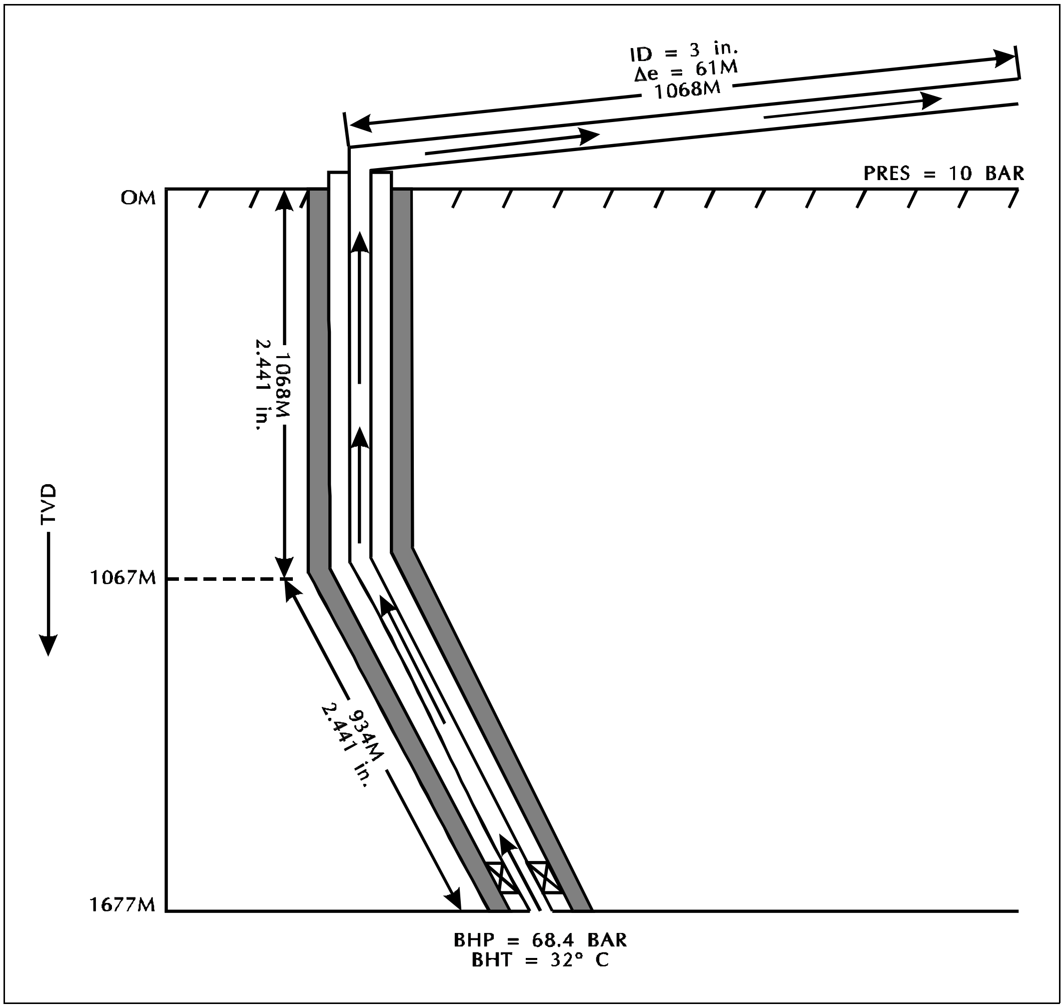
## Problem Description

A dry gas well, 1677 meters deep, has started producing some hydrocarbon liquids. A schematic of this well is given in Figure P12.1. Laboratory PVT analysis indicates the fluid is in the gas phase at reservoir conditions. You have been asked to study the well performance and the phase behavior in the well to explain this behavior. The flowing bottomhole pressure is 68.4 bar and surface pressure is 10 bar. Other data for the well are shown on Figure P12.1 and Table P12.1.

You are required to:

1. Determine the flowrate and the outlet temperature for the given inlet and outlet pressures.
2. Determine if there is a significant Joule-Thomson effect present.
3. Determine the point where first condensation begins.

**Figure P12.1: Retrograde Gas Condensate Well**




P12 Retrograde Gas Condensate Well

| Table P12.1: Process Information | |
|---|---|
| **Fluid Compositions** | |
| **Components** | **Mole %** |
| N2 | 10.2 |
| C1 | 70.1 |
| C2 | 11.9 |
| C3 | 4.11 |
| IC4 | 0.45 |
| NC4 | 1.20 |
| IC5 | 0.35 |
| NC5 | 0.43 |
| NC6 | 0.13 |
| NC7 | 0.03 |
| **Heat Transfer Data** | |
| U | 3.0 Btu/hr-ft $^2$ -F |
| Temp. Gradient | 1.6°C/100 m |
| Ambient Temperature | 8°C |
| **Pipeline Data** | |
| Roughness | 0.018 mm |
| Segment Horizontal Length Change | 1000 m |
| Segment Verticall Length Change | 300 m |

## PIPEPHASE Features Used In This Problem

- The compositional model is used to rigorously model the condensating fluid and Joule-Thomson cooling effects.
- Rigorous heat transfer is used to accurately model the overall heat balance.
- The Beggs-Brill-Moody correlation is used for calculating the pressure drop and holdup. This correlation is well behaved for all ranges of phase behavior.

## Results and Discussion

1. For the given boundary pressure the flowrate was calculated at 7558 Kg/hr (gas volume is equivalent to 8.34 Mscfd). The outlet temperature was -10.4°C, significantly below the ambient temperature of 8°C.
2. Condensation first forms at about 167 meters depth in the well.

## Simulation Highlights

INPUT

- The Peng-Robinson (PR) equation of state was used for phase split, enthalpy, and gas density calculations. The API method was used for liquid density and viscosity determination.
- The values for composition that were input were not normalized; the PIPEPHASE program performs this function.

TECHNIQUE

- The deviated well was simulated by dividing the production string into two tubings. This step provides a more accurate ambient temperature profile and well profile.
- The condensate model is inadequate because it is incapable of simulating more complex phenomena such as Joule-Thomson and retrograde effects, therefore, the compositional model was used.

## Input Data

The Metric units of measure are used throughout the simulation. The keyword input data file for this simulation is given below.

### Keyword Input Data File

Input for a Compositional Analysis.

```
TITLE   PROB=WELL2, PROJ=WELLAPP, USER=SIMSCI
DESC    GAS WELL PRODUCING LIQUIDS
CALC    SINGLE, COMPOSITIONAL
DIME    METRIC
DEFAULT TGRAD=1.6,UTUB(BTUFTF)=3.0, TAMB=8
PRINT   DEVICE=FULL, INPUT=FULL, PLOT=FULL, ITER
SEGMENT DLVERT=300, DLHOR=1000
$
COMPONENT DATA
        LIBID   N2/C1/C2/C3/IC4/NC4/IC5/NC5/NC6/NC7
$
METHOD DATA
        THERMO  SYSTEM=PR
$
STRUCTURE
        SOURCE  NAME=S1, TEMP=32, PRES=68.4, RATE(ESTI,W)=7500, *
        COMP=10.2/70.1/11.9/4.11/0.45/1.20/0.35/ *
        0.43/0.13/0.03,  NOCHECK
$
        TUBING  LENGTH=2002, DEPTH=1677, ID(IN)=2.441, ROUGH=.018
        TUBING  LENGTH=1068, DEPTH=1067, ID(IN)=2.441, ROUGH=.018
        PIPE    LENGTH=1068, ID(IN)=3, ECHG=61
$
        SINK    NAME=SNK1, PRES=10, RATE(ESTI,W)=7500
END
```

## Output

- The device detail report indicates flow is single phase gas until about 167 meters depth.
- The phase envelope shows the traverse of the fluid, which illustrates the retrograde condensation effect. If the well head pressure were lowered, a gas phase would be produced.

## Partial Output

The flash report for the inlet is given below.

```
FLASH REPORT

 NODE S1   AT     32.0 DEG C           AND     68.4 BAR

                     -------------------MOLE FRACTION------------------

                     ----HYDROCARBON----  COMBINED              TOTAL
COMPONENT            VAPOR     LIQUID1    VAP+LIQ1   LIQUID2    STREAM
-----------------    --------  --------   --------   --------   --------
N2                   0.103134  0.000000   0.103134   0.000000   0.103134
C1                   0.708797  0.000000   0.708797   0.000000   0.708797
C2                   0.120324  0.000000   0.120324   0.000000   0.120324
C3                   0.041557  0.000000   0.041557   0.000000   0.041557
IC4                  0.004550  0.000000   0.004550   0.000000   0.004550
NC4                  0.012133  0.000000   0.012133   0.000000   0.012134
IC5                  0.003539  0.000000   0.003539   0.000000   0.003539
NC5                  0.004348  0.000000   0.004348   0.000000   0.004348
NC6                  0.001314  0.000000   0.001314   0.000000   0.001314
NC7                  0.000303  0.000000   0.000303   0.000000   0.000303

TOTAL RATE (INLET TO NODE IF JUNCTION)
          KG/HR        7558.2       0.0     7558.2        0.0     7558.2
          MOLE/HR      353.30      0.00     353.30       0.00     353.30
WT FRAC LIQ                                 0.000000              0.000000

PHASE PROPERTIES
----------------
MASS FRACTION        1.000000  0.000000   1.000000   0.000000   1.000000
VOLUME FRAC          1.000000  0.000000   1.000000   0.000000   1.000000
DENSITY KG/M3          70.73      0.00                   0.00
SPECIFIC GRAV        0.738418  0.000000              0.000000
VISCOSITY CP           0.0136    0.0000                 0.0000
ENTHALPY  KCAL/KG      18.892     0.000                  0.000      18.892
SURF TENS NEWTON/M               0.000                  0.000
MOLECULAR WT          21.3934    0.0000    21.3934     0.0000    21.3934
```

## Partial Output (continued)

The flash report for the outlet is given below. Note the presence of two phases at the outlet and that the outlet temperature goes below the ambient temperature of 8 degrees C.

NODE SNK1 AT **-10.4 DEG C** AND 10.1 BAR

| | --------------------MOLE FRACTION------------------- | | | | |
|---|---|---|---|---|---|
| | ----HYDROCARBON---- | | COMBINED | | TOTAL |
| COMPONENT | VAPOR | LIQUID1 | VAP+LIQ1 | LIQUID2 | STREAM |
| N2 | 0.103304 | 0.001881 | 0.103134 | 0.000000 | 0.103134 |
| C1 | 0.709892 | 0.055134 | 0.708797 | 0.000000 | 0.708797 |
| C2 | 0.120405 | 0.071749 | 0.120324 | 0.000000 | 0.120324 |
| C3 | 0.041443 | 0.109383 | 0.041557 | 0.000000 | 0.041557 |
| IC4 | 0.004502 | 0.033389 | 0.004550 | 0.000000 | 0.004550 |
| NC4 | 0.011923 | 0.138009 | 0.012133 | 0.000000 | 0.012134 |
| IC5 | 0.003354 | 0.113646 | 0.003539 | 0.000000 | 0.003539 |
| NC5 | 0.004034 | 0.191426 | 0.004348 | 0.000000 | 0.004348 |
| NC6 | 0.001006 | 0.185551 | 0.001314 | 0.000000 | 0.001314 |
| NC7 | 0.000137 | 0.099832 | 0.000303 | 0.000000 | 0.000303 |
| TOTAL RATE (INLET TO NODE IF JUNCTION) | | | | | |
| KG/HR | 7519.3 | 38.9 | 7558.2 | 0.0 | 7558.2 |
| MOLE/HR | 352.70 | 0.59 | 353.30 | 0.00 | 353.30 |
| WT FRAC LIQ | | | 0.005152 | | 0.005152 |
| PHASE PROPERTIES | | | | | |
| MASS FRACTION | 0.994848 | 0.005152 | 1.000000 | 0.000000 | 1.000000 |
| VOLUME FRAC | 0.999915 | 0.000085 | 1.000000 | 0.000000 | 1.000000 |
| DENSITY KG/M3 | 10.38 | 630.17 | | 0.00 | |
| SPECIFIC GRAV | 0.735844 | 0.630792 | | 0.000000 | |
| VISCOSITY CP | 0.0102 | 0.2538 | | 0.0000 | |
| ENTHALPY KCAL/KG | 15.672 | -6.309 | | 0.000 | 15.559 |
| SURF TENS NEWTON/M | | 0.016 | | 0.000 | |
| MOLECULAR WT | 21.3189 | 65.8860 | 21.3934 | 0.0000 | 21.3934 |

## Partial Output (continued)

Following are link, node, and device summary reports.

```
                            LINK SUMMARY

  RATE, PRESSURE AND TEMPERATURE SUMMARY
  --------------------------------------

     FROM(F)
     AND
     TO(T)    ----ACTUAL FLOW RATES***--            PRESS:        ----HOLDUP**---
LINK NODE       GAS      OIL      WATER   PRESS:   DROP   TEMP:    GAS      LIQ
             (MMCMHR) (CMHR)   (CMHR)   (BAR)    (BAR)   (C)    (MM      (ACM)
                                                                 SCM)
---- ------- -------- -------- -------- -------- ------- ----- ------- -------
LINK SORS(F) 0.000107    0.000    0.000   68.40*          32.0
     SNK (T) 0.000725    0.062    0.000   10.12*   58.28 -10.4 0.00051    0.06
                      SPHERE GENERATED VOLUME (BASED ON HL)       =        0.1
                      SPHERE GENERATED VOLUME (BASED ON (HL-HLNS))=        0.0

   * - INDICATES KNOWN PRESSURE
   **  REPORTED VOLUME AT 14.7 PSIA AND 60 F (GAS ONLY)
   *** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

                        NODE SUMMARY

NODE   PRES.   -------GAS---- ------OIL------ ----WATER------  TOTAL    TEMP
                RATE    GRAV  RATE     GRAV   RATE    GRAV     RATE
     (BAR)    (KGHR)         (KGHR)          (KGHR)          (KGHR)    (C)
---- -------  -------- ------ -------- ------ -------- ----- -------- -------
SORS   68.40 *   7558.  0.74       0.  0.00       0.  0.00    7558.  3.200E1
              0.008336(MMCMHR)   0.000(CMHR)     0.000(CMHR)
SNK    10.12 *   7558.  0.74       0.  0.00       0.  0.00    7558.  -1.03E1
              0.008336(MMCMHR)   0.000(CMHR)     0.000(CMHR)

   * INDICATES KNOWN PRESSURE OR FLOW
   ** FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

                                  DEVICE SUMMARY

                C
                O                                       ------- OUTLET ------ AVG.
LINK DEVI DEVI  R    INSIDE   MEAS      ELEV                         INSITU  LIQ
NAME NAME TYPE  R    DIAM     LENGTH    CHNG      PRESS:  TEMP: QUALITY HOLDUP
                     (MM)     (M)       (M)      (BAR)   (C)    (FRAC)
---- ---- ---- ---- -------- --------- ------- ------- ------ ------- ------
LINK   ***SOURCE*** RATE=   7558. (KGHR)          68.40   32.0 QUAL=    1.00
     SORS                                          68.40   32.0
     T001 TBNG BM      62.00    934.00  610.00    56.05   23.0    1.00   0.00
     T002 TBNG BM      62.00   1068.00 1067.00    32.12    4.6    0.99 3.8E-3
     P003 PIPE BM      76.20   1068.00   61.00    10.12  -10.4    0.99 9.1E-3
          *** SINK *** PRES=   10.12 (BAR)   TEMP=  -10.4 (C)
```

## Partial Output (continued)

The pressure and temperature and holdup and velocity reports for the link devices are given below. The reports show that liquid starts to drop out of the gas stream with decreasing pressure (retrograde condensate behavior) in segment number 003 of device T002 (at about 167 meters).

LINK "LINK" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

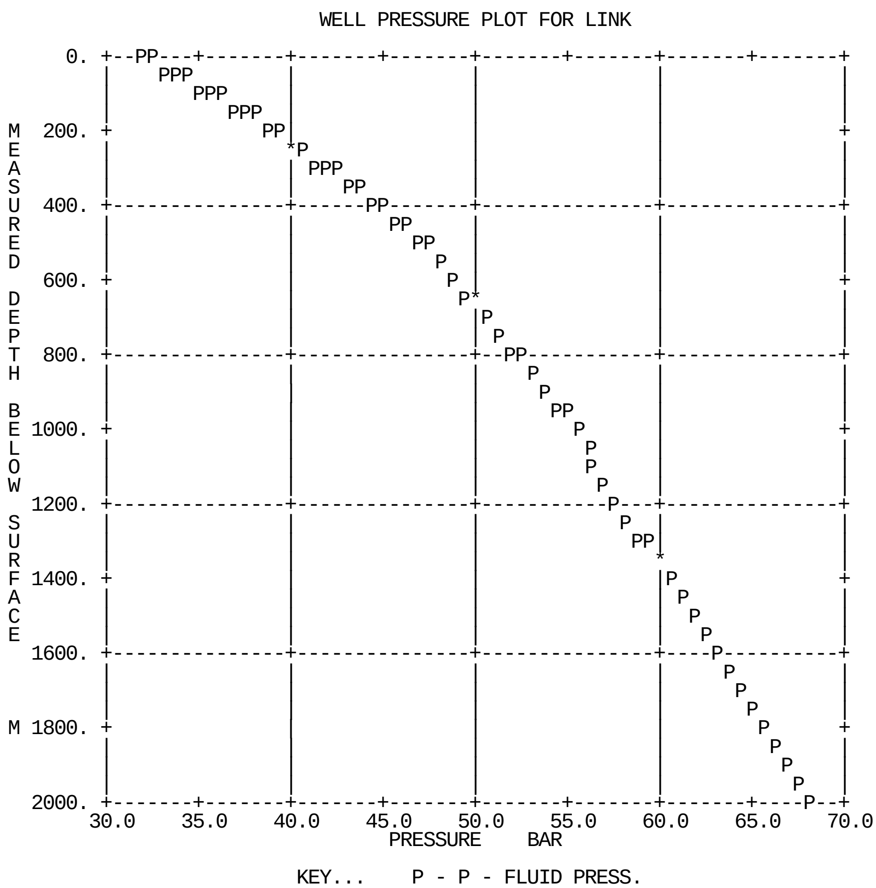
| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (MM) | MWD OR LENGTH FROM INLET (M) | I & O | TVD OR ELEV CHNG (M) | CALC PRESS (BAR) | CALC TEMP (C) | OVERALL U-FACT (KCMC) | AMB TEMP (C) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | 62.00 | 2002.00 | I | 1677.00 | 68.40 | 32.0 | | 32.0 | 1.00 |
| (TBNG) | 0001 | | 1542.77 | | 1377.08 | 62.43 | 27.8 | 14.65 | 27.2 | 1.00 |
| | 0002 | | 1083.55 | | 1077.16 | 56.26 | 23.1 | 14.65 | 22.4 | 1.00 |
| | 0003 | | 1068.00 | O | 1067.00 | 56.05 | 23.0 | 14.65 | 22.2 | 1.00 |
| T002 | 0000 | 62.00 | 1068.00 | I | 1067.00 | 56.05 | 23.0 | | 22.2 | 1.00 |
| (TBNG) | 0001 | | 767.80 | | 767.08 | 51.27 | 18.8 | 14.65 | 17.4 | 1.00 |
| | 0002 | | 467.59 | | 467.15 | 46.34 | 14.4 | 14.65 | 12.6 | 1.00 |
| | **0003** | | **167.39** | | **167.23** | **37.64** | **8.4** | **14.65** | **7.8** | **1.00** |
| | 0004 | | 2.2567E-5 | O | 0.00 | 32.12 | 4.6 | 14.65 | 5.2 | 0.99 |
| P003 | 0000 | 76.20 | 0.00 | I | 0.00 | 32.12 | 4.6 | | 8.0 | 0.99 |
| (PIPE) | 0001 | | 320.40 | | 18.30 | 27.66 | 2.0 | 4.88 | 8.0 | 0.99 |
| | 0002 | | 546.99 | | 12.94 | 23.95 | -0.2 | 4.88 | 8.0 | 0.99 |
| | 0003 | | 773.57 | | 12.94 | 19.41 | -3.1 | 4.88 | 8.0 | 0.99 |
| | 0004 | | 884.22 | | 6.32 | 16.66 | -5.0 | 4.88 | 8.0 | 0.99 |
| | 0005 | | 950.61 | | 3.79 | 14.71 | -6.4 | 4.88 | 8.0 | 0.99 |
| | 0006 | | 1017.01 | | 3.79 | 12.38 | -8.3 | 4.88 | 8.0 | 0.99 |
| | 0007 | | 1068.00 | O | 2.91 | 10.12 | -10.4 | 4.88 | 8.0 | 0.99 |

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ACM) | LIQ VEL (MPS) | ACTUAL GAS VEL (MPS) | MIX . VEL (MPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (MPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.00 | 0.00 | 10.23 | 10.23 | 1-PH | 1-PH | 358.78 |
| | 0002 | 0.00 | 0.00 | 0.00 | 0.00 | 11.18 | 11.18 | 1-PH | 1-PH | 356.02 |
| | 0003 | 0.00 | 0.00 | 0.00 | 0.00 | 11.77 | 11.77 | 1-PH | 1-PH | 364.55 |
| T002 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.00 | 0.00 | 12.26 | 12.26 | 1-PH | 1-PH | 355.89 |
| | 0002 | 0.00 | 0.00 | 0.00 | 0.00 | 13.37 | 13.37 | 1-PH | 1-PH | 353.36 |
| | **0003** | **4.E-4** | **8.E-3** | **6.874E-3** | **0.78** | **15.59** | **15.48** | **DIST** | **ANNU** | **329.70** |
| | 0004 | 7.E-4 | 0.01 | 0.01 | 1.28 | 18.86 | 18.67 | DIST | ANNU | 336.62 |
| P003 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 8.E-4 | 0.01 | 0.03 | 0.96 | 14.65 | 14.49 | DIST | ANNU | 334.50 |
| | 0002 | 7.E-4 | 0.01 | 0.04 | 1.07 | 17.06 | 16.89 | DIST | ANNU | 330.32 |
| | 0003 | 5.E-4 | 9.E-3 | 0.05 | 1.18 | 20.41 | 20.24 | DIST | ANNU | 324.45 |
| | 0004 | 4.E-4 | 7.E-3 | 0.05 | 1.27 | 24.65 | 24.49 | DIST | ANNU | 319.24 |
| | 0005 | 3.E-4 | 6.E-3 | 0.05 | 1.32 | 28.44 | 28.28 | DIST | ANNU | 315.40 |
| | 0006 | 2.E-4 | 5.E-3 | 0.06 | 1.36 | 32.99 | 32.84 | DIST | ANNU | 311.32 |
| | 0007 | 1.E-4 | 3.E-3 | 0.06 | 1.36 | 39.79 | 39.66 | DIST | ANNU | 306.85 |

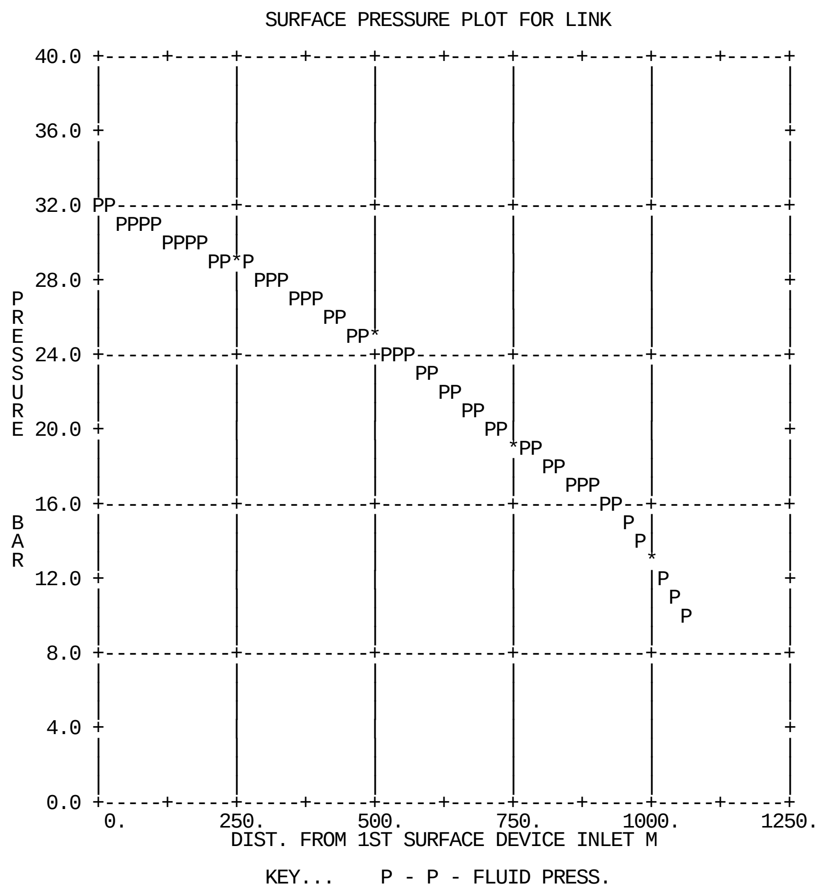
# Partial Output (continued)

The well pressure plot is shown below.



## Partial Output (continued)

The surface pressure plot is shown below.



## Partial Output (continued)

The traverse of the fluid (marked by ‘X’ on the phase envelope) shows the retrograde condensation effect.

```
        P H A S E   E N V E L O P E

P   125.+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        :           :           :           :           :           :
R       :           :           :           :           :           :
        :           :           :           :           :           :
E   113.+           :           :           :           :           +
        :           :           :           :           :           :
S       :           :           :           :     D P D :           :
        :           :           :           :           :           :
S   100.+-----------+-----------+-----------+---D-------+-----------+
        :           :           :           : C         D           :
U       :           :           :           :B          :           :
        :           :           :           B           :           :
R    88.+           :           :           :           :           +
        :           :           :          B:           :           :
E       :           :           :           :           : D         :
        :           :           :         B :           :           :
     75.+-----------+-----------+-----------+-----------+-----------+
B       :           :           :       B   :           :           :
A       :           :           :       I   :           :  D    X   :
R       :           :           :      B    :           :           :
     63.+           :           :           :           :      X    +
        :           :           :     B     :           :           :
        :           :           :    B      :           :     X     :
        :           :           :           :           :  T        :
     50.+-----------+-----------+---B-------+-----------+----X------+
        :           :           :  B        :           :  X        :
        :           :           :           :           :  D        :
        :           :           : B         :           :           :
     38.+           :           :B          :           : X         +
        :           :           B           :           :           :
        :           :          B:           :           :XD         :
        :           :         B :           :           X           :
     25.+-----------+--------B--+-----------+-----------X-----------+
        :           :       B   :           :           :D          :
        :           :      B    :           :          X:           :
        :           :     BB    :           :         XX:           :
     13.+           :   BB      :           :         X D           +
        :           : BB        :           :         XI:           :
        :           BBB         :           :        D  :           :
        :      BBBBB:           :           :     DD    :           :
      0.+----BBB----+-----+-----+-----+-----+-D---+-----+-----+-----+
     -200. -175. -150. -125. -100.  -75.  -50.  -25.    0.   25.   50.

                T E M P E R A T U R E   C

        I = INTERPOLATED     B = BUBBLE          D = DEW
        X = TRAVERSE         T = T EXTREMUM      P = P EXTREMUM
        C = CRITICAL
```

# Geothermal Well

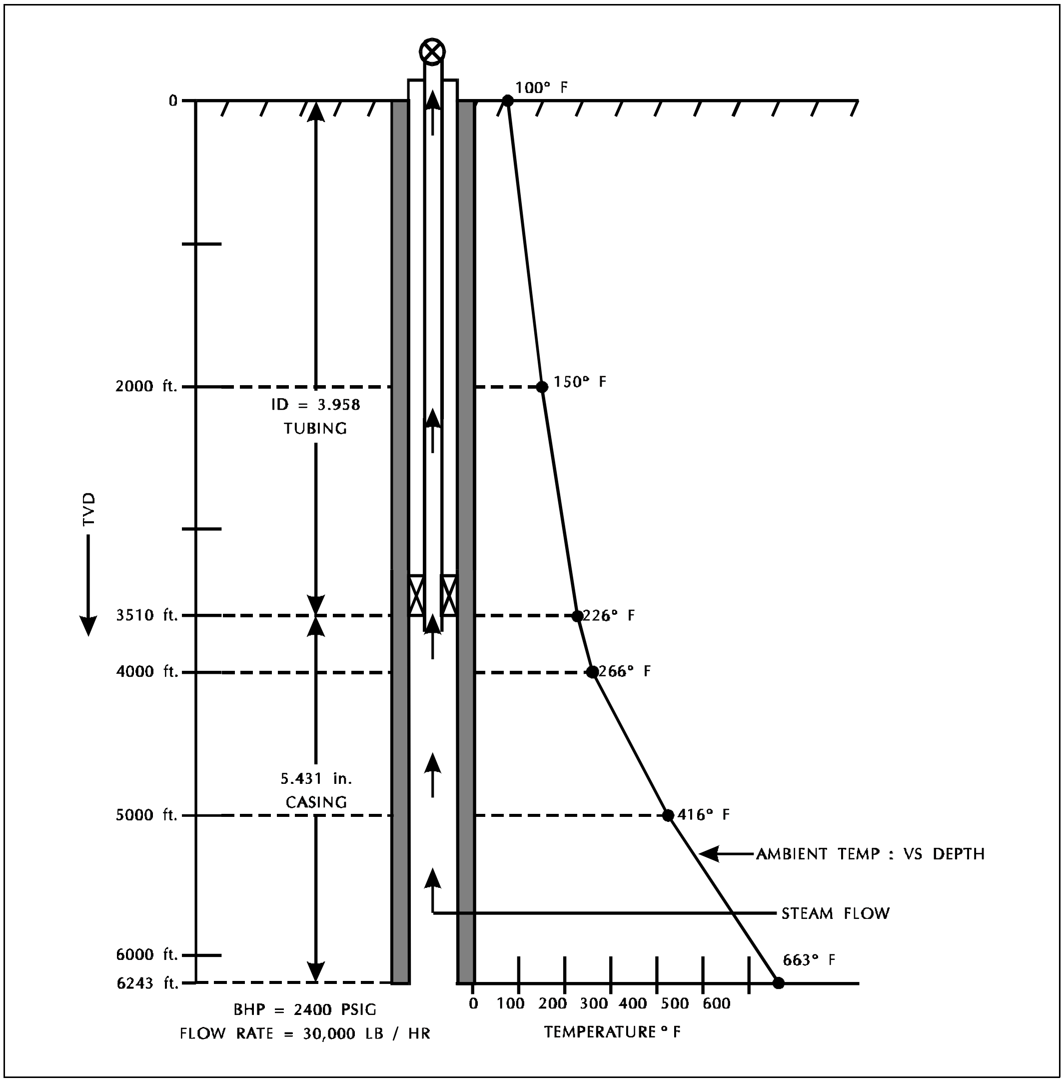
## Problem Description

Steam, produced from a high capacity geothermal well, is to be used for electric power generation. The power plant operator is interested in having a high surface steam quality and enthalpy. The flowrate is set at 30,000 lb/hr. The quality of the steam at the bottomhole is 55%, and the pressure is 2400 psi. Due to the hot producing formation, the geothermal gradient is non-linear. Figure P13.1 shows a schematic of the well. Additional process data is given in Table P13.1.

As the well operator, you are required to:

1. Determine the steam enthalpy and quality at the surface.
2. Determine the increase in the outlet enthalpy if the upper 3500 feet of tubing is insulated to an effective U-value of 0.25 Btu/hr-$ft^2$-F.

**Figure P13.1: Geothermal Well**




| **Table P13.1: Process Information** |
|---|
| **Fluid Steam** |
| Water SP GR = 1.002 |
| Initial Quality = 55% |
| **Heat Transfer Data** |
| U = 3 Btu/hr-ft$^2$-°F |

## PIPEPHASE Features Used In This Problem

- The built-in steam package covers the range of pressure and temperature normally encountered in steam systems.
- Rigorous heat transfer calculations are critical as heat availability is of primary concern for most steam systems.
- The pressure and quality specification completely defines the steam at the source. Pressure and temperature alone do not define the steam quality.
- The case-study feature allows the use of U=0.25 for tubing TUB1. Note that case studies are cumulative.

## Results and Discussion

1. The calculated quality at the wellhead is about 15%, the temperature is 604$^{o}$F and the pressure is 1580 psi. Mixture enthalpy is calculated as (618.97 X .85 + 1190.1 X .15) = 704.6 Btu/lb.
2. If the upper 3500 feet of tubing were insulated to an effective U-valve of 0.25 Btu/hr-ft$^2$-F the quality at the wellhead would be 40% at the temperature of 611$^{o}$F and 1662.3 pressure. This means substantially increased quality over the uninsulated tubing. The mixture enthalpy is now calculated as (628.8 X .6 + 118.1 X .4) = 852.0 Btu/lb.

## Simulation Highlights

INPUT

- A detailed geothermal temperature gradient was input for rigorous heat transfer calculations.
- The tubing overall heat transfer coefficient was set at 3 Btu/hr-ft$^2$-F.
- The Beggs and Brill correlation was used for pressure drop and holdup calculations.
- The segment size was set at 500 feet.
- The specific gravity of the water was greater than 1.0 due to dissolved solids in the processed fluids.

TECHNIQUE

- The non-linear temperature gradient due to the heat source was incorporated into the run by dividing the tubing string into several individual tubings and imposing an average temperature gradient for each depth interval.

## Input Data

### Keyword Input Data File

```
TITLE   PROB=WELL3, PROJ=WELLAPP, USER=SIMSCI
CALC    SINGLE, STEAM
PRINT   INPUT=NONE, DEVICE=PART, PLOT=FULL
DEFAULT IDTUBI=5.431, UTUBING=3
SEGMENT DLVERT=500, DLHOR=500
$
PVT DATA
        SET     SETNO=1,GRAV(WATER,SPGR)=1.002
$
STRUCTURE DATA
        SOURCE  NAME=S1, SETN=1, PRES=2400, QUAL=55, RATE=30000
$
        LINK    NAME=L001, FROM=S1, TO=S2
                TUBING  LENGTH=6243, TGRAD=20
                TUBING  LENGTH=5000, TGRAD=15
                TUBING  LENGTH=4000, TGRAD=8
                TUBING  NAME=TUB4, LENGTH=3510, TGRAD=5, ID=3.958
                TUBING  NAME=TUB5, LENGTH=2000, TGRAD=2.5, ID=3.958
$
        SINK    NAME=S2, PRES(ESTI)=1000, RATE(ESTI)=30000
$
CASE STUDY
        CHANGE  NAME=TUB5, U=0.25
$
CASE STUDY
        CHANGE   NAME=TUB4, U=0.25
```

## Output

- The output gives the quality of the steam at each increment.
- The temperature profile plot indicates that the temperature change is small. This is to be expected as the steam is two-phase. The heat lost by the steam is mostly the latent heat.

P13 Geothermal Well

## Partial Output (Uninsulated Tubing Case)

The output shows parts of the device detail report.

LINK "L001" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | 5.431 | 6243.0 | I | 6243.0 | 2400.0 | 663.0 | | 663.0 | 0.55 |
| (TBNG) | 0001 | | 5743.0 | | 5743.0 | 2335.9 | 659.0 | 3.000 | 563.0 | 0.55 |
| | 0002 | | 5243.0 | | 5243.0 | 2273.5 | 655.0 | 3.000 | 463.0 | 0.53 |
| | 0003 | | 5000.0 | O | 5000.0 | 2243.9 | 653.1 | 3.000 | 414.4 | 0.52 |
| T002 | 0000 | 5.431 | 5000.0 | I | 5000.0 | 2243.9 | 653.1 | | 414.4 | 0.52 |
| (TBNG) | 0001 | | 4500.0 | | 4500.0 | 2185.2 | 649.3 | 3.000 | 339.4 | 0.48 |
| | 0002 | | 4000.0 | O | 4000.0 | 2127.6 | 645.4 | 3.000 | 264.4 | 0.44 |
| T003 | 0000 | 5.431 | 4000.0 | I | 4000.0 | 2127.6 | 645.4 | | 264.4 | 0.46 |
| (TBNG) | 0001 | | 3755.0 | | 3755.0 | 2098.5 | 643.4 | 3.000 | 244.8 | 0.41 |
| | 0002 | | 3510.0 | O | 3510.0 | 2068.9 | 641.4 | 3.000 | 225.2 | 0.39 |
| TUB4 | 0000 | 3.958 | 3510.0 | I | 3510.0 | 2068.9 | 641.4 | | 225.2 | 0.40 |
| (TBNG) | 0001 | | 3010.0 | | 3010.0 | 2006.6 | 637.1 | 3.000 | 200.2 | 0.35 |
| | 0002 | | 2510.0 | | 2510.0 | 1942.5 | 632.5 | 3.000 | 175.2 | 0.31 |
| | 0003 | | 2010.0 | | 2010.0 | 1876.3 | 627.7 | 3.000 | 150.2 | 0.28 |
| | 0004 | | 2000.0 | O | 2000.0 | 1874.9 | 627.6 | 3.000 | 149.7 | 0.28 |
| TUB5 | 0000 | 3.958 | 2000.0 | I | 2000.0 | 1874.9 | 627.6 | | 149.7 | 0.28 |
| (TBNG) | 0001 | | 1500.0 | | 1500.0 | 1806.1 | 622.4 | 3.000 | 137.2 | 0.24 |
| | 0002 | | 1000.0 | | 1000.0 | 1734.4 | 616.9 | 3.000 | 124.7 | 0.20 |
| | 0003 | | 500.0 | | 500.0 | 1659.2 | 610.9 | 3.000 | 112.2 | 0.17 |
| | 0004 | | 0.0 | O | 0.0 | 1579.8 | 604.4 | 3.000 | 99.7 | 0.14 |

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.14 | 0.39 | 5.6 | 1.67 | 6.61 | 4.69 | TRAN | ANNU | 1259.00 |
| | 0002 | 0.14 | 0.37 | 10.9 | 1.75 | 6.63 | 4.81 | TRAN | ANNU | 1246.07 |
| | 0003 | 0.14 | 0.36 | 13.4 | 1.87 | 6.50 | 4.85 | TRAN | ANNU | 1241.74 |
| T002 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.14 | 0.34 | 18.2 | 2.06 | 6.20 | 4.81 | TRAN | ANNU | 1233.08 |
| | 0002 | 0.16 | 0.33 | 22.9 | 2.27 | 5.86 | 4.69 | INTR | ANNU | 1220.50 |
| T003 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.17 | 0.34 | 25.3 | 2.28 | 5.73 | 4.55 | INTR | ANNU | 1205.82 |
| | 0002 | 0.18 | 0.35 | 27.7 | 2.29 | 5.61 | 4.44 | INTR | ANNU | 1187.56 |
| TUB4 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.20 | 0.35 | 30.4 | 4.58 | 9.98 | 8.11 | INTR | ANNU | 1153.62 |
| | 0002 | 0.21 | 0.36 | 33.2 | 4.57 | 9.66 | 7.81 | INTR | ANNU | 1140.16 |
| | 0003 | 0.23 | 0.38 | 36.1 | 4.54 | 9.28 | 7.47 | INTR | ANNU | 1131.37 |
| | 0004 | 0.24 | 0.39 | 36.1 | 4.51 | 9.05 | 7.27 | INTR | ANNU | 1131.85 |
| TUB5 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.26 | 0.40 | 39.2 | 4.47 | 8.82 | 7.07 | INTR | ANNU | 1113.51 |
| | 0002 | 0.28 | 0.43 | 42.4 | 4.38 | 8.31 | 6.63 | INTR | ANNU | 1083.99 |
| | 0003 | 0.31 | 0.45 | 45.9 | 4.26 | 7.74 | 6.16 | INTR | ANNU | 1052.90 |
| | 0004 | 0.35 | 0.48 | 49.5 | 4.10 | 7.11 | 5.66 | INTR | ANNU | 1029.37 |

## Partial Output (Insulated Tubing Case)

The following shows parts of the device detail report for the case when the upper 3500 feet of tubing was insulated (U=0.25 Btu/hr-ft$^2$-F, Case 2):

CASE NO. 2

LINK "L001" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | 5.431 | 6243.0 | I | 6243.0 | 2400.0 | 663.0 | | 663.0 | 0.55 |
| (TBNG) | 0001 | | 5743.0 | | 5743.0 | 2335.9 | 659.0 | 3.000 | 563.0 | 0.55 |
| | 0002 | | 5243.0 | | 5243.0 | 2273.5 | 655.0 | 3.000 | 463.0 | 0.53 |
| | 0003 | | 5000.0 | O | 5000.0 | 2243.9 | 653.1 | 3.000 | 414.4 | 0.52 |
| T002 | 0000 | 5.431 | 5000.0 | I | 5000.0 | 2243.9 | 653.1 | | 414.4 | 0.52 |
| (TBNG) | 0001 | | 4500.0 | | 4500.0 | 2185.2 | 649.3 | 3.000 | 339.4 | 0.48 |
| | 0002 | | 4000.0 | O | 4000.0 | 2127.6 | 645.4 | 3.000 | 264.4 | 0.44 |
| T003 | 0000 | 5.431 | 4000.0 | I | 4000.0 | 2127.6 | 645.4 | | 264.4 | 0.46 |
| (TBNG) | 0001 | | 3755.0 | | 3755.0 | 2098.5 | 643.4 | 3.000 | 244.8 | 0.41 |
| | 0002 | | 3510.0 | O | 3510.0 | 2068.9 | 641.4 | 3.000 | 225.2 | 0.39 |
| TUB4 | 0000 | 3.958 | 3510.0 | I | 3510.0 | 2068.9 | 641.4 | | 225.2 | 0.40 |
| (TBNG) | 0001 | | 3010.0 | | 3010.0 | 2007.9 | 637.2 | 0.250 | 200.2 | 0.39 |
| | 0002 | | 2510.0 | | 2510.0 | 1948.1 | 632.9 | 0.250 | 175.2 | 0.39 |
| | 0003 | | 2010.0 | | 2010.0 | 1889.2 | 628.6 | 0.250 | 150.2 | 0.40 |
| | 0004 | | 2000.0 | O | 2000.0 | 1888.1 | 628.6 | 0.250 | 149.7 | 0.40 |
| TUB5 | 0000 | 3.958 | 2000.0 | I | 2000.0 | 1888.1 | 628.6 | | 149.7 | 0.40 |
| (TBNG) | 0001 | | 1500.0 | | 1500.0 | 1830.2 | 624.3 | 0.250 | 137.2 | 0.40 |
| | 0002 | | 1000.0 | | 1000.0 | 1773.3 | 619.9 | 0.250 | 124.7 | 0.40 |
| | 0003 | | 500.0 | | 500.0 | 1717.4 | 615.6 | 0.250 | 112.2 | 0.40 |
| | 0004 | | 0.0 | O | 0.0 | 1662.3 | 611.2 | 0.250 | 99.7 | 0.40 |

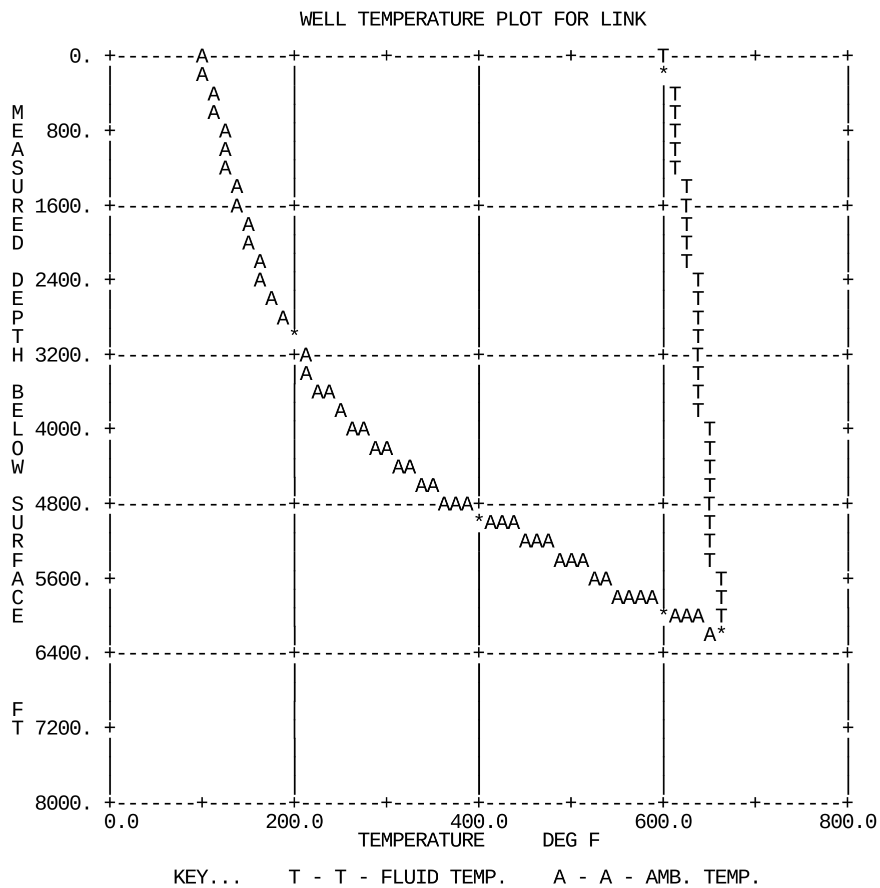
HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.14 | 0.39 | 5.6 | 1.67 | 6.61 | 4.69 | TRAN | ANNU | 1259.00 |
| | 0002 | 0.14 | 0.37 | 10.9 | 1.75 | 6.63 | 4.81 | TRAN | ANNU | 1246.07 |
| | 0003 | 0.14 | 0.36 | 13.4 | 1.87 | 6.50 | 4.85 | TRAN | ANNU | 1241.74 |
| T002 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.14 | 0.34 | 18.2 | 2.06 | 6.20 | 4.81 | TRAN | ANNU | 1233.08 |
| | 0002 | 0.16 | 0.33 | 22.9 | 2.27 | 5.86 | 4.69 | INTR | ANNU | 1220.50 |
| T003 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.17 | 0.34 | 25.3 | 2.28 | 5.73 | 4.55 | INTR | ANNU | 1205.82 |
| | 0002 | 0.18 | 0.35 | 27.7 | 2.29 | 5.61 | 4.44 | INTR | ANNU | 1187.56 |
| TUB4 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.18 | 0.33 | 30.3 | 4.60 | 10.32 | 8.41 | INTR | ANNU | 1173.94 |
| | 0002 | 0.17 | 0.32 | 32.8 | 4.66 | 10.71 | 8.75 | INTR | ANNU | 1172.59 |
| | 0003 | 0.16 | 0.31 | 35.2 | 4.73 | 11.11 | 9.10 | INTR | ANNU | 1167.31 |
| | 0004 | 0.16 | 0.31 | 35.2 | 4.77 | 11.32 | 9.28 | INTR | ANNU | 1169.66 |
| TUB5 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.16 | 0.31 | 37.5 | 4.80 | 11.53 | 9.47 | INTR | ANNU | 1158.81 |
| | 0002 | 0.15 | 0.30 | 39.8 | 4.87 | 11.94 | 9.84 | INTR | ANNU | 1148.10 |
| | 0003 | 0.14 | 0.29 | 42.0 | 4.95 | 12.37 | 10.22 | INTR | ANNU | 1135.57 |
| | 0004 | 0.13 | 0.28 | 44.1 | 5.02 | 12.82 | 10.62 | INTR | ANNU | 1121.60 |

## Partial Output (Uninsulated Case)

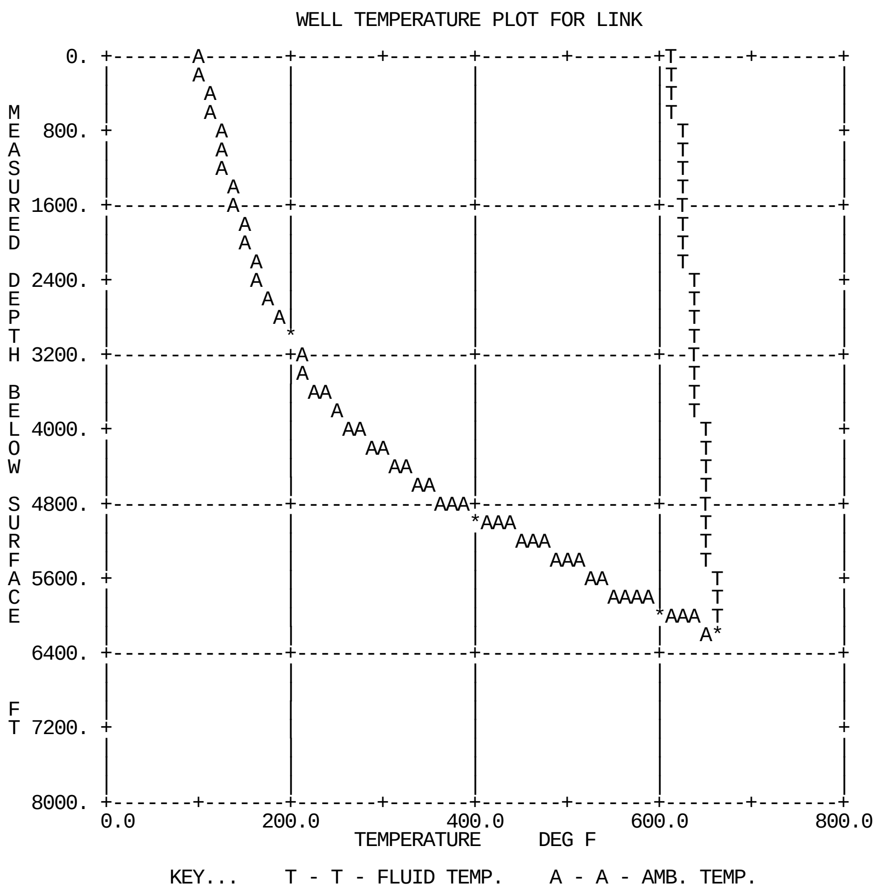
The non-linear ambient temperature profile that was input by the user is shown with the well temperature profile in Figures P13.2 and P13.3 for both the uninsulated and insulated cases.

**Figure P13.2: Temperature Profile for the Uninsulated Case**



## Partial Output (Insulated Case)

**Figure P13.3: Temperature Profile for the Insulated Case**



# Well With Artificial Lift

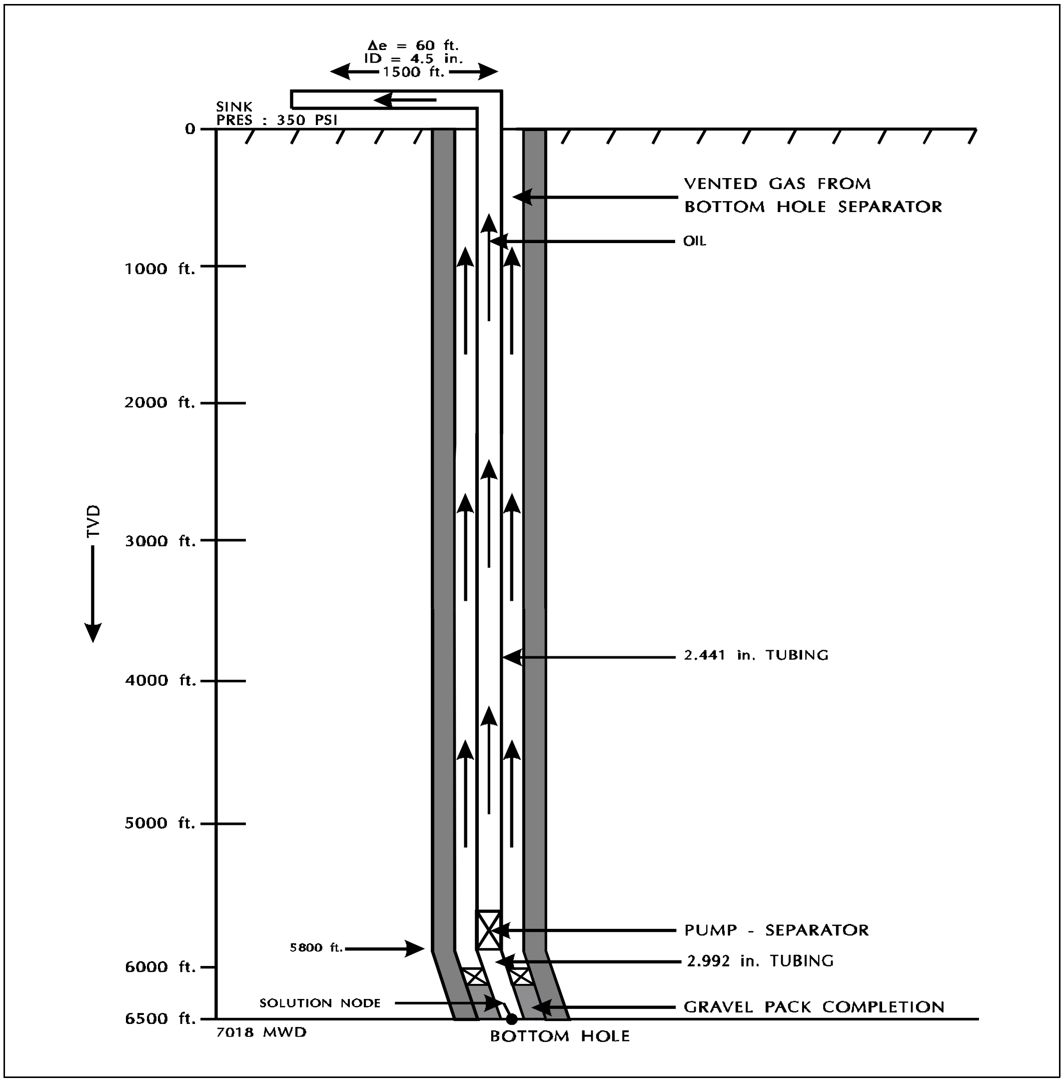
## Problem Description

A 6500 foot deep oil well has a high PI (productivity index) of 40 bbl/d/psi and a low reservoir pressure of 1400 psi. To exploit the production potential of the well, an artificial lift method is necessary. The high PI indicates that submersible pumping is a likely candidate because this method is suitable for high volume production. Two types of pumps are to be evaluated. The schematic is shown in Figure P14.1 and process information is given in Table P12.1.

You are required to:

1. Evaluate the performance of the first pump (75 hp) for a reservoir pressure of 1400 psi, 850 psi, and 650 psi (assume the PI remains the same) with and without bottomhole separators.
2. Evaluate the performance of the second pump (130 hp) for the same set of reservoir pressure conditions.

**Figure P14.1: Well with Artificial Lift**




P14 Well With Artificial Lift

| Table P14.1: Process Information | | |
|---|---|---|
| **Fluid Data** | | |
| Oil Gravity | 28°API | |
| Gas Specific Gravity | 0.56 | |
| Water Specific Gravity | 1.003 | |
| **Completion Data** | | |
| Gravel Permeability | 45 d | |
| Tunnel Length | 2 in | |
| Shot Density | 8 spf | |
| Completion Length | 45 ft | |
| Perforation Diameter | .51 in | |
| **Pump Data** | | |
| **HP/Stage** | **# of Stages** | **Efficiency** |
| 0.75 | 100 | 96% |
| 1.3 | 100 | 96% |
| **Well Data** | | |
| Bottomhole Temperature | 150°F | |
| Gas-oil Ratio | 700 scf/stb | |
| Productivity Index (PI) | 40 stb/d/psi | |
| Separation Pressure | 350 psig | |

## PIPEPHASE Features Used In This Problem

- Sensitivity analysis with compounded parameters enables case studies to be made in a single run instead of multiple runs. All the relevant information is then presented in a concise manner.
- The Blackoil model with heat transfer is appropriate for typical crude oils when limited data is available.
- The Jones gravel-pack completion model is used as it is necessary to be aware of the gravel pack performance to prevent damage to the completion when flowing the well at design production rates.
- Submersible pump and bottomhole separator options are used.

## Results and Discussion

Following are the results for the case study.

**Table P14.2: Case Study Results**

| Reservoir Pressure (psi) | Flowrate (stb/d) | | | |
|---|---|---|---|---|
| | 75 HP Pump without Separator | 75 HP Pump with Separator | 130 HP Pump without Separator | 130 HP Pump with Separator |
| 1400 | 2803 | 2612 | 3512 | 3756 |
| 850 | 1777 | 1903 | 2447 | 2930 |
| 650 | 1352 | 1703 | 1952 | 2669 |

1. For a reservoir pressure of 1400 psi the bottomhole separator lowers production for the smaller pump (75 hp). The gas reduces the efficiency of the pump but helps to lift the oil better. In this case the net effect is greater production if the gas is not separated. For the lower reservoir pressures the bottomhole separation marginally increases production.  Note that two-phase pumphead degradation has been ignored.  The user may account for this by decreasing the pump efficiency.
2. For the larger horsepower pump (130 hp) the bottomhole separator increases production substantially due to increased pumping efficiency.

## Simulation Highlights

INPUT

- The Hagedorn and Brown correlation was chosen for pressure drop in the tubing and the Beggs & Brill correlation chosen for the surface pipe.
- The pump was set at 6000 feet, about 500 feet from the sandface. The length of the pump was about 200 feet.

TECHNIQUE

- The solution node was set at the inlet of the bottom tubing. This isolates the production string performance from the reservoir and completion performance. The resevoir pressure was used as the inflow parameter. The downhole separator and pump were used as the compound outflow parameter.
- PIPEPHASE does not allow zero separation, therefore a small amount of separation was effected by putting in a very small number. The effect on the result is minimal.
- Inputting the pump data as hp per stage instead of total horsepower gives more accurate results, since it takes into account the phase changes after each stage.

## Input Data

The keyword input data file for this simulation problem is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL4, PROJ=WELLAPP, USER=SIMSCI
FCODE   TUBI=HB
SEGMENT DLVERT=500, DLHOR=1000
$
PVT DATA
        SET     SETNO=1, GRAV(OIL)=28, GRAV(GAS)=0.56, *
                GRAV(WATER,SPGR)=1.003
$
STRUCTURE DATA
        SOURCE  NAME=SRC1, TEMP=150, PRES=600, RATE=3000, *
                PI=40, WCUT=10, GOR=700
$
        LINK    NAME=L001, FROM=SRC1, TO=SNK1
                COMPLET NAME=CMP1, JONES, PERFD=0.51, TUNNEL=2, *
                        PERM(GRAVEL)=45, SHOTS=8, LENG=45
                TUBING NAME=TUB1, LENGTH=7010, DEPTH=6500, ID=2.992
                SEPARAT NAME=SEP1, PERC(GAS)=100
                PUMP    NAME=PMP1, POWER=1.3, EFF=96, STAGES=100, *
                        WELL, LENGTH=6000
                TUBING  LENGTH=5800, ID=2.441
                PIPE    LENGTH=1500, ECHG=60, ID=4.5
$
        SINK    NAME=SNK1, PRESSURE=350, RATE(ESTI)=3000
$
SENSITIVITY DATA
        NODE    NAME=TUB1
        FLOW    RATE=1000, 1500, 2000, 2500, 3000, 4000
        DESC    INFLOW=1400 PSI, 850 PSI, 650 PSI
        INFLOW  NAME=SRC1, PRES=1400, 850, 600
        DESC    OUTFLOW=75  HP,75  HP + SEP,130 HP,130 HP + SEP
        OUTFLOW NAME=SEP1, PERCENT(GAS)=0.001, 100, 0.001, 100,*
                NAME=PMP1, POWER=0.75, 0.75, 1.3, 1.3
```

## Output

- The input reprint shows the compound sensitivity parameters.
- The sensitivity pressure and temperature plots are automatically printed along with the completion pressure drop.
- The numerical results from which the plots were generated are printed out.
- The intersection points are also printed.

## Partial Output

The input reprint below shows the parameters used for the sensitivity analysis.

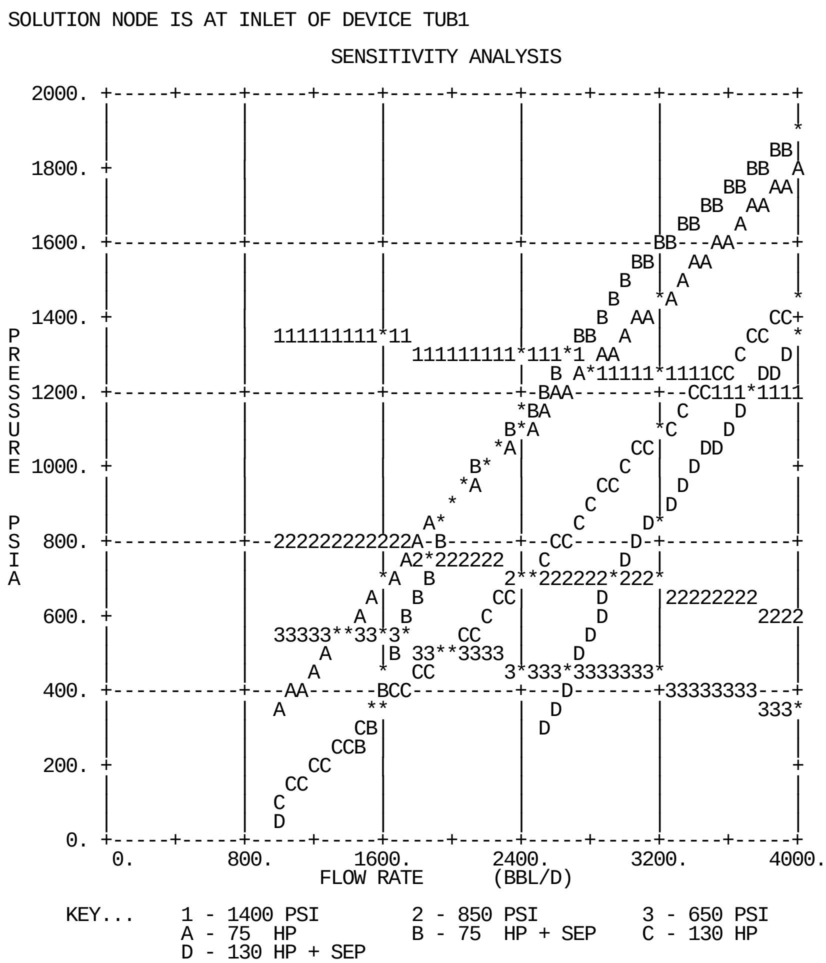
```
 SENSITIVITY ANALYSIS DATA

    SOLUTION NODE IS AT NODE TUB1   (INLET OF DEVICE IF IT IS A DEVICE NAME)


    FLOW RATES, BBL/DAY             1000.00   1500.00   2000.00   2500.00
                                    3000.00   4000.00

    INFLOW   SECTION   SENSITIVITY TO SOURCE                       PARAMETERS


            DESCRIPTION
            -----------
    CASE  1 1400 PSI
    CASE  2 850 PSI
    CASE  3 650 PSI


                           CASE 1      CASE 2      CASE 3
    SOURCE      ,SRC1
    PRESSURE
    PSIG              1400.00403   850.00006   600.00006

                           CASE 1      CASE 2      CASE 3

    OUTFLOW  SECTION   SENSITIVITY TO STRUCTURE                    PARAMETERS


            DESCRIPTION
            -----------
    CASE  1 75  HP
    CASE  2 75  HP + SEP
    CASE  3 130 HP
    CASE  4 130 HP + SEP


                           CASE 1      CASE 2      CASE 3      CASE 4
    SEPARATOR   ,SEP1
    PERCENT(GAS)
                         0.00100   100.00000     0.00100   100.00000
    PUMP        ,PMP1
    POWER
    HP                   0.75000     0.75000     1.30000     1.30000

                           CASE 1      CASE 2      CASE 3      CASE 4
```

P14 Well With Artificial Lift

## Partial Output (continued)

Figure P14.2 below shows the sensitivity analysis plot of pressure versus flowrate.

**Figure P14.2: Sensitivity Analysis Pressure Plot**

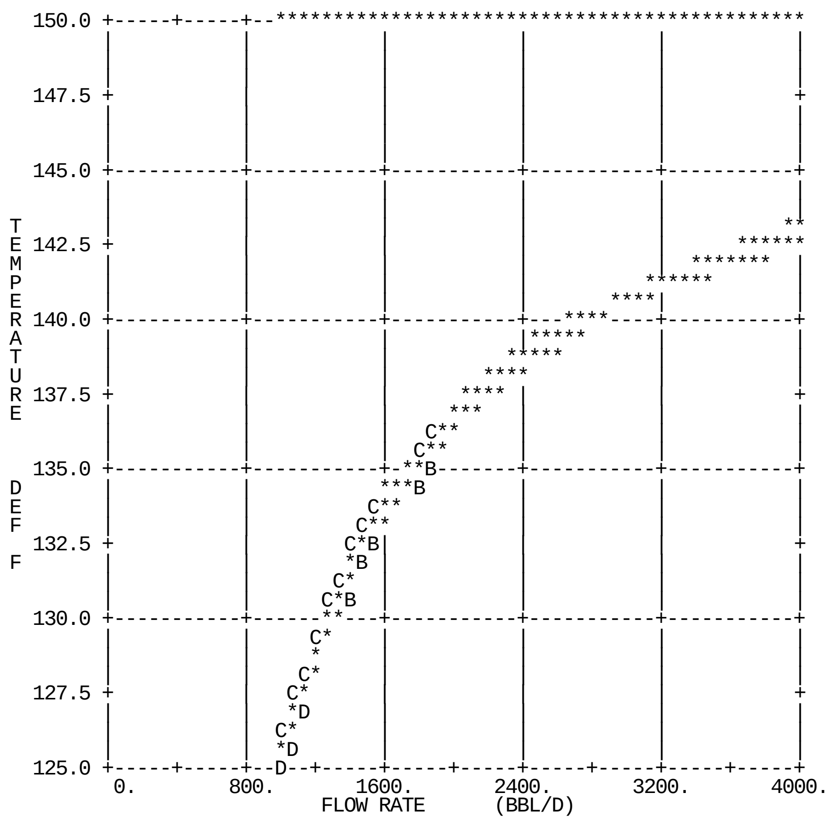


## Partial Output (continued)

Figure P14.3 below shows the sensitivity analysis plot of temperature versus flowrate.

**Figure P14.3: Sensitivity Analysis Temperature Plot**

```
SOLUTION NODE IS AT INLET OF DEVICE TUB1

INFLOW CURVE IS TEMPERATURE INTO DEVICE TUB1
OUTFLOW CURVE IS TEMPERATURE AT SINK
                            SENSITIVITY ANALYSIS
```




```
     KEY...    1 - 1400 PSI        2 - 850 PSI         3 - 650 PSI
               A - 75  HP          B - 75  HP + SEP    C - 130 HP
               D - 130 HP + SEP
```

## Partial Output (continued)

The output below consists of the printout of the data points from which the plots shown in Figures P14.2 and P14.3 were generated.

SOLUTION NODE IS AT INLET OF DEVICE TUB1

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE 1400 PSI | 850 PSI | 650 PSI |
|---|---|---|---|
| 1000.00 | 1366.03 | 810.50 | 556.64 |
| 1500.00 | 1340.13 | 781.76 | 525.87 |
| 2000.00 | 1313.18 | 751.91 | 493.95 |
| 2500.00 | 1285.18 | 720.95 | 460.87 |
| 3000.00 | 1256.13 | 688.89 | 426.61 |
| 4000.00 | 1194.91 | 621.42 | 354.56 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 75 HP | 75 HP + SEP | 130 HP | 130 HP + SEP |
|---|---|---|---|---|
| 1000.00 | 332.40 | 0.00 | 117.22 | 73.08 |
| 1500.00 | 620.04 | 264.61 | 297.61 | 0.00 |
| 2000.00 | 882.42 | 876.96 | 517.96 | 0.00 |
| 2500.00 | 1125.73 | 1220.85 | 748.87 | 290.65 |
| 3000.00 | 1359.90 | 1478.20 | 981.82 | 759.03 |
| 4000.00 | 1813.11 | 1896.39 | 1456.66 | 1354.96 |

SOLUTION NODE IS AT INLET OF DEVICE TUB1

NODE TEMPERATURES FOR INFLOW VARIABLES (DEG F )

| RATE (BBL/D) | INFLOW VARIABLE 1400 PSI | 850 PSI | 650 PSI |
|---|---|---|---|
| 1000.00 | 150.00 | 150.00 | 150.00 |
| 1500.00 | 150.00 | 150.00 | 150.00 |
| 2000.00 | 150.00 | 150.00 | 150.00 |
| 2500.00 | 150.00 | 150.00 | 150.00 |
| 3000.00 | 150.00 | 150.00 | 150.00 |
| 4000.00 | 150.00 | 150.00 | 150.00 |

OUTLET TEMPERATURES FOR OUTFLOW VARIABLES (DEG F )

| RATE (BBL/D) | OUTFLOW VARIABLE 75 HP | 75 HP + SEP | 130 HP | 130 HP + SEP |
|---|---|---|---|---|
| 1000.00 | 125.90 | 125.73 | 125.94 | 125.18 |
| 1500.00 | 132.79 | 131.99 | 132.86 | 132.61 |
| 2000.00 | 136.64 | 136.06 | 136.73 | 136.47 |
| 2500.00 | 139.09 | 138.63 | 139.18 | 138.71 |
| 3000.00 | 140.79 | 140.41 | 140.88 | 140.50 |
| 4000.00 | 142.97 | 142.70 | 143.06 | 142.78 |

## Partial Output (continued)

Valid solutions for the sensitivity analysis plot shown in Figure P14.2 occur at the intersection and are given in the table below.

```
SOLUTION NODE IS AT INLET OF DEVICE TUB1


INFLOW-OUTFLOW CURVE INTERSECTION POINTS
----------------------------------------
```

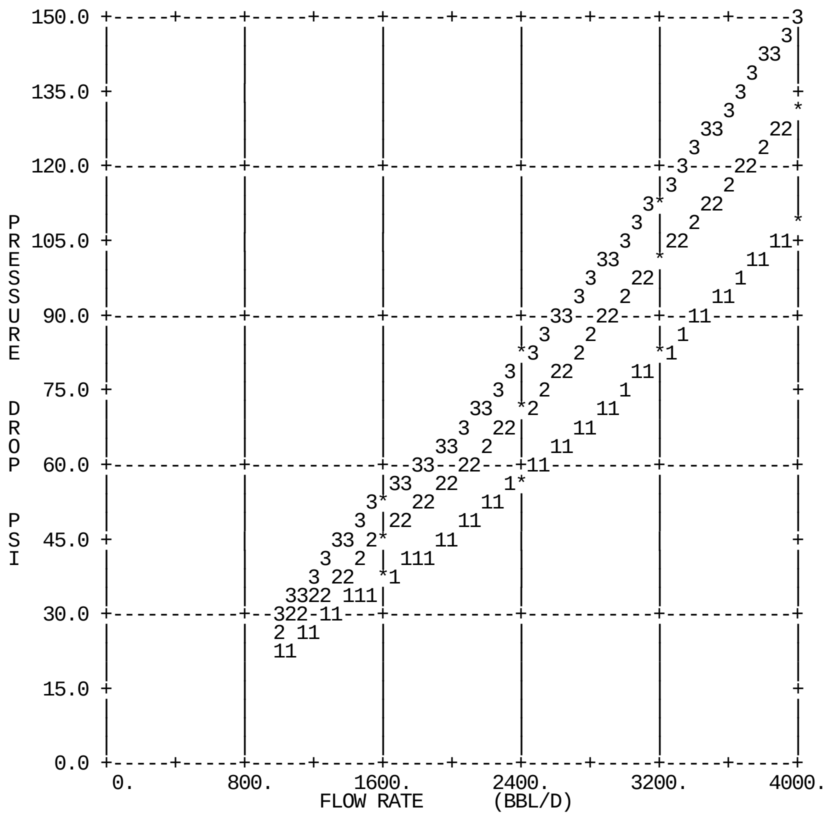
| INFLOW CASE | OUTFLOW CASE | RATE (BBL/D) | PRESSURE (PSIA) |
|---|---|---|---|
| 1400 PSI | 75 HP | 2802.88 | 1267.58 |
| | 75 HP + SEP | 2612.31 | 1278.65 |
| | 130 HP | 3511.72 | 1224.80 |
| | 130 HP + SEP | 3756.44 | 1209.82 |
| 850 PSI | 75 HP | 1776.69 | 765.24 |
| | 75 HP + SEP | 1902.64 | 757.72 |
| | 130 HP | 2446.70 | 724.25 |
| | 130 HP + SEP | 2929.93 | 693.38 |
| 650 PSI | 75 HP | 1352.12 | 534.97 |
| | 75 HP + SEP | 1702.76 | 512.93 |
| | 130 HP | 1952.42 | 496.99 |
| | 130 HP + SEP | 2669.32 | 449.26 |

## Partial Output (continued)

The completion pressure drop results are shown below in Figure P14.4. This plot may be used for analyzing the completion performance.

**Figure P14.4: Sensitivity Analysis Completion Pressure Drop Plot**

```
SOLUTION NODE IS AT INLET OF DEVICE TUB1
                SENSITIVITY ANALYSIS - COMPLETION PRESSURE DROP
```




```
KEY...    1 - 1400 PSI    2 - 850 PSI     3 - 650 PSI
```

P14 Well With Artificial Lift

## Partial Output (continued)

The output below consists of the printout of the data points from which the plot shown in Figure P14.4 was generated.

COMPLETION ZONE PRESSURE DROPS (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE 1400 PSI | 850 PSI | 650 PSI |
|---|---|---|---|
| 1000.00 | 20.89 | 26.41 | 30.28 |
| 1500.00 | 32.91 | 41.27 | 47.15 |
| 2000.00 | 45.97 | 57.23 | 65.19 |
| 2500.00 | 60.08 | 74.30 | 84.39 |
| 3000.00 | 75.23 | 92.47 | 104.75 |
| 4000.00 | 108.68 | 132.16 | 149.03 |

P14 Well With Artificial Lift

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# Compositional Modeling For Gas-lift Well

## Problem Description

A gas condensate well is producing from a resevoir with a low PI (productivity index) of 0.2637 Mkg/hr/bar. A high pressure drop across the sandface creates a low bottom hole pressure which is not sufficient to produce the liquid condensate. As a result, the liquid phase builds up in the wellbore and kills the well's production. Gas lift may be able to stimulate the well's production by decreasing the fluid density. Refer to Figure P15.1 and Table P15.1 for additional process data.

You are therefore required to:

1. Determine if injecting lift gas into the bottom of the wellbore will allow the well to produce.
2. Determine the minimum lift gas injection rate required if the well is to produce at a wellhead pressure of 33 bar (685 psia).

**Figure P15.1: Compositional Modeling for Gas-Lift Well**

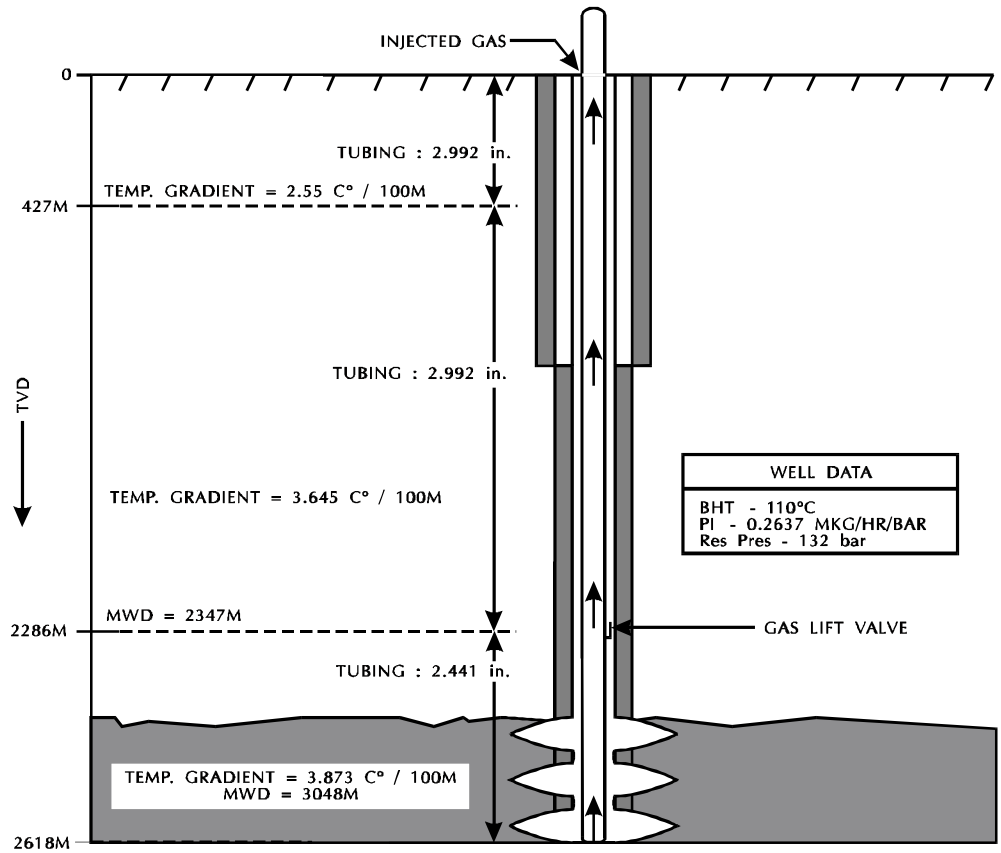

**Table P15.1: Process Information**

**Fluid Composition**

| Component | Reservoir Fluid Mole % | Lift Gas Mole % | MW | Density $Kg/m^3$ | NBP °C |
|---|---|---|---|---|---|
| N2 | 1.30 | - | - | - | - |
| CO2 | 12.34 | - | - | - | - |
| C1 | 72.06 | 90.0 | - | - | - |
| C2 | 8.73 | 8.0 | - | - | - |
| C3 | 2.71 | 2.0 | - | - | - |
| IC4 | 0.37 | - | - | - | - |
| NC4 | 0.70 | - | - | - | - |
| IC5 | 0.20 | - | - | - | - |
| NC5 | 0.25 | - | - | - | - |
| G127 | 0.25 | - | 81.00 | 700.50 | 53.0 |
| G183 | 0.29 | - | 94.00 | 721.20 | 84.0 |
| G249 | 2.00 | - | 111.57 | 744.10 | 121.0 |
| G387 | 2.00 | - | 161.07 | 788.80 | 197.0 |
| G593 | 0.70 | - | 259.90 | 847.41 | 312.0 |
| G828 | 0.60 | - | 405.60 | 907.28 | 442.0 |

**Tubing Data**

| Depth (m) | Length (m) | Inside Diameter (in) | Temp. Gradient °C/100 ft | Heat Transfer Coefficient $Btu/hr\text{-}ft^2\text{-}F$ |
|---|---|---|---|---|
| 427 | 427 | 2.992 | 2.55 | 1.5 |
| 2286 | 2347 | 2.992 | 3.645 | 1.5 |
| 2618 | 3048 | 2.441 | 3.873 | 3.0 |

## PIPEPHASE Features Used In The Problem

- Compositional gas-lift using the lateral source option is used since the Blackoil Model is inadequate for modeling condensate phase behavior.
- Pseudocomponents are used to simulate the heavier fractions. Data, in terms of petroleum cuts, were available for the heavier compositions from laboratory analysis.
- Rigorous heat and energy balance is required because condensate phase behavior is very sensitive to temperature.
- The Sensitivity Analysis feature enables the study of system sensitivity to parameters of interest in a single computer run (gas injection rate in this case). The results are also presented in graphical form.

## Results and Discussion

1. Gas-lifting the condensate well decreased the unstable (density dominated) flow region. This is a viable method of preventing liquid build up in the well.
2. For a wellhead pressure of 33 bar, the minimum gas injection rate is slightly below 273 Kg/hr. The corresponding stable production rate is about 1700 Kg/hr.

## Simulation Highlights

INPUT

- The Orkiszewski correlation was used. This correlation is good for gas dominated wells.
- The Peng-Robinson equation of state is used for flash calculations along with the API method for liquid density.

TECHNIQUE

- Compositional gas-lift was simulated using the lateral source feature. The rate of the lift gas was varied as the inflow parameter in the sensitivity analysis. The sink is used as the solution node. When a lateral source is used, the sensitivity analysis can only vary parameters on the side of the solution node that contains the lateral source. As a result, the solution for the minimum lift gas rate must be interpolated from the available cases.

## Input Data

Metric units of measure are used throughout the simulation. The keyword input file for this simulation problem is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL5, PROJECT=WELLAPP, USER=SIMSCI
DESC    NODE IS AT THE WELLHEAD
PRINT   INPUT=NONE, DEVICE=FULL
DIME    METRIC
SEGMENT DLHOR=100, DLVERT=100
CALC    SINGLE, COMPOSITION
FCODE   TUBI=ORK
DEFAULT IDTUBI(IN)=2.992, UTUBI(BTUFTF)=1.5
$
COMPONENT DATA
        LIBID   CO2/N2/C1/C2/C3/IC4/NC4/IC5/NC5
        PETRO(KGM3,C)   BP53,81,700.5,53/*
                        BP84,94,721.2,84/*
                        BP121,111.57,744.1,121/*
                        BP197,161.07,788.8,197/*
                        BP312,259.9,847.41,312/*
                        BP442,405.6,907.28,442
$
METHODS DATA
        THERMO  SYSTEM=PR
$
STRUCTURE DATA
        SOURCE  NAME=S1, TEMP=110, PRES=132, RATE(W)=4545, *
                PI=0.264, COMP=11.8/1.2/69.0/8.3/2.6/0.4/0.7/ *
                0.2/0.2/0.2/0.3/1.9/1.9/0.7/0.6
        SOURCE  NAME=G1, TEMP=93.3, PRES=120, RATE(W,KGHR)=2273, *
                COMP=0/0/90/8/2/0/0/0/0/0/0/0/0/0/0
$
        LINK    NAME=L001, FROM=S1, TO=S2
                TUBING  NAME=TUB1, LENGTH=3048, DEPTH=2618, *
                ID(IN)=2.441, U(BTUFTF)=3, TGRAD=3.873
                INJECT  FROM=G1
                TUBING  NAME=TUB2, LENGTH=2347, DEPTH=2286, TGRAD=3.645
                TUBING  NAME=TUB3, LENGTH=427 , TGRAD=2.55
$
        SINK    NAME=WHSP, PRES(ESTI)=33, RATE(ESTI)=6818
$
SENSITIVITY DATA
        NODE    SINK
        FLOW    RATE(W,KGHR)=455,1364,2273,4545,6818,9091
        DESC    INFLOW=0 KGHR, 273 KGHR,1091 KGHR, 2727 KGHR
        INFLOW  NAME=G1, RATE(W, KGHR)=0, 273, 1091, 2727
END
```

## Output

- The portion of the pressure versus flowrate curve with a positive slope represents the density-dominated, unstable flow region. This shows up clearly in the sensitivity plot given in Figure P15.2.
- For higher gas injection rates the shift from density-dominated flow to friction-dominated flow takes place at lower production flowrates. Also, the lower the gas injection rate, the greater the unstable flow region.

## Partial Output

The sensitivity plot and the tabulated results are given below in Figure P15.2. The positive slope highlighted on the figure below indicates the unstable flow region.

**Figure P15.2: Pressure vs. Flowrate Plot (Sensitivity Analysis)**

```
SOLUTION NODE IS AT OUTLET OF DEVICE TUB3

                           SENSITIVITY ANALYSIS

  40.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
       |           |           |           |           |           |
       |    3      |           |           |           |           |
       |     33    |           |           |           |           |
  36.0 +       33  |           |           |           |           +
       |         33|   22      |           |           |           |
       |           *322  22    |           |           |           |
       |           |233    22  |           |           |           |
  32.0 +-----------2---3-----**1111--------+-----------+-----------+
       |         22|   1**111  *2  1       |           |           |
       |        2  |  1   3    | 22 11     |           |           |
       |       2   |  1    3   |   22 1    |           |           |
  28.0 +    4*2    | 1      33 |     2 1   |           |           +
       |    2 444  |1         3|      2 11 |           |           |
P      |         44|1          *       22 1|           |           |
R      |           *44         |33       2 *           |           |
E 24.0 +----------1+--444------+--33------221----------+-----------+
S      |         1 |     4444  |    33     |211        |           |
S      |         1 |         44*4      33   | 2 1       |           |
U      |        1  |           | 444    333|  221      |           |
R 20.0 +       1   |           |    4444   *3   21     |           +
E      |       1   |           |        444| 33  2*1   |           |
       |      1    |           |           *444333 21   |           |
       |     1     |           |           |   4443321  |           |
B 16.0 +-----1-----+-----------+-----------+------44***1-----------+
A      |    1      |           |           |          ***          |
R      |           |           |           |           |2**44      |
       |           |           |           |           |  *3344    |
  12.0 +           |           |           |           |   *133    +
       |           |           |           |           |    2*     |
       |           |           |           |           |      *    |
       |           |           |           |           |           |
   8.0 +-----------+-----------+-----------+-----------+-----------+
       |           |           |           |           |           |
       |           |           |           |           |           |
       |           |           |           |           |           |
   4.0 +           |           |           |           |           +
       |           |           |           |           |           |
       |           |           |           |           |           |
       |           |           |           |           |           |
   0.0 +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
        0.       1000.       2000.       3000.       4000.       5000.
                           FLOW RATE      (KGHR)

KEY...    1 - 0 KGHR       2 - 273 KGHR     3 - 1091 KGHR    4 - 2727 KGHR
```

## Partial Output (continued)

The node pressures and temperatures are shown in the tables below.

SOLUTION NODE IS AT OUTLET OF DEVICE TUB3

NODE PRESSURES FOR INFLOW VARIABLES (BAR )

| RATE (KGHR) | INFLOW VARIABLE 0 KGHR | 273 KGHR | 1091 KGHR | 2727 KGHR |
|---|---|---|---|---|
| 455.00 | 15.04 | 27.22 | 38.20 | 28.23 |
| 1364.00 | 30.66 | 35.02 | 32.07 | 23.53 |
| 2273.00 | 31.74 | 30.18 | 23.82 | 21.07 |
| 4545.00 | 9.65 | 10.26 | 11.97 | 13.50 |
| 6818.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9091.00 | 0.00 | 0.00 | 0.00 | 0.00 |

NODE TEMPERATURES FOR INFLOW VARIABLES (DEG C )

| RATE (KGHR) | INFLOW VARIABLE 0 KGHR | 273 KGHR | 1091 KGHR | 2727 KGHR |
|---|---|---|---|---|
| 455.00 | 19.54 | 20.77 | 25.26 | 31.47 |
| 1364.00 | 24.07 | 25.88 | 29.74 | 34.37 |
| 2273.00 | 29.36 | 30.60 | 32.87 | 38.13 |
| 4545.00 | 36.98 | 38.38 | 41.51 | 44.55 |
| 6818.00 | 46.38 | 52.00 | 53.72 | 56.08 |
| 9091.00 | 70.32 | 66.74 | 72.52 | 67.57 |

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# Optimizing Gas-oil Ratios (GOR) for a Gas-lift Well



## Problem Description

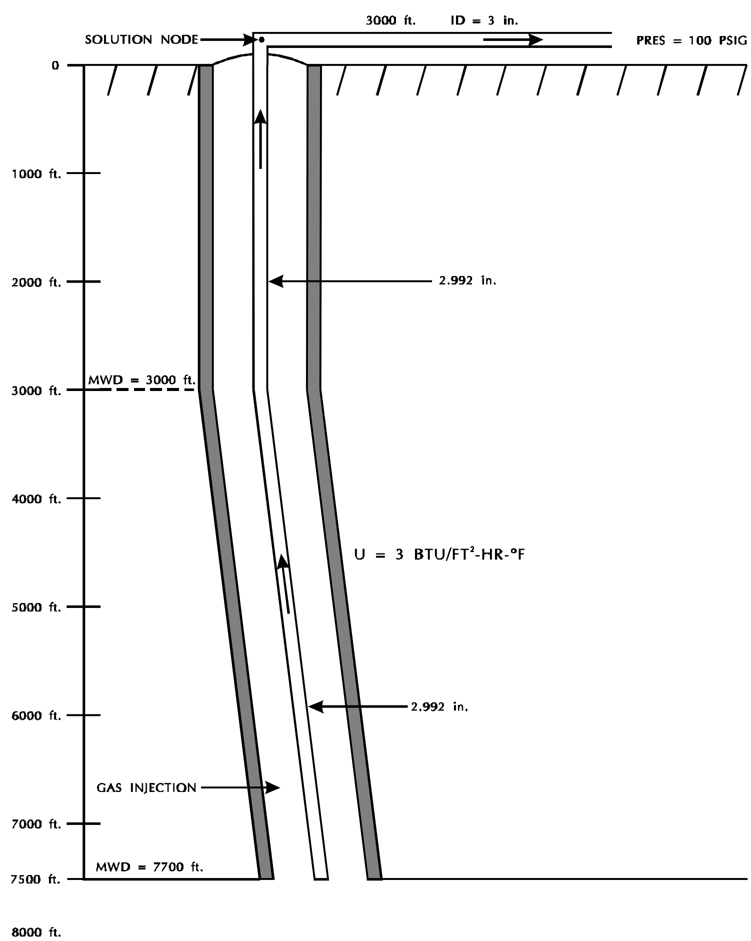
A 7700 foot deep oil well, shown in the Figure P16.1, is producing at a formation gas-oil ratio (GOR) of 400 scf/stb. To increase production, gas-lifting the well is a possible option. The reservoir pressure is 2600 psig and the watercut is 10%. Other pertinent process data are given in Table P16.1.

You are required to:

1. Determine the optimum GOR required to achieve the maximum rate in the tubing flowline system. Determine this maximum rate.
2. Determine the required gas injection rate.
3. Determine the maximum oil production if the watercut increases to 35% from the existing 10%. Determine the new optimum GOR.
4. Determine the new required gas injection rate.

P16 Optimizing Gas-oil Ratios (GOR) for a Gas-lift Well

**Figure P16.1: Optimizing GOR for Gas-Lift Well**



P16 Optimizing Gas-oil Ratios (GOR) for a Gas-lift Well

| Table P16.1: Process Information | |
|---|---|
| **Heat Transfer Data** | |
| Temp. Gradient | 1.3 °F/100 ft |
| U PIPE | 3 Btu/hr-ft$^2$-F |
| TUBE ID | 2.992 inch |
| **Well Data** | |
| Source Temperature | 180°F |
| Source Pressure | 2600 psig |
| Source Rate (estimated) | 1000 bbl/d |
| Sink Pressure | 100 psig |
| Vogel Index | 6000 bbl/d |
| **Fluid Data** | |
| Oil Gravity | 28 API |
| Gas Specific Gravity | 0.62 |
| Water Specific Gravity | 1.003 |
| GOR | 400 scf/stb |
| Water Cut | 10% |

## PIPEPHASE Features Used In This Problem

- The Sensitivity Analysis feature of PIPEPHASE can be used to quickly obtain a preliminary feasibility study and the optimum GOR using the GOR as a parameter.
- The Blackoil model with heat transfer is used. Accurate temperature prediction leads to better results.
- The reservoir IPR (Inflow Performance Relationship) is described by the VOGEL method. This method is appropriate for reservoirs producing below the bubble point.
- The case study feature is used to study the effects of a 35% water cut.

## Results and Discussion

1. The GOR required to maximize production is about 1200 scf/stb. The maximum oil flowrate is about 2790 bbl/d at 10% water cut.
2. The required gas injection rate is 2.23 MMscfd for 10% water cut.
3. The maximum oil production rate will be 1976 stb/d at 35% water cut. The GOR required for this rate is 1600 scf/stb.
4. The required gas injection rate is 2.37 MMscfd for 35% water cut.
5. For both cases, the production is increased only slightly by increasing the GOR near the maximum. A GOR of 800 for the 10% water cut and a GOR of 1200 for the 35% water cut may be a more economical selection.

## Simulation Highlights

INPUT

- The solution node was set at the wellhead since wellhead pressures are easily available. The calculated node pressures can be directly compared with this data for design evaluation in the future.
- The Orkiszewski pressure drop correlation was used for pressure drop in the tubing, since it is known to be well suited for high GOR wells (e.g. gas lift wells).

TECHNIQUE

- The gas-lift analysis was done by using GOR as a sensitivity parameter in both the inflow and outflow segments.
- Of the various intersection points, the solutions relevant to the gas lift problems are the intersection points for which the GORs are the same for both the inflow and the outflow side.
- If a line connecting these intersection points is drawn, the maximum flowrate can be easily obtained. The optimum GOR is then taken to be at the point of maximum flowrate. See Figures P16.2 and P16.3 for details.
- It was assumed that the injection gas gravity is the same as produced gas and that the injection is at the bottomhole.

## Input Data

The keyword input file for this simulation problem is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL6, PROJ=WELLAPP, USER=SIMSCI
DESC    OPTIMIZING GOR FOR GAS LIFT WELL
CALC    SINGLE, BLACKOIL
PRINT   DEVICE=PART
SEGMENT DLHOR=300, DLVERT=300
FCODE   TUBI=ORK
DEFAULT IDTUBI=2.992, UTUBI=3, TGRAD=1.3
$
PVT PROPERTY DATA
        SET     SETNO=1, GRAV(OIL)=28, GRAV(GAS)=0.62, *
                GRAV(WATER,SPGR)=1.003
$
STRUCTURE DATA
        SOURCE  NAME=S1, TEMP=180, PRES=2600, RATE(ESTI)=1000, *
                GOR=500, VOGEL=6000, WCUT=10
$
        LINK    NAME=L001, FROM=S1, TO=S2
                TUBING  LENGTH=7700, DEPTH=7500
                TUBING  LENGTH=3000, DEPTH=3000
                PIPE    NAME=PIP1, LENGTH=3000, ID=3
        $
SINK    NAME=S2, PRES=100, RATE(ESTI)=1000
$
SENSITIVITY ANALYSIS
        NODE    NAME=PIP1
        FLOW    RATE=500, 800, 1000, 1200, 1500, *
                2000, 2500, 3000, 3500
        DESCRIP INFLOW=400  GOR,800  GOR,1200 GOR, *
                1600 GOR, 2000 GOR
        INFLOW  GOR=400,800,1200,1600,2000
        DESCRIP OUTFLOW=400  GOR,800  GOR,1200 GOR, *
                1600 GOR,2000 GOR
        OUTFLOW GOR=400,800,1200,1600,2000
$
CASE STUDY
        CHANGE  NAME=S1, WCUT=35
END
```

## Output

- The sensitivity plot and tables indicate the intersection points. The solution points have to be chosen according to the technique described in the Simulation Highlights section above.

## Partial Output

The calculated points for the nodal plot are given below together with the intersection points for the 10% watercut case (solution node is at inlet of PIP1).

SOLUTION NODE IS AT INLET OF DEVICE PIP1

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE 400 GOR | 800 GOR | 1200 GOR | 1600 GOR | 2000 GOR |
|---|---|---|---|---|---|
| 500.00 | 410.37 | 739.77 | 956.83 | 1123.36 | 1259.02 |
| 800.00 | 509.24 | 879.49 | 1105.91 | 1253.90 | 1339.20 |
| 1000.00 | 549.34 | 919.88 | 1116.40 | 1215.94 | 1279.70 |
| 1200.00 | 562.77 | 916.29 | 1066.93 | 1154.97 | 1213.19 |
| 1500.00 | 553.19 | 843.31 | 975.48 | 1053.92 | 1114.57 |
| 2000.00 | 462.42 | 692.62 | 819.85 | 911.75 | 982.10 |
| 2500.00 | 324.83 | 538.74 | 664.57 | 752.76 | 803.52 |
| 3000.00 | 181.74 | 365.87 | 473.99 | 528.01 | 545.18 |
| 3500.00 | 0.00 | 104.18 | 146.78 | 25.82 | 0.00 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 400 GOR | 800 GOR | 1200 GOR | 1600 GOR | 2000 GOR |
|---|---|---|---|---|---|
| 500.00 | 132.96 | 144.92 | 156.08 | 166.92 | 178.05 |
| 800.00 | 151.48 | 175.31 | 197.00 | 218.56 | 239.88 |
| 1000.00 | 166.00 | 198.45 | 228.27 | 257.07 | 284.76 |
| 1200.00 | 181.95 | 223.41 | 261.36 | 296.97 | 331.27 |
| 1500.00 | 207.93 | 263.60 | 313.45 | 359.69 | 403.74 |
| 2000.00 | 255.51 | 335.04 | 403.99 | 467.38 | 527.31 |
| 2500.00 | 306.74 | 410.15 | 498.21 | 577.88 | 653.34 |
| 3000.00 | 361.06 | 487.25 | 593.99 | 690.14 | 780.79 |
| 3500.00 | 417.15 | 566.09 | 691.26 | 803.74 | 908.71 |

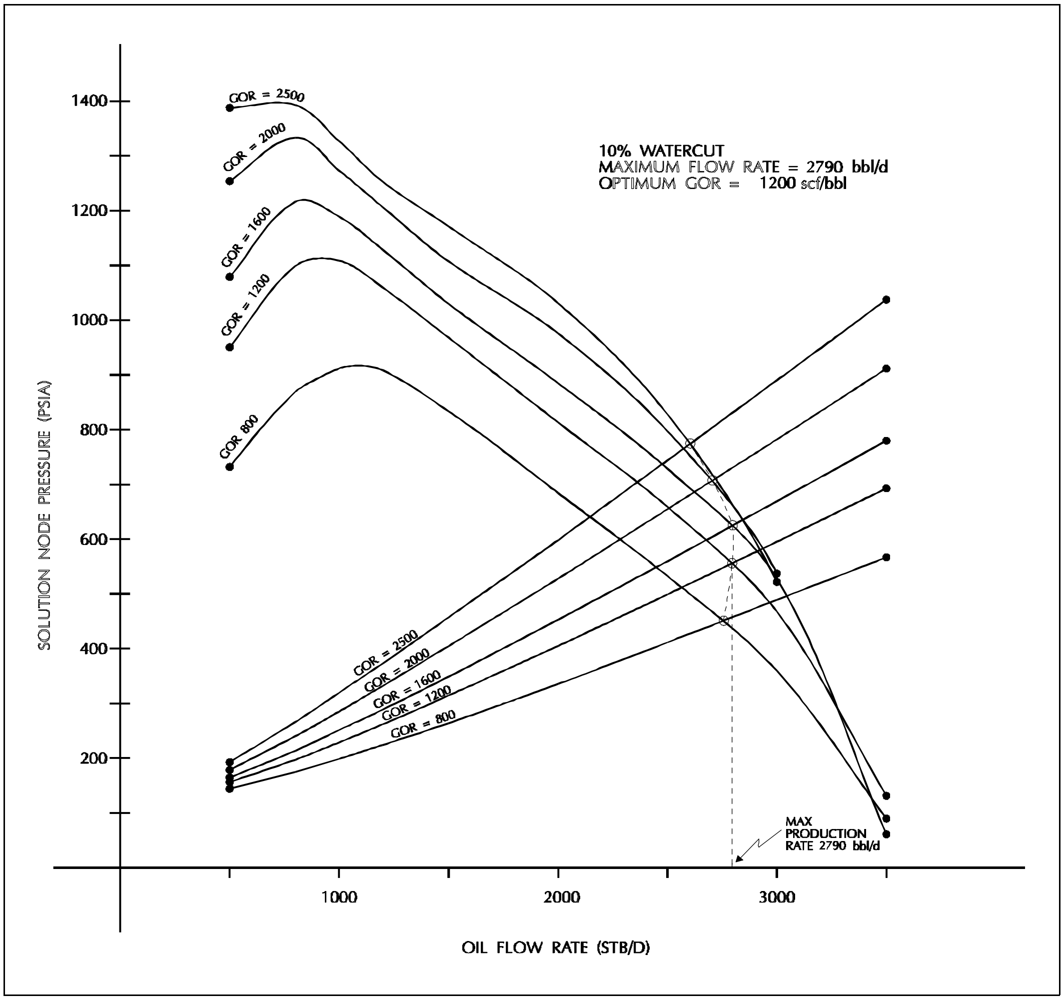
INFLOW-OUTFLOW CURVE INTERSECTION POINTS

| INFLOW CASE | OUTFLOW CASE | RATE (BBL/D) | PRESSURE (PSIA) |
|---|---|---|---|
| 400 GOR | 400 GOR | 2545.83 | 311.72 |
| | 800 GOR | 2299.43 | 380.02 |
| | 1200 GOR | 2126.03 | 427.74 |
| | 1600 GOR | 1987.50 | 464.68 |
| | 2000 GOR | 1848.62 | 489.90 |
| 800 GOR | 400 GOR | 3007.58 | 361.91 |
| | 800 GOR | 2757.21 | 449.82 |
| | 1200 GOR | 2575.44 | 512.66 |
| | 1600 GOR | 2425.97 | 561.52 |
| | 2000 GOR | 2295.29 | 601.74 |
| 1200 GOR | 400 GOR | 3147.32 | 377.59 |
| | 800 GOR | 2975.23 | 483.43 |
| | 1200 GOR | 2790.48 | 553.85 |
| | 1600 GOR | 2643.13 | 610.02 |
| | 2000 GOR | 2517.66 | 657.84 |
| 1600 GOR | 400 GOR | 3149.52 | 377.83 |
| | 800 GOR | 3035.08 | 492.78 |
| | 1200 GOR | 2897.08 | 574.28 |
| | 1600 GOR | 2759.46 | 636.14 |
| | 2000 GOR | 2641.15 | 689.32 |
| 2000 GOR | 1200 GOR | 2931.09 | 580.79 |
| | 1600 GOR | 2804.43 | 646.23 |
| | 2000 GOR | 2694.65 | 702.95 |

## Partial Output (continued)

The pressure versus flowrate values from the PIPEPHASE sensitivity plots for 10% water cut were used to create the Sensitivity Analysis graph shown in Figure P16.2.

**Figure P16.2: Sensitivity Analysis for Water Cut of 10%**



## Partial Output

The calculated points for the nodal plot are given below for the 35% water cut case.

SOLUTION NODE IS AT INLET OF DEVICE PIP1

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE 400 GOR | 800 GOR | 1200 GOR | 1600 GOR | 2000 GOR |
|---|---|---|---|---|---|
| 500.00 | 331.97 | 645.94 | 853.06 | 1009.98 | 1132.44 |
| 800.00 | 394.72 | 735.51 | 922.04 | 1029.84 | 1093.70 |
| 1000.00 | 398.83 | 718.46 | 857.76 | 942.17 | 999.26 |
| 1200.00 | 376.42 | 647.24 | 770.83 | 848.83 | 909.81 |
| 1500.00 | 292.80 | 525.49 | 649.29 | 732.78 | 795.71 |
| 2000.00 | 146.02 | 333.37 | 452.10 | 527.25 | 569.30 |
| 2500.00 | 0.00 | 0.00 | 127.61 | 137.80 | 21.51 |
| 3000.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3500.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 400 GOR | 800 GOR | 1200 GOR | 1600 GOR | 2000 GOR |
|---|---|---|---|---|---|
| 500.00 | 136.85 | 151.15 | 164.43 | 177.23 | 189.79 |
| 800.00 | 160.88 | 189.71 | 215.61 | 240.79 | 264.79 |
| 1000.00 | 179.93 | 219.33 | 254.69 | 287.74 | 318.98 |
| 1200.00 | 200.96 | 251.13 | 295.52 | 336.58 | 375.45 |
| 1500.00 | 235.21 | 302.00 | 359.95 | 412.37 | 462.00 |
| 2000.00 | 297.56 | 392.02 | 471.39 | 543.49 | 610.05 |
| 2500.00 | 364.78 | 486.03 | 586.91 | 677.62 | 761.23 |
| 3000.00 | 436.11 | 583.31 | 705.71 | 814.43 | 914.88 |
| 3500.00 | 510.28 | 683.34 | 826.59 | 953.50 | 1070.60 |

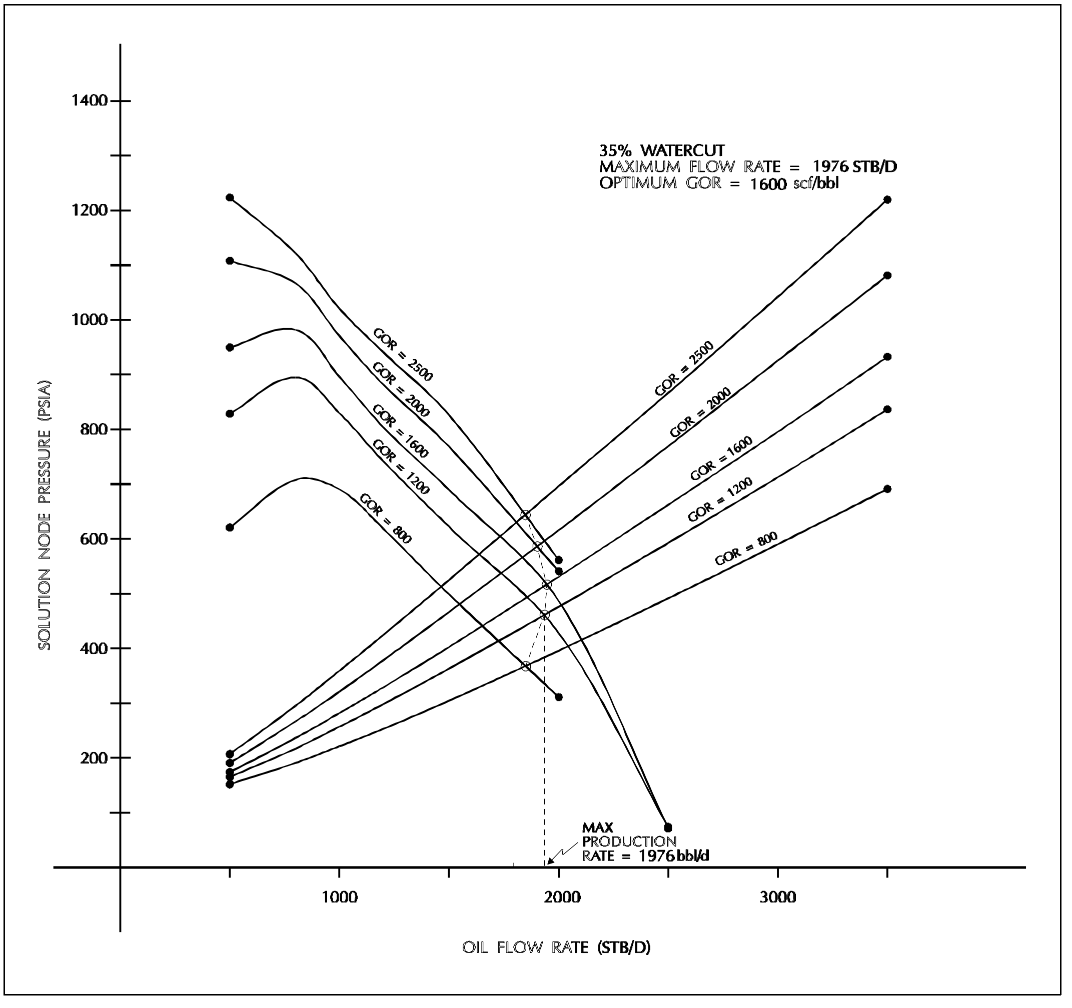
INFLOW-OUTFLOW CURVE INTERSECTION POINTS

| INFLOW CASE | OUTFLOW CASE | RATE (BBL/D) | PRESSURE (PSIA) |
|---|---|---|---|
| 400 GOR | 400 GOR | 1637.68 | 252.38 |
| | 800 GOR | 1479.46 | 298.52 |
| | 1200 GOR | 1363.93 | 330.72 |
| | 1600 GOR | 1274.96 | 355.52 |
| | 2000 GOR | 1201.70 | 375.94 |
| 800 GOR | 800 GOR | 1896.07 | 373.31 |
| | 1200 GOR | 1772.67 | 420.72 |
| | 1600 GOR | 1674.98 | 458.26 |
| | 2000 GOR | 1593.32 | 489.63 |
| 1200 GOR | 400 GOR | 2197.26 | 324.08 |
| | 800 GOR | 2071.78 | 405.52 |
| | 1200 GOR | 1968.76 | 464.42 |
| | 1600 GOR | 1860.82 | 506.99 |
| | 2000 GOR | 1771.24 | 542.31 |
| 1600 GOR | 400 GOR | 2251.48 | 331.37 |
| | 800 GOR | 2139.86 | 418.31 |
| | 1200 GOR | 2055.31 | 484.17 |
| | 1600 GOR | 1975.89 | 537.16 |
| | 2000 GOR | 1882.91 | 575.38 |
| 2000 GOR | 400 GOR | 2220.92 | 327.26 |
| | 800 GOR | 2138.11 | 417.99 |
| | 1200 GOR | 2073.80 | 488.44 |
| | 1600 GOR | 2018.92 | 548.56 |
| | 2000 GOR | 1945.59 | 593.94 |

## Partial Output

The pressure versus flowrate values from the PIPEPHASE sensitivity plots for 35% water cut were used to create the Sensitivity Analysis graph shown in Figure P16.3.

**Figure P16.3: Sensitivity Analysis for Water Cut of 35%**




P16 Optimizing Gas-oil Ratios (GOR) for a Gas-lift Well

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# Gas Condensate Production Networks

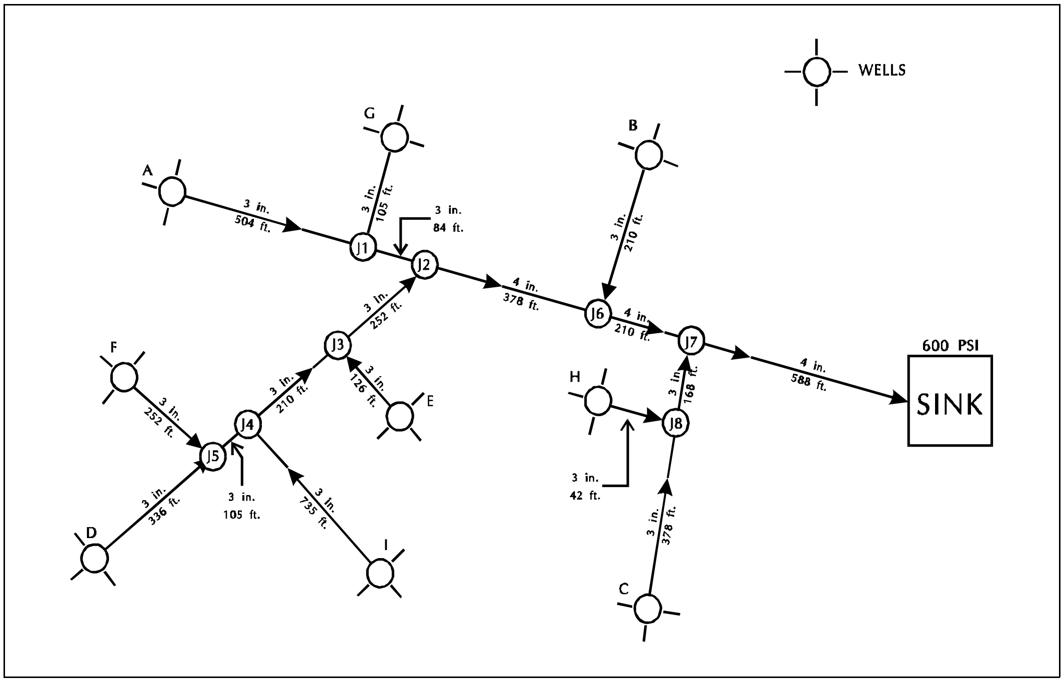
## Problem Description

A gas condensate field has four producing wells (A, B, C, and D). A surface gathering network is installed to deliver the produced gas to a gathering station. The gathering station inlet pressure requirement is 600 psig. To accommodate the increasing demand on production, it is decided to add five more infill wells. The effect of bringing in the new wells onto the existing network needs to be evaluated. A schematic of the new network is given in Figure P17.1 and process information is given in Table P17.1.

You are required to:

1. Determine the production rate in each of the four wells before the in-fill wells are tied into the network.
2. Determine the change in flowrate in the old wells after the infill wells are brought into production.
3. Determine the increase in the total throughput.

**Figure P17.1: Gas Condensate Production**




P17 Gas Condensate Production Networks

## Table P17.1: Process Information

### Tubing Data

| Link | Length (ft) | Depth (in) | ID (in) |
|---|---|---|---|
| A to J1 | 6150 | 5500 | 2.441 |
| B to J6 | 6350 | 6100 | 2.441 |
| C to J8 | 6350 | 5900 | 2.441 |
| D to J5 | 6450 | 6000 | 2.441 |
| E to J3 | 6300 | 5900 | 2.441 |
| F to J5 | 6300 | 6000 | 2.441 |
| G to J1 | 6300 | 6000 | 2.441 |
| H to J8 | 6400 | 6000 | 2.441 |
| I to J4 | 6300 | 6000 | 2.441 |

### Well Data

| | |
|---|---|
| Temperature Gradient | 1.4°F/100 ft |
| Water Gravity | 1.02 |
| Gas Gravity | 0.65 |
| Condensate Gravity | 55 API |

### Source Data

| Source | Temperature °F | Pressure psig | Gas Flowrate (MMscf/d) | Condensate-Gas Ratio (CGR) | Water Gas Ratio (WGR) | Gas Flow Equation Parameters | |
|---|---|---|---|---|---|---|---|
| | | | | | | Coefficient Mcfd | Exponent |
| A | 165 | 1500 | 3 (estim.) | 600 | 20 | 20000 | 0.89 |
| B | 170 | 1520 | 3 (estim.) | 600 | 30 | 21000 | 0.89 |
| C | 169 | 1510 | 3 (estim.) | 600 | 10 | 18000 | 0.89 |
| D | 169 | 1515 | 3 (estim.) | 600 | 25 | 22000 | 0.89 |
| E | 166 | 1510 | 3 (estim.) | 600 | 10 | 19000 | 0.89 |
| F | 165 | 1515 | 3 (estim.) | 600 | 10 | 19000 | 0.89 |
| G | 165 | 1515 | 3 (estim.) | 600 | 10 | 19000 | 0.89 |
| H | 165 | 1515 | 3 (estim.) | 600 | 10 | 19000 | 0.89 |
| I | 165 | 1515 | 3 (estim.) | 600 | 10 | 19000 | 0.89 |

## PIPEPHASE Features Used In This Problem

- The condensate model is used.
- The Gray-Moody equation, which is specially suited for condensate wells, is used for the wells while the Beggs-Brill-Moody method is used for the surface lines by default.

## Results and Discussion

1. The production rate in the four existing wells prior to bringing the new wells to production (mscfd) was calculated as given for Case 1 in Table P17.2.
2. If the five new wells are brought into production (mscfd) the flowrate in each well would be as given for Case 2 in Table P17.2.

**Table P17.2: Results**

| Well | Case 1 | | Case 2 | |
|---|---|---|---|---|
| | Gas Flowrate MMscf/D | Liquid Flowrate BBL/D | Gas Flowrate MMscf/D | Liquid Flowrate BBL/D |
| A | 4.442 | 2665 | 3.204 | 1993 |
| B | 4.118 | 2647 | 3.432 | 2059 |
| C | 4.645 | 2787 | 3.780 | 2268 |
| D | 4.184 | 2511 | 2.232 | 1339 |
| E | N/A | N/A | 2.761 | 1657 |
| F | N/A | N/A | 2.357 | 1414 |
| G | N/A | N/A | 3.145 | 1887 |
| H | N/A | N/A | 3.723 | 2234 |
| I | N/A | N/A | 2.345 | 1407 |
| | 17.389 | 10610 | 26.979 | 16258 |

3. The total production increases from 17220 MMscfd to 26474 MMscfd.

   From the two cases it is apparent that the production in the existing wells will decline. This is due to the fact that the surface lines are too small for a higher flowrate.

## Simulation Highlights

INPUT

- Since most of the pipes were 3 inches and tube IDs all 2.441 inches, the DEFAULT statement was used to specify these values.
- The segment was set at 400 feet for wells. The smaller the segment size, the more accurate the simulated results. For this example, the non-compositional PVT does not pose excess run time problems.
- Junction pressure has to be estimated and are made consistent with the flow direction assumed.

TECHNIQUE

- Since reservoir and IPR data (Inflow Performance Relationship) were reliable, these were set as the fixed boundary conditions for the well.
- The Taitel-Dukler-Barnea map was used to check on the flow pattern especially in the surface lines. Gray-Moody does not predict flow patterns.

## Input Data

The keyword input data files for both Case 1 (Wells A-D producing) and Case 2 (Wells A-I producing) for this simulation problem are given below.

### Keyword Input Data File (Case 1: Wells A, B, C, D Producing)

```
TITLE   PROB=WELL7, PROJECT=WELLAPP, USER=SIMSCI, DATE=12/20/93
DESC    GAS CONDENSATE PRODUCTION

PRINT   INPUT=FULL, DEVICE=FULL, PLOT=FULL
CALCU   NETWORK, CONDENSATE
FCODE   TUBING=GRYM
DEFAULT TGRAD=1.4, IDPIPE=3, IDTUBING=2.441
SEGMENT DLHORIZ=100, DLVERTICAL=400
$
PVT PROPERTY DATA
SET     SETNO=1, GRAV(GAS)=0.65, GRAV(COND)=55, GRAV(WATER,SPGR)=1.02
$
STRUCTURE DATA
SOURCE  NAME=A, SETNO=1, TEMP=165, PRES=1500, RATE(ESTI)=3, *
        CGR=600, WGR=20, COEFF=20000, EXP=0.89
SOURCE  NAME=B, SETNO=1, TEMP=170, PRES=1520, RATE(ESTI)=3, *
        CGR=600, WGR=30, COEFF=21000, EXP=0.89
SOURCE  NAME=C, SETNO=1, TEMP=169, PRES=1510, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=18000, EXP=0.89
SOURCE  NAME=D, SETNO=1, TEMP=169, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=25, COEFF=22000, EXP=0.89
$
JUNC    NAME=J2
JUNC    NAME=J6
JUNC    NAME=J7
$
LINK    NAME=A2, FROM=A, TO=J2
        TUBE    LENGTH=6150, DEPTH=5500
        PIPE    LENGTH=588
LINK    NAME=B6, FROM=B, TO=J6
        TUBE    LENGTH=6350, DEPTH=6100
        PIPE    LENGTH=210
LINK    NAME=C7, FROM=C, TO=J7
        TUBE    LENGTH=6350, DEPTH=5900
        PIPE    LENGTH=546
LINK    NAME=D2, FROM=D, TO=J2
        TUBE    LENGTH=6450, DEPTH=6000
        PIPE    LENGTH=903
LINK    NAME=J67, FROM=J6, TO=J7
        PIPE    LENGTH=210, ID=4
LINK    NAME=J26, FROM=J2, TO=J6
        PIPE    LENGTH=378, ID=4
LINK    NAME=J7SK, FROM=J7, TO=SK
        PIPE    LENGTH=588, ID=4
$
SINK    NAME=SK, PRES=600, RATE(ESTI)=40
END
```

## Keyword Input Data File

## (Case 2: Wells A, B, C, D, E, F, G, H, I Producing)

```
TITLE   PROB=WELL7, PROJECT=WELLAPP, USER=SIMSCI, DATE=12/20/93
DESCRIP Gas condensate production

PRINT   INPUT=None, DEVICE=Full, PLOT=Full
CALCULA Network, Condensate
FCODE   TUBING=GRYM
DEFAULT TGRAD=1.4, IDPIPE=3, IDTUBING=2.441
SEGMENT DLHORIZ=1000, DLVERTICAL=400
$
METHODS DATA
TOLER   PRES=0.2
$
PVT PROPERTY DATA
SET     SETNO=1, GRAV(GAS)=0.65, GRAV(COND)=55, GRAV(WATER,SPGR)=1.02
$
STRUCTURE DATA
SOURCE  NAME=A, SETNO=1, TEMP=165, PRES=1500, RATE(esti)=3, *
        CGR=600, WGR=20, COEFF=20000, EXP=0.89
SOURCE  NAME=B, SETNO=1, TEMP=170, PRES=1520, RATE(ESTI)=3, *
        CGR=600, WGR=30, COEFF=21000, EXP=0.89
SOURCE  NAME=C, SETNO=1, TEMP=169, PRES=1510, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=18000, EXP=0.89
SOURCE  NAME=D, SETNO=1, TEMP=169, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=25, COEFF=22000, EXP=0.89
SOURCE  NAME=E, SETNO=1, TEMP=166, PRES=1510, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=19000, EXP=0.89
SOURCE  NAME=F, SETNO=1, TEMP=165, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=19000, EXP=0.89
SOURCE  NAME=G, SETNO=1, TEMP=165, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=19000, EXP=0.89
SOURCE  NAME=H, SETNO=1, TEMP=165, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=19000, EXP=0.89
SOURCE  NAME=I, SETNO=1, TEMP=165, PRES=1515, RATE(ESTI)=3, *
        CGR=600, WGR=10, COEFF=19000, EXP=0.89
$
JUNC    NAME=J1
JUNC    NAME=J2
JUNC    NAME=J3
JUNC    NAME=J4
JUNC    NAME=J5
JUNC    NAME=J6
JUNC    NAME=J7
JUNC    NAME=J8
$
```

## Keyword Input Data File (continued)
## (Case 2: Wells A, B, C, D, E, F, G, H, I Producing)

```
LINK    NAME=A2, FROM=A, TO=J1
        TUBE    LENGTH=6150, DEPTH=5500
        PIPE    LENGTH=504
LINK    NAME=B6, FROM=B, TO=J6
        TUBE    LENGTH=6350, DEPTH=6100
        PIPE    LENGTH=210
LINK    NAME=C8, FROM=C, TO=J8, rate(esti)=5
        TUBE    LENGTH=6350, DEPTH=5900
        PIPE    LENGTH=378
LINK    NAME=D2, FROM=D, TO=J5
        TUBE    LENGTH=6450, DEPTH=6000
        PIPE    LENGTH=336
LINK    NAME=EJ3, FROM=E, TO=J3
        TUBE    LENGTH=6300, DEPTH=5900
        PIPE    LENGTH=126
LINK    NAME=FJ5, FROM=F, TO=J5
        TUBE    LENGTH=6300, DEPTH=6000
        PIPE    LENGTH=252
LINK    NAME=GJ1, FROM=G, TO=J1
        TUBE    LENGTH=6300, DEPTH=6000
        PIPE    LENGTH=105
LINK    NAME=HJ8, FROM=H, TO=J8
        TUBE    LENGTH=6400, DEPTH=6000
        PIPE    LENGTH=42
LINK    NAME=IJ4, FROM=I, TO=J4
        TUBE    LENGTH=6300, DEPTH=6000
        PIPE    LENGTH=735
LINK    NAME=J8J7, FROM=J8, TO=J7
        PIPE    LENGTH=168
LINK    NAME=J3J2, FROM=J3, TO=J2
        PIPE    LENGTH=252
LINK    NAME=J4J3, FROM=J4, TO=J3
        PIPE    LENGTH=210
LINK    NAME=J5J4, FROM=J5, TO=J4
        PIPE    LENGTH=105
LINK    NAME=J1J2, FROM=J1, TO=J2
        PIPE    LENGTH=84
LINK    NAME=J7SK, FROM=J7, TO=SK
        PIPE    LENGTH=588, ID=4
LINK    NAME=J67, FROM=J6, TO=J7
        PIPE    LENGTH=210, ID=4
LINK    NAME=J26, FROM=J2, TO=J6
        PIPE    LENGTH=378, ID=4
$
SINK    NAME=SK, PRES=600, RATE(ESTI)=40
```

## Output

- The pressure traverse of each link is printed out in order to evaluate the surface line pressure drops and flow pattern. The Taitel-Dukler-Barnea flow pattern map was used to predict the flow pattern. All the devices indicated annular flow.
- The node reports without and with the new wells show the effect of bringing the new wells on line. The well summary gives both the average reservoir pressure and the flowing bottomhole pressure resulting from the gas flow equation.

## Partial Output

The link, node and well summaries for Case 1 (Wells A-D) are shown below.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | | ----ACTUAL FLOW RATES***-- GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | ----HOLDUP**--- GAS (MM SCF) | LIQ (STB) |
|---|---|---|---|---|---|---|---|---|---|---|
| A2 | A | (F) | 0.0453 | 1515.3 | 90.5 | 1500.0* | | 165.0 | | |
| | J2 | (T) | 0.0952 | 1560.7 | 90.5 | 738.5 | 761.5 | 156.6 | 0.0136 | 5.9 |
| B6 | B | (F) | 0.0450 | 1446.7 | 135.0 | 1520.0* | | 170.0 | | |
| | J6 | (T) | 0.0976 | 1487.8 | 135.0 | 724.4 | 795.6 | 161.9 | 0.0132 | 5.2 |
| C7 | C | (F) | 0.0476 | 1536.2 | 47.4 | 1510.0* | | 169.0 | | |
| | J7 | (T) | 0.1052 | 1582.9 | 47.3 | 705.6 | 804.4 | 160.0 | 0.0138 | 5.6 |
| D2 | D | (F) | 0.0427 | 1383.3 | 106.7 | 1515.0* | | 169.0 | | |
| | J2 | (T) | 0.0900 | 1452.6 | 106.6 | 738.5 | 776.5 | 158.3 | 0.0149 | 6.7 |
| J26 | J2 | (F) | 0.1852 | 3013.1 | 197.0 | 738.5 | | 157.4 | | |
| | J6 | (T) | 0.1887 | 3021.3 | 197.0 | 724.4 | 14.0 | 156.7 | 0.0012 | 1.3 |
| J67 | J6 | (F) | 0.2863 | 4507.8 | 331.9 | 724.4 | | 158.5 | | |
| | J7 | (T) | 0.2942 | 4501.0 | 331.9 | 705.6 | 18.8 | 158.2 | 0.0007 | 0.6 |
| J7SK | J7 | (F) | 0.3993 | 6084.7 | 379.3 | 705.6 | | 158.7 | | |
| | SK | (T) | 0.4724 | 5976.0 | 379.3 | 600.0* | 105.6 | 158.1 | 0.0018 | 1.5 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

NODE SUMMARY

| NODE | PRES. (PSIG) | ---STANDARD FLOW RATES ---** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | TEMP. (F) |
|---|---|---|---|---|---|
| A | 1500.0* | 4.4420 | 2665.2 | 88.8 | 165.0 |
| B | 1520.0* | 4.4118 | 2647.1 | 132.4 | 170.0 |
| C | 1510.0* | 4.6445 | 2786.7 | 46.4 | 169.0 |
| D | 1515.0* | 4.1841 | 2510.5 | 104.6 | 169.0 |
| J2 | 738.5 | 0.0000* | 0.0 | 0.0 | 157.4 |
| J6 | 724.4 | 0.0000* | 0.0 | 0.0 | 158.5 |
| J7 | 705.6 | 0.0000* | 0.0 | 0.0 | 158.7 |
| SK | 600.0* | -17.6825 | -10609.5 | -372.2 | 158.1 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

WELL SUMMARY

| WELL LINK | NODE | WELLHEAD PRESS: (PSIG) | WELLHEAD TEMP: (F) | FLOWING PRESS: (PSIG) | FLOWING TEMP: (F) | RESERVOIR PRESS: (PSIG) | IPR | |
|---|---|---|---|---|---|---|---|---|
| A2 | A | 763.8 | 158.3 | 1500.0 | 165.0 | 1500.0 | 2.00E7 M FT3/DAY-(PSI)2<br>EXP = 0.9 | 0. |
| B6 | B | 733.7 | 162.6 | 1520.0 | 170.0 | 1520.0 | 2.10E7 M FT3/DAY-(PSI)2<br>EXP = 0.9 | 0. |
| C7 | C | 731.4 | 161.6 | 1510.0 | 169.0 | 1510.0 | 1.80E7 M FT3/DAY-(PSI)2<br>EXP = 0.9 | 0. |
| D2 | D | 773.1 | 161.1 | 1515.0 | 169.0 | 1515.0 | 2.20E7 M FT3/DAY-(PSI)2<br>EXP = 0.9 | 0. |

## Partial Output

The link summary for Case 2 (Wells A-I) is shown below.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | | ----ACTUAL FLOW RATES***-- GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | ----HOLDUP**--- GAS (MM SCF) | LIQ (STB) |
|---|---|---|---|---|---|---|---|---|---|---|
| A2 | A | (F) | 0.0327 | 1093.1 | 65.3 | 1500.0* | | 165.0 | | |
| | J1 | (T) | 0.0543 | 1175.6 | 65.2 | 914.5 | 585.5 | 153.9 | 0.0144 | 6.3 |
| B6 | B | (F) | 0.0350 | 1125.4 | 105.0 | 1520.0* | | 170.0 | | |
| | J6 | (T) | 0.0624 | 1201.7 | 104.9 | 867.0 | 653.0 | 159.8 | 0.0139 | 5.7 |
| C8 | C | (F) | 0.0387 | 1250.3 | 38.6 | 1510.0* | | 169.0 | | |
| | J8 | (T) | 0.0701 | 1330.9 | 38.5 | 849.6 | 660.4 | 158.7 | 0.0143 | 5.7 |
| D2 | D | (F) | 0.0228 | 738.0 | 56.9 | 1515.0* | | 169.0 | | |
| | J5 | (T) | 0.0353 | 828.7 | 56.7 | 974.1 | 540.9 | 153.1 | 0.0149 | 6.5 |
| EJ3 | E | (F) | 0.0281 | 934.2 | 28.1 | 1510.0* | | 166.0 | | |
| | J3 | (T) | 0.0448 | 1019.6 | 28.1 | 952.4 | 557.6 | 153.6 | 0.0141 | 5.6 |
| FJ5 | F | (F) | 0.0238 | 803.0 | 24.0 | 1515.0* | | 165.0 | | |
| | J5 | (T) | 0.0370 | 894.5 | 23.9 | 974.1 | 540.9 | 149.8 | 0.0146 | 6.1 |
| GJ1 | G | (F) | 0.0318 | 1071.4 | 32.0 | 1515.0* | | 165.0 | | |
| | J1 | (T) | 0.0533 | 1154.5 | 32.0 | 914.5 | 600.5 | 153.9 | 0.0139 | 5.5 |
| HJ8 | H | (F) | 0.0376 | 1268.2 | 37.9 | 1515.0* | | 165.0 | | |
| | J8 | (T) | 0.0685 | 1340.3 | 37.9 | 849.6 | 665.4 | 155.5 | 0.0137 | 5.2 |
| IJ4 | I | (F) | 0.0237 | 798.8 | 23.9 | 1515.0* | | 165.0 | | |
| | J4 | (T) | 0.0367 | 904.3 | 23.8 | 970.2 | 544.8 | 147.3 | 0.0157 | 7.2 |
| J1J2 | J1 | (F) | 0.1076 | 2330.1 | 97.1 | 914.5 | | 153.9 | | |
| | J2 | (T) | 0.1083 | 2331.2 | 97.1 | 908.3 | 6.2 | 153.7 | 0.0002 | 0.2 |
| J26 | J2 | (F) | 0.2724 | 5972.9 | 229.6 | 908.3 | | 151.7 | | |
| | J6 | (T) | 0.2860 | 5959.3 | 229.6 | 867.0 | 41.3 | 151.3 | 0.0015 | 1.3 |
| J3J2 | J3 | (F) | 0.1561 | 3650.8 | 132.5 | 952.4 | | 150.7 | | |
| | J2 | (T) | 0.1641 | 3642.0 | 132.5 | 908.3 | 44.1 | 150.3 | 0.0006 | 0.5 |
| J4J3 | J4 | (F) | 0.1092 | 2629.0 | 104.4 | 970.2 | | 149.9 | | |
| | J3 | (T) | 0.1113 | 2630.9 | 104.4 | 952.4 | 17.8 | 149.5 | 0.0005 | 0.5 |
| J5J4 | J5 | (F) | 0.0722 | 1722.6 | 80.6 | 974.1 | | 151.4 | | |
| | J4 | (T) | 0.0725 | 1725.2 | 80.6 | 970.2 | 3.9 | 151.2 | 0.0002 | 0.2 |
| J67 | J6 | (F) | 0.3485 | 7156.7 | 334.4 | 867.0 | | 152.9 | | |
| | J7 | (T) | 0.3647 | 7131.4 | 334.4 | 831.0 | 36.0 | 152.7 | 0.0008 | 0.7 |
| J7SK | J7 | (F) | 0.5065 | 9802.5 | 410.8 | 831.0 | | 153.8 | | |
| | SK | (T) | 0.7139 | 9422.5 | 411.1 | 600.0* | 231.0 | 153.5 | 0.0019 | 1.6 |
| J8J7 | J8 | (F) | 0.1386 | 2671.1 | 76.4 | 849.6 | | 157.1 | | |
| | J7 | (T) | 0.1418 | 2669.8 | 76.4 | 831.0 | 18.7 | 156.8 | 0.0004 | 0.3 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

## Partial Output (continued)

The node and well summaries for Case 2 (Wells A-I) are shown below.

NODE SUMMARY

| NODE | PRES. (PSIG) | ---STANDARD FLOW RATES ---** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | TEMP. (F) |
|---|---|---|---|---|---|
| A | 1500.0* | 3.2043 | 1922.6 | 64.1 | 165.0 |
| B | 1520.0* | 3.4321 | 2059.3 | 103.0 | 170.0 |
| C | 1510.0* | 3.7800 | 2268.0 | 37.8 | 169.0 |
| D | 1515.0* | 2.2323 | 1339.4 | 55.8 | 169.0 |
| E | 1510.0* | 2.7614 | 1656.9 | 27.6 | 166.0 |
| F | 1515.0* | 2.3574 | 1414.4 | 23.6 | 165.0 |
| G | 1515.0* | 3.1452 | 1887.1 | 31.5 | 165.0 |
| H | 1515.0* | 3.7230 | 2233.8 | 37.2 | 165.0 |
| I | 1515.0* | 2.3450 | 1407.0 | 23.4 | 165.0 |
| J1 | 914.5 | 0.0000* | 0.0 | 0.0 | 153.9 |
| J2 | 908.3 | 0.0000* | 0.0 | 0.0 | 151.7 |
| J3 | 952.4 | 0.0000* | 0.0 | 0.0 | 150.7 |
| J4 | 970.2 | 0.0000* | 0.0 | 0.0 | 149.9 |
| J5 | 974.1 | 0.0000* | 0.0 | 0.0 | 151.4 |
| J6 | 867.0 | 0.0000* | 0.0 | 0.0 | 152.9 |
| J7 | 831.0 | 0.0000* | 0.0 | 0.0 | 153.8 |
| J8 | 849.6 | 0.0000* | 0.0 | 0.0 | 157.1 |
| SK | 600.0* | -26.9806 | -16188.4 | -404.0 | 153.5 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

WELL SUMMARY

| WELL LINK | NODE | WELLHEAD PRESS: (PSIG) | WELLHEAD TEMP: (F) | FLOWING PRESS: (PSIG) | FLOWING TEMP: (F) | RESERVOIR PRESS: (PSIG) | IPR | |
|---|---|---|---|---|---|---|---|---|
| A2 | A | 924.0 | 155.9 | 1500.0 | 165.0 | 1500.0 | 2.00E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| B6 | B | 871.9 | 160.6 | 1520.0 | 170.0 | 1520.0 | 2.10E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| C8 | C | 859.8 | 160.1 | 1510.0 | 169.0 | 1510.0 | 1.80E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| D2 | D | 977.1 | 154.9 | 1515.0 | 169.0 | 1515.0 | 2.20E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| EJ3 | E | 954.1 | 154.1 | 1510.0 | 166.0 | 1510.0 | 1.90E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| FJ5 | F | 976.5 | 151.1 | 1515.0 | 165.0 | 1515.0 | 1.90E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| GJ1 | G | 916.4 | 154.3 | 1515.0 | 165.0 | 1515.0 | 1.90E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| HJ8 | H | 850.8 | 155.7 | 1515.0 | 165.0 | 1515.0 | 1.90E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |
| IJ4 | I | 977.3 | 151.0 | 1515.0 | 165.0 | 1515.0 | 1.90E7 M FT3/DAY-(PSI)2 EXP = 0.9 | 0. |

## Partial Output (continued)

For Case 2, the detail report and Taitel-Dukler-Barnea flow pattern map for the sink link (J7SK) are shown below and on the following page. Note that the Taitel-Dukler-Barnea map is considered to be the most accurate flow pattern predictor available. Taitel-Dukler-Barnea map calculations do not affect the pressure drop calculations which are based on the device flow code specified by the user. In this case, the Beggs-Brill-Moody flow correlation predicts results in the BBM correlation the *distributed* flow pattern for pipes as shown below in the "FLOW REGM" column. This column will not have any entries if the flow correlation used does not depend on flow pattern (for example using the Hagedorn-Brown method).

LINK "J7SK" DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) |
|---|---|---|---|---|---|---|---|---|---|
| P024 | 0000 | 4.000 | 0.0 | I | 0.0 | 831.0 | 153.8 | | 80.0 |
| (PIPE) | 0001 | | 147.0 | | 0.0 | 779.6 | 153.8 | 1.000 | 80.0 |
| | 0002 | | 294.0 | | 0.0 | 724.6 | 153.7 | 1.000 | 80.0 |
| | 0003 | | 441.0 | | 0.0 | 665.2 | 153.6 | 1.000 | 80.0 |
| | 0004 | | 588.0 | O | 0.0 | 600.0 | 153.5 | 1.000 | 80.0 |

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| P024 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.10 | 0.19 | 0.4 | 40.37 | 85.56 | 77.07 | **DIST** | ANNU | 870.24 |
| | 0002 | 0.09 | 0.18 | 0.8 | 42.13 | 90.98 | 82.25 | **DIST** | ANNU | 867.30 |
| | 0003 | 0.08 | 0.17 | 1.2 | 44.25 | 97.68 | 88.68 | **DIST** | ANNU | 860.16 |
| | 0004 | 0.08 | 0.16 | 1.6 | 46.91 | 106.33 | 97.00 | **DIST** | ANNU | 847.66 |

## Partial Output (continued)

```
         !+--------------+--------------+---------------+-------------+!
    75.00+ DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD AAAAAAAAA+
         ! DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD AAAAAAAAAA!
         ! DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD AAAAAAAAAAAA!
         ! DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD IIIIIII DD AAAAAAAAAAAAA!
         ! DDDDDDDDDDDDDDDDDDDDDDDDD IIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAA!
         ! DDDDDDDDDDDDDDDDDD IIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAA!
         ! DDDDDDDDDDD IIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAA!
         ! DDDD IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAA!
    10.00+ IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIIII AAAAA+AAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
     1.00+ IIIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA+
         ! IIIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! IIIIIIIIIIIIIIIIIII AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
VSL      ! IIIIII WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         !  SSSS WWWWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSS WWWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSS WWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSS WWWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSS WWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
     0.10+ SSSSSSSSSSSSSS WWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAAA+
         ! SSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSS WWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAA!
         ! SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAA!
     0.01+ SSSSSSSSSSSSSSSSS WWWWWWWWWWWWWWWW AAAAAAAAAAAAAAAAAAAAAAAAA+
         !+--------------+--------------+---------------+-------------+!
         0.1            1.0           10.0           100.0         900.0

                                        VSG
VSL = SUPERFICIAL LIQUID VELOCITY (FPS)
VSG = SUPERFICIAL GAS VELOCITY (FPS)
+   = OPERATING POINT
   PRESSURE=      914.4861(PSIG)
   TEMP:   =      153.9311(F)
   ANGLE   =        0.0000(DEG)
```

# Steam Injection Network

## Problem Description

A steam distribution network supplies a fixed quantity of steam for fourteen injection wells into a heavy oil reservoir. The reservoir pressure for these wells varies from 1,140 psig to 1,260 psig. The surface lines are insulated to reduce surface heat losses. Process information are provided on Figure P18.1 and in Table P18.1.

You are required to:

1. Determine the required source pressure for this steam network.
2. Determine the injection rate, wellhead pressure, and the wellhead temperature for each well.
3. Determine the steam quality delivered at the sandface.

**Figure P18.1: Steam Injection Network**

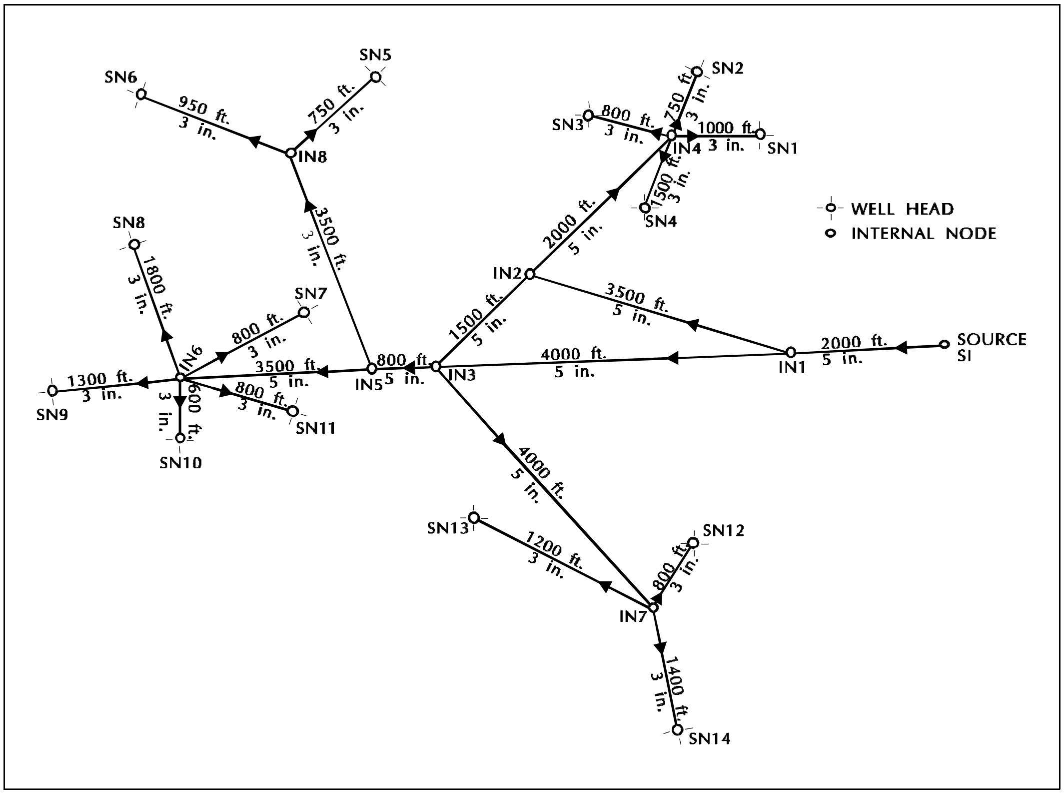


**Table P18.1: Process Information**

**Heat Transfer Data**

| | |
|---|---|
| Temp. Gradient | 1.4°F/100 ft |
| U PIPE | 0.05 Btu/hr-ft$^2$-F |
| U TUBING | 0.5 Btu/hr-ft$^2$-F |
| Source Temperature | 650°F |
| Source Rate | 2000 X10$^3$lb/d |
| Steam Specific Gravity | 1.01 |

**Well and Reservoir Data**

| Well | Injectivity Index (II) (Mlb/hr/psi) | Pressure (psig) | Depth (ft) | ID (in) |
|---|---|---|---|---|
| SN1 | 2.0 | 1200 | 3200 | 3.548 |
| SN2 | 1.8 | 1250 | 3100 | 3.548 |
| SN3 | 1.6 | 1260 | 3000 | 3.548 |
| SN4 | 2.0 | 1246 | 3350 | 3.548 |
| SN5 | 1.5 | 1235 | 3120 | 3.548 |
| SN6 | 1.4 | 1230 | 3400 | 3.548 |
| SN7 | 1.7 | 1140 | 3300 | 3.548 |
| SN8 | 1.7 | 1150 | 3150 | 3.548 |
| SN9 | 1.7 | 1140 | 3090 | 3.548 |
| SN10 | 1.7 | 1140 | 3060 | 3.548 |
| SN11 | 1.7 | 1140 | 3050 | 3.548 |
| SN12 | 1.5 | 1150 | 3025 | 3.548 |
| SN13 | 1.6 | 1160 | 3500 | 3.548 |
| SN14 | 1.6 | 1190 | 3060 | 3.548 |

## PIPEPHASE Features Used In This Problem

- Networks with mixed boundary conditions and a loop can be easily solved by the program.
- Rigorous heat balance is necessary in order to obtain accurate results on steam quality and phase properties.
- The steam model is used for phase split and fluid properties. It is based on PIPEPHASE's built-in steam table.

## Results and Discussion

1. The source pressure required was calculated at 1265 psig.
2. The injection rate, wellhead pressure, and wellhead temperature for each well is given in the following table.

**Table P18.1: Well Results**

| Well Name | $Q_{INJ}$ (Mlb/d) | Injected Quality (%) | WHT (°F) | WHP (psig) |
|---|---|---|---|---|
| SN1 | 152.5 | 92 | 619.3 | 1106 |
| SN2 | 102.4 | 84 | 619.3 | 1109 |
| SN3 | 89.6 | 81 | 618.4 | 1109 |
| SN4 | 121.0 | 86 | 615.9 | 1106 |
| SN5 | 88.6 | 79 | 605.8 | 1070 |
| SN6 | 109.6 | 83 | 605.6 | 1069 |
| SN7 | 173.8 | 94 | 613.4 | 1062 |
| SN8 | 152.4 | 92 | 608.6 | 1059 |
| SN9 | 161.2 | 93 | 611.0 | 1060 |
| SN10 | 160.4 | 94 | 614.1 | 1064 |
| SN11 | 159.3 | 94 | 613.2 | 1063 |
| SN12 | 187.4 | 96 | 614.4 | 1089 |
| SN13 | 204.6 | 95 | 612.9 | 1085 |
| SN14 | 136.9 | 90 | 610.8 | 1090 |

3. The quality of the steam delivered is between 79 - 96%. The quality at the sandface can be obtained by looking at the node summary and device summaries of each link.

## Simulation Highlights

INPUT

- The total source rate is given. The inlet steam quality is defaulted to 100%. Initial estimates for source pressure and sink rates are required for the Newton-Raphson network convergence method used by the program.
- The DEFAULT statement is used to input the temperature gradient and U-factors for pipes and tubings.
- The reservoir IPR (Inflow Performance Relationship) is simulated using the injectivity indices which are supplied in Table P18.1. It is used to calculate the pressure drop from the bottomhole to the reservoir.

TECHNIQUE

- Steam PVT is used in the problem. The built-in steam tables provide the quality (phase split) and other fluid properties required for the calculations. Steam PVT may be used for steam or steam condensate systems.

## Input Data

The keyword input file for this problem is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL8, PROJ=WELLAPP, USER=SIMSCI
CALCULA STEAM, NETWORK
DIMENSI RATE(W)=MLBD
DEFAULT UTUBI=0.5, TGRAD=1.4, IDPIPE=3, UPIPE=0.05, IDTUBI=3.548
PRINT   DEVI=FULL, INPUT=NONE, CONNECT=NONE
SEGMENT DLHOR=1000, DLVERT=500
$
METHODS DATA
TOLER   PRES=0.2
$
PVT DATA
SET     SETNO=1, GRAV(WATER, SPGR)=1.01
$
STRUCTURE
SOURCE  NAME=S1, SETNO=1, TEMP=650, PRES(ESTI)=800, RATE=2000
$
JUNCTIO NAME=IN1
JUNCTIO NAME=IN2
JUNCTIO NAME=IN3
JUNCTIO NAME=IN4
JUNCTIO NAME=IN5
JUNCTIO NAME=IN6
JUNCTIO NAME=IN7
JUNCTIO NAME=IN8
$
LINK    NAME=LN11, FROM=S1, TO=IN1
        PIPE    LENGTH=2000 , ID=5
LINK    NAME=LN12, FROM=IN1, TO=IN2
        PIPE    LENGTH=3500, ID=5
LINK    NAME=LN13, FROM=IN1, TO=IN3
        PIPE    LENGTH=4000, ID=5
LINK    NAME=LN23, FROM=IN2, TO=IN3
        PIPE    LENGTH=1500, ID=5
LINK    NAME=LN24, FROM=IN2, TO=IN4
        PIPE    LENGTH=2000, ID=5
LINK    NAME=LN35, FROM=IN3, TO=IN5
        PIPE    LENGTH=800, ID=5
LINK    NAME=LN56, FROM=IN5, TO=IN6
        PIPE    LENGTH=3500, ID=5
LINK    NAME=LN37, FROM=IN3, TO=IN7
        PIPE    LENGTH=4000, ID=5
LINK    NAME=41, FROM=IN4, TO=SN1
        PIPE    LENGTH=1000
        TUBI    LENGTH=3200
LINK    NAME=42, FROM=IN4, TO=SN2
        PIPE    LENGTH=750
        TUBI    LENGTH=3100
```

## Keyword Input Data File (continued)

```
LINK    NAME=43, FROM=IN4, TO=SN3
        PIPE    LENGTH=800
        TUBI    LENGTH=3000
LINK    NAME=44, FROM=IN4, TO=SN4
        PIPE    LENGTH=1500
        TUBI    LENGTH=3350
LINK    NAME=58, FROM=IN5, TO=IN8
        PIPE    LENGTH=3500
LINK    NAME=85, FROM=IN8, TO=SN5
        PIPE    LENGTH=750
        TUBI    LENGTH=3120
LINK    NAME=86, FROM=IN8, TO=SN6
        PIPE    LENGTH=950
        TUBI    LENGTH=3400
LINK    NAME=67, FROM=IN6, TO=SN7
        PIPE    LENGTH=800
        TUBI    LENGTH=3300
LINK    NAME=68, FROM=IN6, TO=SN8
        PIPE    LENGTH=1800
        TUBI    LENGTH=3150
LINK    NAME=69, FROM=IN6, TO=SN9
        PIPE    LENGTH=1300
        TUBI    LENGTH=3090
LINK    NAME=610, FROM=IN6, TO=SN10
        PIPE    LENGTH=600
        TUBI    LENGTH=3060
LINK    NAME=611, FROM=IN6, TO=SN11
        PIPE    LENGTH=800
        TUBI    LENGTH=3050
LINK    NAME=712, FROM=IN7, TO=SN12
        PIPE    LENGTH=800
        TUBI    LENGTH=3025
LINK    NAME=713, FROM=IN7, TO=SN13
        PIPE    LENGTH=1200
        TUBI    LENGTH=3500
LINK    NAME=714, FROM=IN7, TO=SN14
        PIPE    LENGTH=1400
        TUBI    LENGTH=3060
$
SINK    NAME=SN1, PRES=1200, RATE(ESTI)=100, INJECT, II=2.0
SINK    NAME=SN2, PRES=1250, RATE(ESTI)=100, INJECT, II=1.8
SINK    NAME=SN3, PRES=1260, RATE(ESTI)=100, INJECT, II=1.6
SINK    NAME=SN4, PRES=1246, RATE(ESTI)=100, INJECT, II=2.0
SINK    NAME=SN5, PRES=1235, RATE(ESTI)=100, INJECT, II=1.5
SINK    NAME=SN6, PRES=1230, RATE(ESTI)=100, INJECT, II=1.4
SINK    NAME=SN7, PRES=1140, RATE(ESTI)=100, INJECT, II=1.7
SINK    NAME=SN8, PRES=1150, RATE(ESTI)=100, INJECT, II=1.7
SINK    NAME=SN9, PRES=1140, RATE(ESTI)=100, INJECT, II=1.7
SINK    NAME=SN10, PRES=1140, RATE(ESTI)=100, INJECT, II=1.7
SINK    NAME=SN11, PRES=1140, RATE(ESTI)=100, INJECT, II=1.7
SINK    NAME=SN12, PRES=1150, RATE(ESTI)=100, INJECT, II=1.5
SINK    NAME=SN13, PRES=1160, RATE(ESTI)=100, INJECT, II=1.6
SINK    NAME=SN14, PRES=1190, RATE(ESTI)=100, INJECT, II=1.6
```

## Output

- The DEVICE=FULL prinout option is necessary to provide all intermediate data points. The quality, pressure, and temperature profiles for each link are printed out in detail. Flow patterns are also output wherever two-phase flow occurs.

## Partial Output

The link, node, and well summaries are shown below and on the following page.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | ----ACTUAL FLOW RATES***-- GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | ----HOLDUP**--- GAS (MM SCF) | LIQ (ABBL) |
|---|---|---|---|---|---|---|---|---|---|
| LN11 | S1 (F) | 0.8275 | 0.0 | 0.0 | 1265.0 | | 650.0 | | |
| | IN1 (T) | 0.7402 | 0.0 | 0.2 | 1164.1 | 100.9 | 638.1 | 0.0107 | 0.0 |
| LN12 | IN1 (F) | 0.4511 | 0.0 | 0.0 | 1164.1 | | 638.1 | | |
| | IN2 (T) | 0.3896 | 0.0 | 9.503E-2 | 1116.6 | 47.5 | 629.0 | 0.0178 | 0.0 |
| LN13 | IN1 (F) | 0.4475 | 0.0 | 0.0 | 1164.1 | | 638.1 | | |
| | IN3 (T) | 0.3889 | 0.0 | 9.114E-2 | 1110.5 | 53.6 | 627.8 | 0.0203 | 0.0 |
| LN23 | IN2 (F) | 0.2506 | 0.0 | 0.0 | 1116.6 | | 629.0 | | |
| | IN3 (T) | 0.2103 | 0.0 | 4.399E-2 | 1110.5 | 6.0 | 625.5 | 0.0075 | 0.0 |
| LN24 | IN2 (F) | 0.2166 | 0.0 | 0.0 | 1116.6 | | 629.0 | | |
| | IN4 (T) | 0.1817 | 0.0 | 3.519E-2 | 1110.5 | 6.0 | 623.9 | 0.0100 | 0.0 |
| LN35 | IN3 (F) | 0.4691 | 0.0 | 0.0 | 1110.5 | | 627.0 | | |
| | IN5 (T) | 0.3971 | 0.0 | 8.410E-2 | 1099.4 | 11.2 | 624.9 | 0.0040 | 0.0 |
| LN37 | IN3 (F) | 0.2467 | 0.0 | 0.0 | 1110.5 | | 627.0 | | |
| | IN7 (T) | 0.2098 | 0.0 | 0.3 | 1094.9 | 15.6 | 617.5 | 0.0199 | 0.0 |
| LN56 | IN5 (F) | 0.3799 | 0.0 | 0.0 | 1099.4 | | 624.9 | | |
| | IN6 (T) | 0.3296 | 0.0 | 5.046E-2 | 1067.3 | 32.1 | 616.7 | 0.0172 | 0.0 |
| 41 | IN4 (F) | 0.0707 | 0.0 | 0.0 | 1110.5 | | 623.9 | | |
| | SN1 (T) | 0.0502 | 0.0 | 47.9 | 1200.0* | -89.5 | 569.1 | 0.0100 | 1.9 |
| 42 | IN4 (F) | 0.0475 | 0.0 | 0.0 | 1110.5 | | 623.9 | | |
| | SN2 (T) | 0.0294 | 0.0 | 64.6 | 1250.0* | -139.5 | 574.2 | 0.0090 | 3.7 |
| 43 | IN4 (F) | 0.0415 | 0.0 | 0.0 | 1110.5 | | 623.9 | | |
| | SN3 (T) | 0.0246 | 0.0 | 67.1 | 1260.0* | -149.5 | 575.2 | 0.0088 | 4.2 |
| 44 | IN4 (F) | 0.0561 | 0.0 | 0.0 | 1110.5 | | 623.9 | | |
| | SN4 (T) | 0.0357 | 0.0 | 66.9 | 1246.0* | -135.5 | 573.8 | 0.0111 | 3.6 |
| 58 | IN5 (F) | 0.0933 | 0.0 | 0.0 | 1099.4 | | 624.9 | | |
| | IN8 (T) | 0.0806 | 0.0 | 9.623E-2 | 1071.5 | 27.9 | 610.9 | 0.0062 | 0.0 |
| 610 | IN6 (F) | 0.0771 | 0.0 | 0.0 | 1067.3 | | 616.7 | | |
| | SN10(T) | 0.0569 | 0.0 | 40.3 | 1140.0* | -72.7 | 562.8 | 0.0087 | 1.4 |
| 611 | IN6 (F) | 0.0766 | 0.0 | 0.0 | 1067.3 | | 616.7 | | |
| | SN11(T) | 0.0565 | 0.0 | 40.8 | 1140.0* | -72.7 | 562.8 | 0.0090 | 1.5 |
| 67 | IN6 (F) | 0.0835 | 0.0 | 0.0 | 1067.3 | | 616.7 | | |
| | SN7 (T) | 0.0618 | 0.0 | 42.9 | 1140.0* | -72.7 | 562.9 | 0.0097 | 1.4 |
| 68 | IN6 (F) | 0.0732 | 0.0 | 0.0 | 1067.3 | | 616.7 | | |
| | SN8 (T) | 0.0525 | 0.0 | 49.1 | 1150.0* | -82.7 | 563.9 | 0.0109 | 2.0 |
| 69 | IN6 (F) | 0.0774 | 0.0 | 0.0 | 1067.3 | | 616.7 | | |
| | SN9 (T) | 0.0570 | 0.0 | 42.7 | 1140.0* | -72.7 | 562.8 | 0.0100 | 1.6 |
| 712 | IN7 (F) | 0.0873 | 0.0 | 0.0 | 1094.9 | | 617.5 | | |
| | SN12(T) | 0.0672 | 0.0 | 32.8 | 1150.0* | -55.1 | 564.0 | 0.0092 | 0.9 |
| 713 | IN7 (F) | 0.0953 | 0.0 | 0.0 | 1094.9 | | 617.5 | | |
| | SN13(T) | 0.0721 | 0.0 | 41.4 | 1160.0* | -65.1 | 565.1 | 0.0111 | 1.3 |
| 714 | IN7 (F) | 0.0638 | 0.0 | 0.0 | 1094.9 | | 617.5 | | |
| | SN14(T) | 0.0446 | 0.0 | 53.4 | 1190.0* | -95.1 | 568.1 | 0.0102 | 2.3 |
| 85 | IN8 (F) | 0.0419 | 0.0 | 0.0 | 1071.5 | | 610.9 | | |
| | SN5 (T) | 0.0243 | 0.0 | 73.3 | 1235.0* | -163.5 | 572.6 | 0.0087 | 4.7 |
| 86 | IN8 (F) | 0.0518 | 0.0 | 0.0 | 1071.5 | | 610.9 | | |
| | SN6 (T) | 0.0316 | 0.0 | 74.8 | 1230.0* | -158.5 | 572.2 | 0.0098 | 4.4 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F (GAS ONLY)
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

## Partial Output (continued)

NODE SUMMARY

| NODE | PRES. (PSIG) | STEAM QUAL. | TOTAL RATE (MLBD) | TEMP. (F) |
|---|---|---|---|---|
| S1 | 1265.0 | 1.00 | 2000.00* | 650.0 |
| IN1 | 1164.1 | 1.00 | 0.00* | 638.1 |
| IN2 | 1116.6 | 1.00 | 0.00* | 629.0 |
| IN3 | 1110.5 | 1.00 | 0.00* | 627.0 |
| IN5 | 1099.4 | 1.00 | 0.00* | 624.9 |
| IN4 | 1110.5 | 1.00 | 0.00* | 623.9 |
| IN6 | 1067.3 | 1.00 | 0.00* | 616.7 |
| IN7 | 1094.9 | 1.00 | 0.00* | 617.5 |
| IN8 | 1071.5 | 1.00 | 0.00* | 610.9 |
| SN1 | 1200.0 * | 0.92 | -152.53 | 569.1 |
| SN2 | 1250.0 * | 0.84 | -102.43 | 574.2 |
| SN3 | 1260.0 * | 0.81 | -89.57 | 575.2 |
| SN4 | 1246.0 * | 0.86 | -120.98 | 573.8 |
| SN10 | 1140.0 * | 0.94 | -160.39 | 562.8 |
| SN11 | 1140.0 * | 0.94 | -159.53 | 562.8 |
| SN7 | 1140.0 * | 0.94 | -173.84 | 562.9 |
| SN8 | 1150.0 * | 0.92 | -152.39 | 563.9 |
| SN9 | 1140.0 * | 0.93 | -161.20 | 562.8 |
| SN12 | 1150.0 * | 0.96 | -187.41 | 564.0 |
| SN13 | 1160.0 * | 0.95 | -204.55 | 565.1 |
| SN14 | 1190.0 * | 0.90 | -136.92 | 568.1 |
| SN5 | 1235.0 * | 0.79 | -88.64 | 572.6 |
| SN6 | 1230.0 * | 0.83 | -109.64 | 572.2 |

* INDICATES KNOWN PRESSURE OR FLOW

WELL SUMMARY

| | | WELLHEAD | | FLOWING | | RESERVOIR | |
|---|---|---|---|---|---|---|---|
| WELL LINK | NODE | PRESS: (PSIG) | TEMP: (F) | PRESS: (PSIG) | TEMP: (F) | PRESS: (PSIG) | IPR |
| 41 | IN4 | 1105.9 | 619.3 | 1203.2 | 569.1 | 1200.0 | 2.000 MLB/HR-PSI |
| 42 | IN4 | 1108.9 | 619.3 | 1252.4 | 574.2 | 1250.0 | 1.800 MLB/HR-PSI |
| 43 | IN4 | 1109.2 | 618.4 | 1262.3 | 575.2 | 1260.0 | 1.600 MLB/HR-PSI |
| 44 | IN4 | 1106.1 | 615.9 | 1248.5 | 573.8 | 1246.0 | 2.000 MLB/HR-PSI |
| 610 | IN6 | 1064.1 | 614.1 | 1144.0 | 562.8 | 1140.0 | 1.700 MLB/HR-PSI |
| 611 | IN6 | 1063.0 | 613.2 | 1144.0 | 562.8 | 1140.0 | 1.700 MLB/HR-PSI |
| 67 | IN6 | 1062.3 | 613.4 | 1144.4 | 562.9 | 1140.0 | 1.700 MLB/HR-PSI |
| 68 | IN6 | 1058.6 | 608.6 | 1153.8 | 563.9 | 1150.0 | 1.700 MLB/HR-PSI |
| 69 | IN6 | 1060.3 | 611.0 | 1144.0 | 562.8 | 1140.0 | 1.700 MLB/HR-PSI |
| 712 | IN7 | 1089.3 | 614.4 | 1155.2 | 564.0 | 1150.0 | 1.500 MLB/HR-PSI |
| 713 | IN7 | 1084.9 | 612.9 | 1165.3 | 565.1 | 1160.0 | 1.600 MLB/HR-PSI |
| 714 | IN7 | 1089.6 | 610.8 | 1193.5 | 568.1 | 1190.0 | 1.600 MLB/HR-PSI |
| 85 | IN8 | 1070.2 | 605.8 | 1237.3 | 572.6 | 1235.0 | 1.500 MLB/HR-PSI |
| 86 | IN8 | 1069.1 | 605.6 | 1233.1 | 572.2 | 1230.0 | 1.400 MLB/HR-PSI |

# Partial Output (continued)

The device detail report for link 86 is shown below.

LINK "86  " DEVICE DETAIL REPORT

PRESSURE AND TEMPERATURE REPORT

| DEVICE NAME AND TYPE | SEGM NO | INSIDE DIAM. (IN) | MWD OR LENGTH FROM INLET (FT) | I & O | TVD OR ELEV CHNG (FT) | CALC PRESS (PSIG) | CALC TEMP (F) | OVERALL U-FACT (BTUFT-F) | AMB TEMP (F) | QUAL (FRAC) |
|---|---|---|---|---|---|---|---|---|---|---|
| P020 | 0000 | 3.000 | 0.0 | I | 0.0 | 1071.5 | 611.0 | | 80.0 | 1.00 |
| (PIPE) | 0001 | | 237.5 | | 0.0 | 1070.9 | 609.6 | 0.050 | 80.0 | 1.00 |
| | 0002 | | 475.0 | | 0.0 | 1070.3 | 608.3 | 0.050 | 80.0 | 1.00 |
| | 0003 | | 712.5 | | 0.0 | 1069.7 | 606.9 | 0.050 | 80.0 | 1.00 |
| | 0004 | | 950.0 | O | 0.0 | 1069.1 | 605.6 | 0.050 | 80.0 | 1.00 |
| T021 | 0000 | 3.548 | 0.0 | I | 0.0 | 1069.1 | 605.6 | | 80.0 | 1.00 |
| (TBNG) | 0001 | | 500.0 | | 500.0 | 1076.3 | 578.1 | 0.500 | 87.0 | 1.00 |
| | 0002 | | 1000.0 | | 1000.0 | 1084.2 | 556.2 | 0.500 | 94.0 | 1.00 |
| | 0003 | | 1500.0 | | 1500.0 | 1103.3 | 558.4 | 0.500 | 101.0 | 0.96 |
| | 0004 | | 2000.0 | | 2000.0 | 1129.9 | 561.3 | 0.500 | 108.0 | 0.93 |
| | 0005 | | 2500.0 | | 2500.0 | 1162.1 | 564.8 | 0.500 | 115.0 | 0.89 |
| | 0006 | | 3000.0 | | 3000.0 | 1199.5 | 568.7 | 0.500 | 122.0 | 0.86 |
| | 0007 | | 3400.0 | O | 3400.0 | 1233.1 | 572.2 | 0.500 | 127.6 | 0.83 |

HOLDUP AND VELOCITY DETAIL REPORT

| DEVICE NAME AND TYPE | SEG. NO. | ---LIQUID HOLDUP--- NO SLIP | SLIP | TOTAL (ABBL) | LIQ VEL (FPS) | ACTUAL GAS VEL (FPS) | MIX . VEL (FPS) | FLOW REGM | T-D FLOW REGM | SONIC VEL (FPS) |
|---|---|---|---|---|---|---|---|---|---|---|
| P020 | 0000 | | | | | | | | | |
| (PIPE) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 12.20 | 12.20 | 1-PH | 1-PH | 1823.37 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 12.17 | 12.17 | 1-PH | 1-PH | 1820.82 |
| | 0003 | 0.00 | 0.00 | 0.0 | 0.00 | 12.14 | 12.14 | 1-PH | 1-PH | 1818.27 |
| | 0004 | 0.00 | 0.00 | 0.0 | 0.00 | 12.11 | 12.11 | 1-PH | 1-PH | 1815.73 |
| T021 | 0000 | | | | | | | | | |
| (TBNG) | 0001 | 0.00 | 0.00 | 0.0 | 0.00 | 8.33 | 8.33 | 1-PH | 1-PH | 1786.95 |
| | 0002 | 0.00 | 0.00 | 0.0 | 0.00 | 7.70 | 7.70 | 1-PH | 1-PH | 1724.11 |
| | 0003 | 1.E-3 | 0.07 | 0.4 | 0.11 | 7.77 | 7.21 | SEGR | ANNU | 1178.65 |
| | 0004 | 3.E-3 | 0.12 | 1.2 | 0.18 | 7.72 | 6.81 | SEGR | ANNU | 1264.37 |
| | 0005 | 6.E-3 | 0.16 | 2.1 | 0.23 | 7.53 | 6.38 | SEGR | ANNU | 1298.64 |
| | 0006 | 8.E-3 | 0.19 | 3.3 | 0.26 | 7.30 | 5.95 | SEGR | ANNU | 1301.68 |
| | 0007 | 0.01 | 0.22 | 4.4 | 0.29 | 7.06 | 5.56 | SEGR | ANNU | 1277.41 |

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P18 Steam Injection Network

# Water Injection Well

## Problem Description

A 3390 foot deep water injection well is performing below design capacity. A multi-rate injectivity pressure transient test was conducted to evaluate the performance. The wellhead and bottomhole pressures were monitored during the test. The pressure transient analysis indicated that there is wellbore damage. The well was perforated at 8 spf. If the damage can be removed, then higher injection rates can be achieved. The decision to be made is whether to acidize the well or reperforate it to achieve this objective. All data for the well are given in Figure P19.1. The process conditions and measured data are provided in Tables P19.1 and P19.2.

You are required to:

1. Determine how well the predicted bottomhole pressures match the measured data.
2. Determine the principal cause of the well performing below expectations.
3. Analyze what remedial action is required to improve the performance of the well.

**Figure P19.1: Water Injection Well**

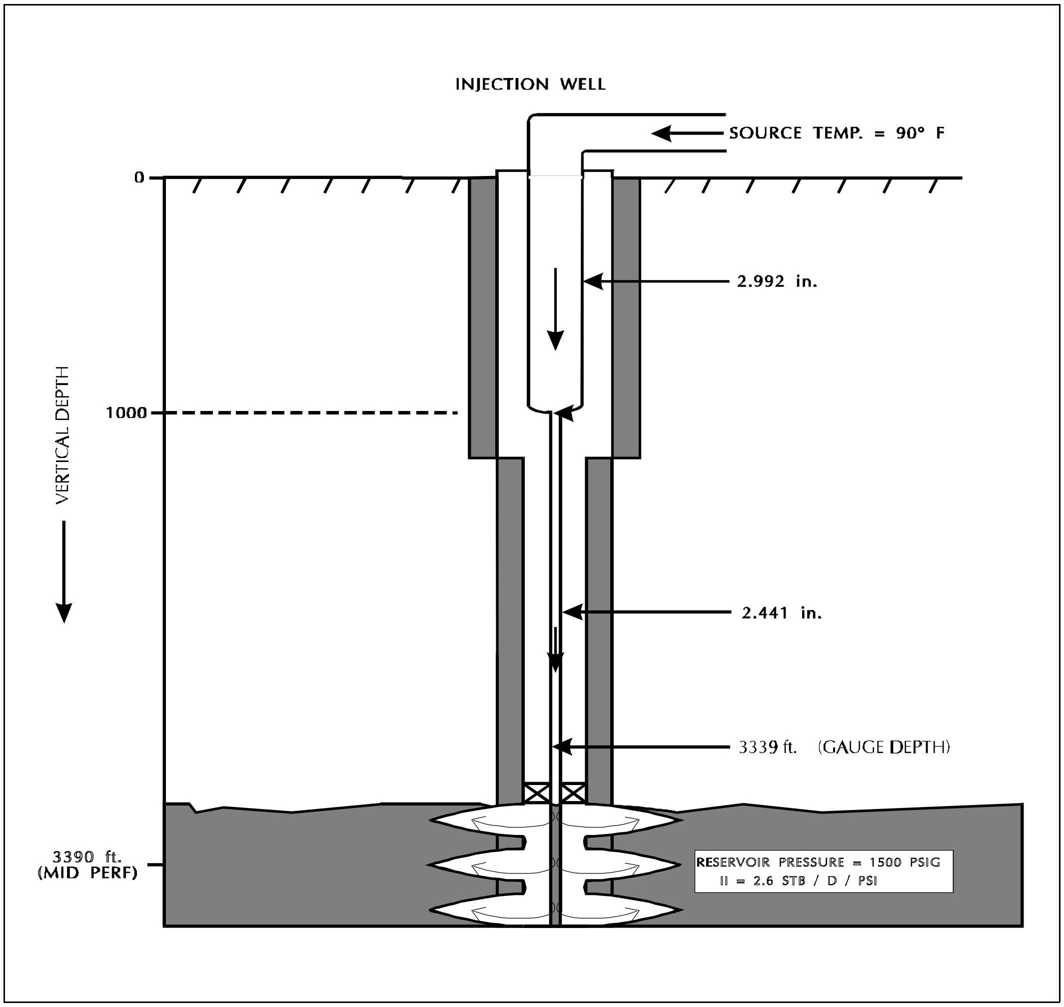


**Table P19.1: Process Information**

**Tubing Data**

| Depth | I D |
|---|---|
| 1000 ft | 2.992 in |
| 3339 ft | 2.441 in |
| 3390 ft | 2.441 in |

**Reservoir Data**

| | |
|---|---|
| Reservoir Pressure | 1500 psig |
| Injectivity Index | 2.6 bbl/day/psi |
| Temperature Gradient | 1.4°F/100 ft |
| Water Gravity | 1.02 (water = 1) |
| Source Temperature | 90°F |

**Completion Data**

| | |
|---|---|
| Reservoir Permeability | 30 MD |
| Shot Density | 8 spf |
| Perforation Diameter | 0.5 in |
| Penetration Depth | 6 in |
| Perforation Condition | Underbalanced |
| Perforated Interval | 30 ft |
| Crushed Zone Thickness | 0.5 in |

**P19 Water Injection Well**

**Table P19.2: Measured Data**

**Measured Data**

| Wellhead Pressure (WHP) | Bottomhole Pressure | Flowrate |
|---|---|---|
| 450 psig (32.0 bar) | 1950 psia | 550 bbl/d |
| 600 psig (42.4 bar) | 2100 psia | 755 bbl/d |
| 750 psig (52.7 bar) | 2255 psia | 955 bbl/d |

## PIPEPHASE Features Used In This Problem

- Sensitivity analysis allows an easy comparison of measured and calculated results. The sensitivity plot shows all the cases in one plot giving the entire picture.
- The McLeod model for open perforated completion is used to evaluate the effect of the completion. By using this model, it is possible to distinguish between formation damage and flow impairment as a result of too few holes open to flow.

## Results and Discussion

1. The measured pressures at the bottomhole fall close to the predicted values. This indicates that the sensitivity curves generated can be used for diagnosis.
2. The data match follows the general trend of the 2 spf outflow curve for the three test rates. This suggests that the system is operating at an effective shot density of approximately 2 spf. This is markedly lower than the designed shot density of 8 spf, strongly indicating that the number of shots open to flow is much lower than the design hoped for. If the skin damage was mainly due to wellbore damage the measured bottomhole pressure would have been linear with the flowrate. This would have caused the measured pressures to cut across the outflow curves instead of following the general trend of one of the outflow curves.
3. The data indicates that the dominant impairment to flow is the low effective shot density. Reperforating the well will be the correct remedial action to be taken in such a case.



## Simulation Highlights

INPUT

- The liquid model was used with water specific gravity specified. This enables the program to simulate the pressure drops using water fluid properties.
- The bottomhole completion was modeled using the McLeod model for open-hole completions.

TECHNIQUE

- Sensitivity analysis is used to evaluate the effect of wellhead pressure and shot density. The measured wellhead pressures were supplied as inflow parameters. Shot densities ranging from 2-12 were supplied as the outflow parameters. The solution node was placed at the point were the pressure gauge was located to monitor the bottomhole pressures. This enables the predicted node pressure to be directly compared with the measured pressure data.

## Input Data

The keyword input file for this problem is shown below.

### Keyword Input Data File

```
TITLE   PROB=WELL9, PROJ=WELLAPP, USER=SIMSCI
DESC    WATER INJECTION WELL
CALC    SINGLE, LIQUID
DEFAULT TGRAD=1.4
PRINT   INPUT=FULL, DEVICE=PART
SEGMENT DLVERT=1000
$
PVT DATA
        SET     SETNO=1, GRAV(WATER, SPGR)=1.02
$
STRUCTURE DATA
        SOURCE  NAME=SOUR, TEMP=90, PRESS=450, RATE(ESTI)=1000
$
        LINK    NAME=L001, FROM=SOUR, TO=SNK
                TUBING  LENGTH=1000, ID=2.992
                TUBING  LENGTH=3339, ID=2.441
                TUBING  NAME=TUB3,  LENGTH=3390, ID=2.441
                COMPLET MCLEOD LENGTH=30, PERFD=.5, PENE=6, SHOTS=12, *
                        PERM(RES,MD)=30, UNDER, NAME=CMPL
$
        SINK    NAME=SNK, PRES=1500, RATE(ESTI)=1000, INJECTI, II=2.6
$
SENSITIVITY DATA
        NODE    NAME=TUB3
        FLOW    RATE(BPD)=400, 600, 800, 1000, 1200, *
                1400, 1600, 1800, 2000
        DESC    INFLOW=WHP 450, WHP 600, WHP 750
        INFLOW  NAME=SOUR, PRES=450, 600, 750
        DESC    OUTFLOW=2 SHOTS, 4 SHOTS, 6 SHOTS, 8 SHOTS, 12 SHOTS
        OUTFLOW NAME=CMPL, SHOTS=2,4,6,8,12
END
```

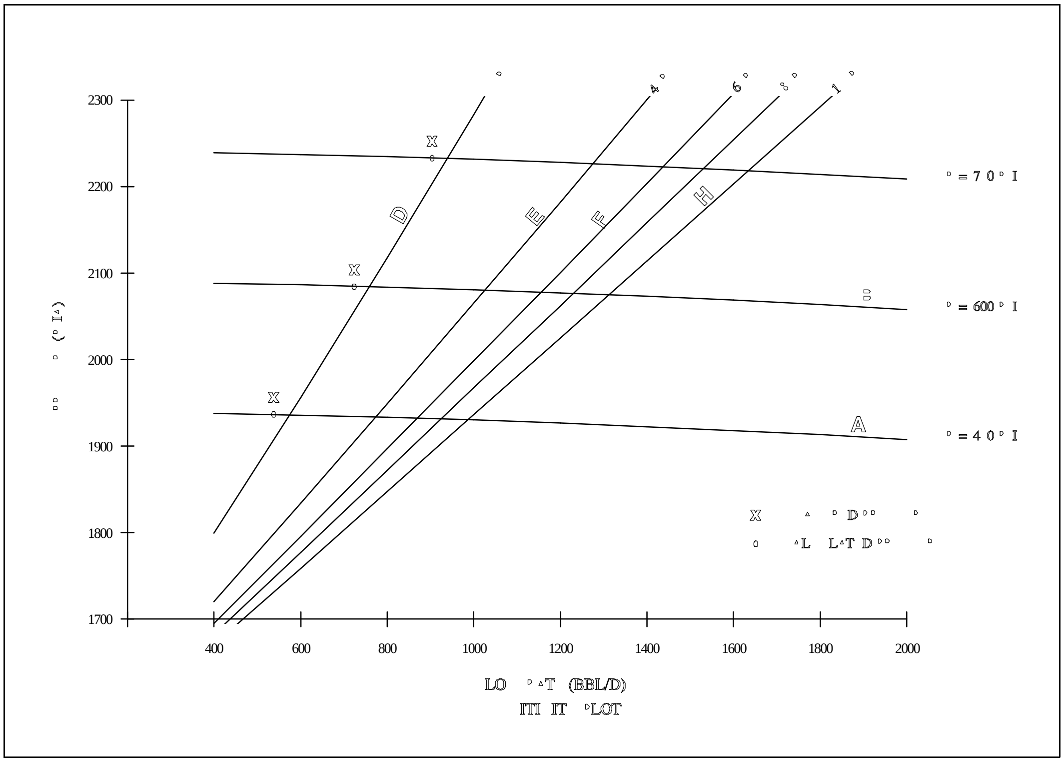
## Output

- The sensitivity plot shows the effect of wellhead pressure and shot density on the downhole gauge pressure (solution node). Measured data are added to the plot for comparison.
- The completion pressure drops predicted for various completion shot densities are plotted. This plot is useful for investigating the sensitivity of pressure drop to shot density.

## Partial Output

The PIPEPHASE output gives the sensitivity results in graphical and tabular format. Figure P19.2 below was generated by importing the tabular results into a plotting package and adding measured data.

**Figure P19.2: Pressure vs. Flowrate Sensitivity Plot**



## Partial Output (continued)

The tables below and on the following page show the data used to generate the plot shown in Figure P19.2.

SOLUTION NODE IS AT INLET OF DEVICE TUB3

NODE PRESSURES FOR INFLOW VARIABLES (PSIA )

| RATE (BBL/D) | INFLOW VARIABLE WHP 450 | WHP 600 | WHP 750 |
|---|---|---|---|
| 400.00 | 1937.85 | 2088.52 | 2239.19 |
| 600.00 | 1935.75 | 2086.42 | 2237.09 |
| 800.00 | 1933.24 | 2083.91 | 2234.58 |
| 1000.00 | 1930.25 | 2080.92 | 2231.59 |
| 1200.00 | 1926.75 | 2077.42 | 2228.09 |
| 1400.00 | 1922.72 | 2073.40 | 2224.07 |
| 1600.00 | 1918.17 | 2068.84 | 2219.51 |
| 1800.00 | 1913.08 | 2063.76 | 2214.44 |
| 2000.00 | 1907.47 | 2058.15 | 2208.83 |

NODE PRESSURES FOR OUTFLOW VARIABLES (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 2 SHOTS | 4 SHOTS | 6 SHOTS | 8 SHOTS | 12 SHOTS |
|---|---|---|---|---|---|
| 400.00 | 1799.57 | 1720.37 | 1695.04 | 1682.59 | 1670.26 |
| 600.00 | 1956.33 | 1834.19 | 1795.91 | 1777.22 | 1758.83 |
| 800.00 | 2117.49 | 1949.02 | 1897.17 | 1872.05 | 1847.47 |
| 1000.00 | 2283.28 | 2064.96 | 1998.91 | 1967.14 | 1936.22 |
| 1200.00 | 2453.78 | 2182.06 | 2101.15 | 2062.52 | 2025.10 |
| 1400.00 | 2629.02 | 2300.33 | 2203.92 | 2158.19 | 2114.10 |
| 1600.00 | 2809.00 | 2419.79 | 2307.21 | 2254.15 | 2203.24 |
| 1800.00 | 2993.73 | 2540.44 | 2411.03 | 2350.41 | 2292.52 |
| 2000.00 | 3183.20 | 2662.28 | 2515.39 | 2446.98 | 2381.93 |

INFLOW-OUTFLOW CURVE INTERSECTION POINTS

| INFLOW CASE | OUTFLOW CASE | RATE (BBL/D) | PRESSURE (PSIA) |
|---|---|---|---|
| WHP 450 | 2 SHOTS | 574.10 | 1936.02 |
| | 4 SHOTS | 773.11 | 1933.58 |
| | 6 SHOTS | 868.89 | 1932.21 |
| | 8 SHOTS | 924.77 | 1931.38 |
| | 12 SHOTS | 986.98 | 1930.45 |
| WHP 600 | 2 SHOTS | 758.97 | 2084.43 |
| | 4 SHOTS | 1026.47 | 2080.46 |
| | 6 SHOTS | 1155.11 | 2078.20 |
| | 8 SHOTS | 1229.89 | 2076.82 |
| | 12 SHOTS | 1312.48 | 2075.16 |
| WHP 750 | 2 SHOTS | 938.75 | 2232.50 |
| | 4 SHOTS | 1275.28 | 2226.57 |
| | 6 SHOTS | 1437.36 | 2223.22 |
| | 8 SHOTS | 1531.08 | 2221.08 |
| | 12 SHOTS | 1634.49 | 2218.64 |

## Partial Output (continued)

COMPLETION ZONE PRESSURE DROPS (PSIA )

| RATE (BBL/D) | OUTFLOW VARIABLE 2 SHOTS | 4 SHOTS | 6 SHOTS | 8 SHOTS | 12 SHOTS |
|---|---|---|---|---|---|
| 400.00 | 153.57 | 74.36 | 49.03 | 36.57 | 24.25 |
| 600.00 | 233.37 | 111.23 | 72.94 | 54.25 | 35.86 |
| 800.00 | 317.57 | 149.09 | 97.23 | 72.12 | 47.54 |
| 1000.00 | 406.39 | 188.06 | 122.00 | 90.24 | 59.31 |
| 1200.00 | 499.92 | 228.17 | 147.27 | 108.63 | 71.21 |
| 1400.00 | 598.17 | 269.46 | 173.04 | 127.30 | 83.22 |
| 1600.00 | 701.16 | 311.92 | 199.33 | 146.27 | 95.35 |
| 1800.00 | 808.88 | 355.56 | 226.14 | 165.52 | 107.61 |
| 2000.00 | 921.33 | 400.37 | 253.47 | 185.06 | 120.00 |

# Gas-lift Study

## Problem Description

A 3765 feet deviated blackoil well is completed but had trouble producing oil with 300 psig wellhead pressure. The results of a well test indicated that the productivity index (PI), gas-oil ratio (GOR) and reservoir pressure are 62 stb/day/psi, 250 scf/stb, and 1,200 psig respectively. In order to explore the possibility of producing the well at the rate of 5,000 bpd, the gas-lift method is considered. A schematic of the well is shown in Figure 20.1, while the process information is given in Table P20.1.

You are required to:

1. Determine the gas injection depth required for 5,000 bpd production and a wellhead pressure of about 300 psig, assuming that the optimum total gas-oil ratio is 1,000 scf/stb and the maximum injection gas pressure at the wellhead is 800 psig,
2. Determine if the 800 psig casing head pressure is sufficient for the lift gas knowing there is a 50 psi pressure drop across the gas-lift valve.

**Figure P20.1: Gas-Lift Study**

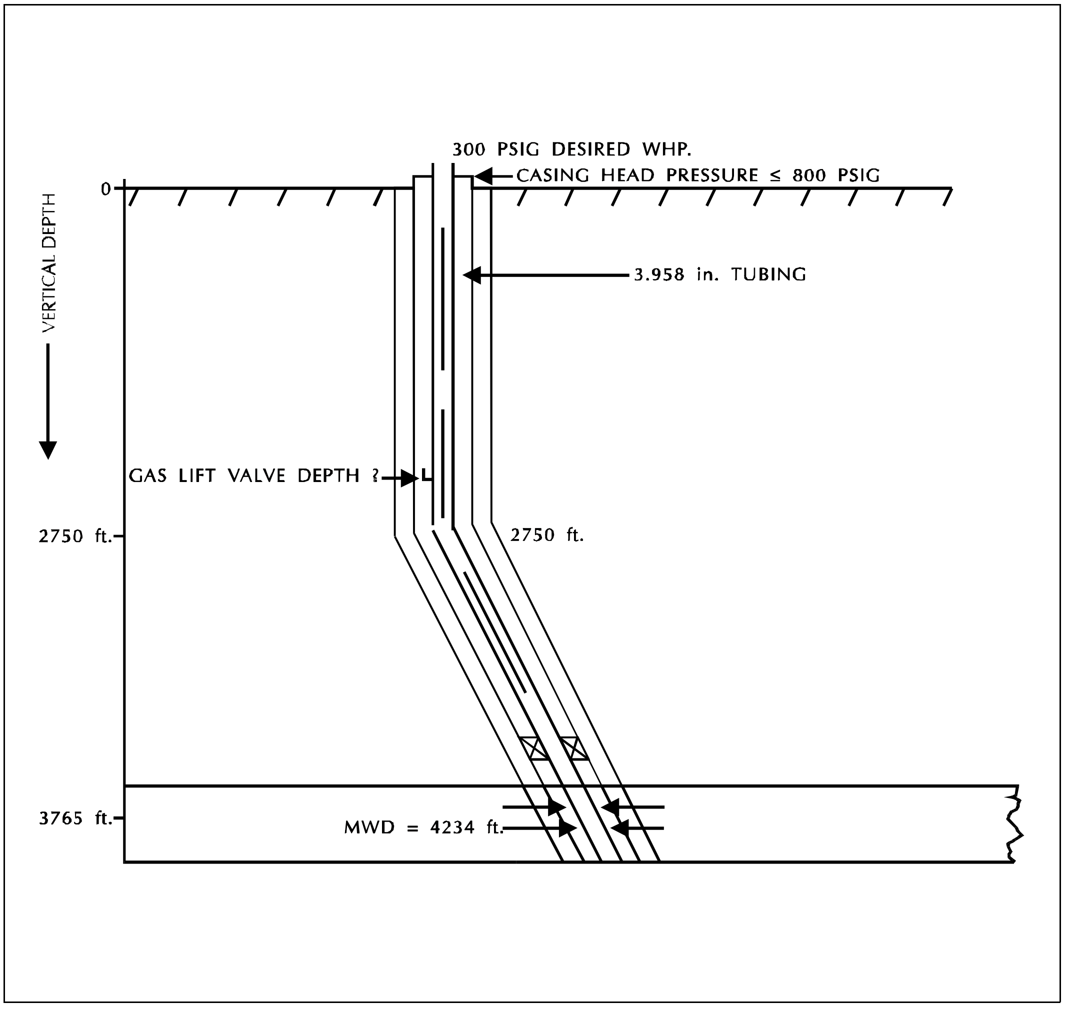


**Table P20.1: Process Information**

**Fluid Data**

| | |
|---|---|
| Oil Gravity | 26°API |
| Gas gravity | 0.66 (air = 1) |
| Water gravity | 1.04 (water = 1) |
| Lift Gas Gravity | 0.62 |

**Contaminants**

| | |
|---|---|
| N2 | 0.48% |
| C02 | 4.22% |
| H2S | 0.01% |

**PVT Data**

| Pres (psig) | Solution Gas-Oil Ratio | Formation Volume Factor |
|---|---|---|
| 1636 (BPP) | 451 (scf/stb) | 1.345 |
| 900 | 267 (scf/stb) | 1.265 |
| 127 | 65 (scf/stb) | 1.141 |
| Viscosity (at BPP and Resevoir Temp. 225°F) | | 0.656 CP |
| Compressibility | | 11.6E-6 $psi^{-1}$ |

**Well Reservoir Data**

| | |
|---|---|
| Reservoir Pressure | 1200 psi |
| Reservoir Temperature | 150°F |
| PI | 62 stb/day/psi |
| Rate | 5,000 stbo/day |
| Reservoir GOR | 250 scf/stb |
| Water Cut | 5% |
| Injection Gas Temperature | 95°F |
| Gas Injection Rate | 2.25 MMscf/day |

**Casing and Tubing Data**

| MWD (ft) | Vertical Depth (ft) | Tubing ID (in) | Tubing OD (in) | Casing ID (in) |
|---|---|---|---|---|
| 4234 | 3765 | 3.548 | 4.0 | 6.049 |
| 2750 | 2750 | 3.958 | 4.5 | 7.125 |

**Heat Transfer Data**

| | |
|---|---|
| U (Tubing) | 2.5 Btu/hr-$ft^2$-F |
| Temp. Gradient | 1.4°F/100 ft |

## PIPEPHASE Features Used In This Problem

- Gas-lift Analysis is used to determine the location of the gas-lift value for the required wellhead pressure.
- Rigorous heat transfer is used to accurately model the overall heat balance.
- The Hagedorn and Brown correlation is used for pressure drop and holdup.
- The Adjusted Standing correlation is used to incorporate measured data.
- The Moody pressure drop equation is used for the gas injection in the annulus.

## Results and Discussion

1. For the required production rate of 5,000 bpd, wellhead pressure of 300 psig and total GOR of 1,000 scf/stb, the required injection depth is 2,400 feet.
2. The calculated tubing pressure at injection depth of about 2,400 feet is 623.7 psig, and casing pressure is 850 psig, this allows more than 50 psi pressure drop across the gas-lift valve.

## Simulation Highlights

INPUT

- The Standing model for PVT properties was adjusted to better fit measured data as supplied in the Figure P20.1.
- For total GOR of 700 scf/stb and natural GOR of 250 scf/stb, an injection gas rate of 2.25 MMscfd is input into the program.
- Several gas-lift valve locations are input as trial injection depths by the user.

TECHNIQUE

- Two vertical flow devices are used to demonstrate the input for both inclined casing-tubing annulus and tapered tubing strings.
- The gas-lift flowrate, temperature and pressure are given. The wellhead pressure is determined for each possible injection depth supplied to the simulation.

## Input Data

The keyword input file for this simulation example is given below.

### Keyword Input Data File

```
TITLE   PROB=WELL10, PROJ=WELLAPP, USER=SIMSCI
DESC    GASLIFT STUDY FOR BLACKOIL WELL
CALC    GASLIFT
DEFAULT TGRAD=1.4, UTUBE=2.5
FCODE   TUBI=HB, ANNU=MOODY
SEGMENT DLVERT=400
PRINT   DEVICE=FULL, PROP=FULL
$
PVT DATA
        SET     SETNO=1, GRAV(OIL)=26, GRAV(GAS)=0.66, *
        GRAV(WATER, SPGR)=1.04, CONT=0.48, 4.22, 0.01
        ADJUST  TRES=225, VISC=0.656, COMPRESS=0.0000116, *
        PRES=1635,900,127, SGOR=451,267,65, FVF=1.345,1.265,1.141
        LIFTGAS GRAV(GAS)=0.62
        DEFAULT VISC(OIL)=STANDING, SGOR=STANDING, FVF=STANDING
$
STRUCTURE DATA
        SOURCE  NAME=SR1, TEMP=150, PRESS=1200, RATE=5000, *
                PI=62, GOR=250, WCUT=5
$
        LINK    NAME=PROD, FROM=SR1, TO=SNK
                TUBING  LENGTH=4234, DEPTH=3765, ID=3.548
                TUBING  LENGTH=2750, DEPTH=2750, ID=3.958
        LINK    NAME=GASL
                ANNULUS LENGTH=4234, DEPTH=3765, IDANN=6.049, ODTUB=4.0
                ANNULUS LENGTH=2750, DEPTH=2750, IDANN=7.125, ODTUB=4.5
$
        SINK    NAME=SNK, PRES=300, RATE(ESTI)=5000
$
GASLIFT
        LOCATIO PRES=800, TEMP=95, RATE=2.25, *
                DEPTH=3000/2500/2000/1500/1000
END
```

## Output

- A table and plot showing pressure versus lift gas injection depth are generated by PIPEPHASE for the production wellhead. The results show that the injection depth of 2,500 feet gives the closest match to the production wellhead pressure of 300 psig.
- The injection string pressure and production string pressure are calculated independent of each other. The user should verify that the injection pressure is sufficiently higher than the production pressure at the gas-lift valve. In this case, the production pressure is 659.1 psig and injection pressure is 849.4 psig.
- The node and device detail reports give the results for the case where the lift gas is injected at 2500 ft.
- The pressure detail report clearly shows the change in two-phase from a density 49.9 lb/ft$^3$ to 20.1 lb/ft$^3$ due to the lift gas injection.

P20 Gas-lift Study

## Partial Output

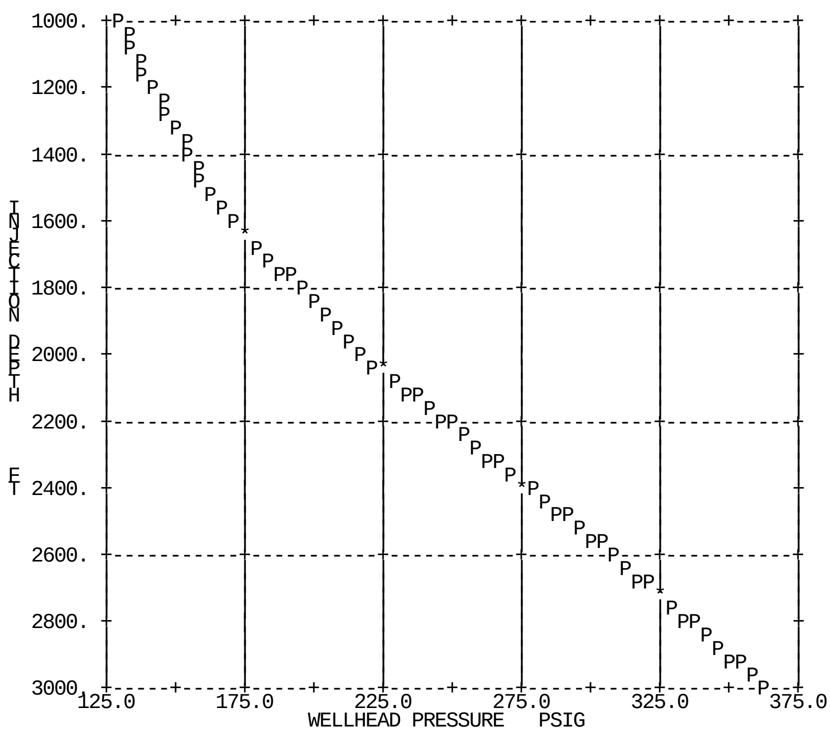
A table and plot of injection depths versus calculated wellhead pressure are printed out as shown below.

```
           GASLIFT SUMMARY RESULTS -- OPTION 3
OIL  PROD:       RATE=  5000.0(BPD)
WATER PROD:      RATE=   263.2(BPD)
GAS  PROD:       RATE=  3.5000(MMCFD)
GAS  INJECTION  RATE=  2.2500(MMCFD)
CASING HEAD PRES    =   800.0(PSIG)
```

WELLHEAD PRESSURE VERSUS INJECTION DEPTH

| CASE NO. | INJEC: DEPTH (FT) | WELLHEAD PRES: (PSIG) | VALVE TUBING PRES: (PSIG) | VALVE TUBING TEMP: (F) | VALVE CASING PRES: (PSIG) | VALVE CASING TEMP: (F) | VALVE PRES: DROP (PSIG) |
|---|---|---|---|---|---|---|---|
| 1 | 3000.0 | 361.3 | 839.2 | 149.6 | 859.3 | 102.3 | 20.1 |
| **2** | **2500.0** | **294.6** | **659.1** | **149.1** | **849.4** | **98.4** | **190.2** |
| 3 | 2000.0 | 218.1 | 492.3 | 148.3 | 839.3 | 95.5 | 347.0 |
| 4 | 1500.0 | 162.0 | 356.1 | 147.4 | 829.3 | 93.5 | 473.2 |
| 5 | 1000.0 | 127.3 | 250.8 | 146.2 | 819.4 | 92.6 | 568.6 |

GAS-LIFT OPTION 3  PLOT SUMMARY INJECTION DEPTH VS WHP



## Partial Output (continued)

The link, node, and device summaries for the tubing wellhead pressure that matches the desired wellhead pressure (case 2 -- 294.6 psig) closest is included below.

LINK SUMMARY

RATE, PRESSURE AND TEMPERATURE SUMMARY

| LINK | FROM(F) AND TO(T) NODE | ACTUAL FLOW RATES*** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | PRESS: (PSIG) | PRESS: DROP (PSIG) | TEMP: (F) | HOLDUP** GAS (MM SCF) | LIQ (STB) |
|---|---|---|---|---|---|---|---|---|---|
| GASL | CSHD(F) | 0.0385 | 0.0 | 0.0 | 800.0* | | 95.0 | | |
| | INJB(T) | 0.0362 | 0.0 | 0.0 | 874.4 | -74.4 | 109.6 | 0.0382 | 0.0 |
| PROD | BOTM(F) | 0.0008 | 5982.0 | 267.0 | 1200.0* | | 150.0 | | |
| | WLHD(T) | 0.0281 | 5595.1 | 267.2 | **294.6** | 905.4 | 143.6 | 0.0042 | 30.9 |

* - INDICATES KNOWN PRESSURE
** REPORTED VOLUME AT 14.7 PSIA AND 60 F
*** RATE REPORTED AT ACTUAL TEMPERATURE AND PRESSURE CONDITIONS

NODE SUMMARY

| NODE | PRES. (PSIG) | STANDARD FLOW RATES** GAS (MMCFD) | OIL (BPD) | WATER (BPD) | TEMP. (F) |
|---|---|---|---|---|---|
| INJB | 874.4 | 2.2500 | 0.0 | 0.0 | 109.6 |
| CSHD | 800.0* | 2.2500* | 0.0 | 0.0 | 95.0 |
| BOTM | 1200.0* | 1.2500 | 5000.0* | 263.2 | 150.0 |
| WLHD | **294.6** | 1.2500 | 5000.0 | 263.2 | 143.6 |

* INDICATES KNOWN PRESSURE OR FLOW
** STANDARD FLOW RATES REPORTED AT 14.7 PSIA AND 60 F

DEVICE SUMMARY

| LINK NAME | DEVI NAME | DEVI TYPE | CORR | INSIDE DIAM (IN) | MEAS LENGTH (FT) | ELEV CHNG (FT) | OUTLET PRESS: (PSIG) | OUTLET TEMP: (F) | INSITU GLR (CFBBL) | AVG. LIQ HOLDUP |
|---|---|---|---|---|---|---|---|---|---|---|
| GASL | ***SOURCE*** RATE= 2.2500 (MMCFD) | | | | | | 800.0 | 95.0 | | |
| | CSHD | | | | | | 800.0 | 95.0 | | |
| | A004 | ANLS | FF | 2.625 | 2750.0 | 2750.0 | 854.4 | 100.1 | | |
| | A003 | ANLS | FF | 2.049 | 1484.0 | 1015.0 | 874.4 | 109.6 | | |
| | *** SINK *** PRES= 874.4 (PSIG) TEMP= 109.6 (F) | | | | | | | | | |
| PROD | **RESERVOIR** RATE= 5000.0 (BPD) PI = 62.000 (BPDPSI) | | | | | | 1200.0 | 150.0 | GLR= 238. | |
| | BOTM | IPR | PI | | | | 1115.1 | 150.0 | | |
| | T001 | TBNG | HB | 3.548 | 1484.0 | 1015.0 | 747.8 | 149.3 | 0. | 1.00 |
| | T002 | TBNG | HB | 3.958 | 2750.0 | 2750.0 | **294.6** | 143.6 | 25. | 0.34 |
| | *** SINK *** PRES= **294.6** (PSIG) TEMP= 143.6 (F) | | | | | | | | | |

## Partial Output (continued)

The link device detail reports are given below and on the following 2 pages.

```
                  LINK "PROD" DEVICE DETAIL REPORT

 PRESSURE AND TEMPERATURE REPORT
 -------------------------------
 DEVICE              MWD OR       TVD
 NAME                LENGTH   I   OR
 AND    SEGM INSIDE   FROM    &   ELEV     CALC    CALC    OVERALL AMB
 TYPE   NO   DIAM.   INLET    O   CHNG     PRESS   TEMP    U-FACT  TEMP
             (IN)     (FT)        (FT)     (PSIG)  (F)     (BTUFT- (F)
                                                           F)
 ------ ---- ------ --------- - -------- ------- ------ ------- ------
  T001  0000  3.548    4234.0 I   3765.0  1115.1  150.0           150.0
 (TBNG) 0001           3649.2     3365.0   970.8  149.9   2.500  144.4
        0002           3064.3     2965.0   826.6  149.6   2.500  138.8
        0003           2750.0 O   2750.0   747.8  149.3   2.500  135.8
  T002  0000  3.958    2750.0 I   2750.0   747.8  149.3           135.8
 (TBNG) 0001           2625.0     2625.0   703.5  149.2   2.500  134.0
        0002           2500.0 O   2500.0   659.1  149.1   2.500  132.3
        0000           2500.0 I   2500.0 GAS INJECTED          2.2500 MM FT3/D
 (GVAL)                                  GLR FT3/BBL  IN    238.  OUT   665.
                       2500.0 I   2500.0   659.1  149.1
  T002  0000  3.958    2500.0     2500.0   659.1  149.1           132.3
 (TBNG) 0001           2100.0     2100.0   596.5  148.5   2.500  126.7
        0002           1700.0     1700.0   535.8  147.9   2.500  121.1
        0003           1300.0     1300.0   476.6  147.1   2.500  115.5
        0004            900.0      900.0   418.9  146.1   2.500  109.9
        0005            500.0      500.0   362.7  145.1   2.500  104.3
        0006            100.0      100.0   308.0  143.9   2.500   98.7
        0007              0.0 O      0.0   294.6  143.6   2.500   97.3

 HOLDUP AND VELOCITY DETAIL REPORT
 ---------------------------------
 DEVICE
 NAME      ---LIQUID HOLDUP---          ACTUAL                   T-D
 AND    SEG. NO                  LIQ      GAS      MIX .  FLOW FLOW   SONIC
 TYPE   NO.  SLIP  SLIP   TOTAL  VEL      VEL      VEL    REGM REGM   VEL
                         (ABBL)  (FPS)    (FPS)    (FPS)               (FPS)
 ------ ---- ----- ----- -------- ------- ------- ------- ---- ---- -------
  T001  0000
 (TBNG) 0001  1.00  1.00      7.2    5.95    0.00    5.95 ---- 1-PH    0.00
        0002  1.00  1.00     14.3    5.96    0.00    5.96 ---- 1-PH    0.00
        0003  1.00  1.00     18.1    5.84    0.00    5.84 ---- 1-PH    0.00
  T002  0000
 (TBNG) 0001  1.00  1.00     20.0    4.70    0.00    4.70 ---- 1-PH    0.00
        0002  1.00  1.00     22.0    4.70    0.00    4.70 ---- 1-PH    0.00
 (GVAL) 0000
        0001
  T002  0000
 (TBNG) 0001  0.38  0.38     24.3   12.39   12.39   12.39 ---- ANNU  662.71
        0002  0.34  0.36     26.5   12.85   13.94   13.55 ---- ANNU  645.03
        0003  0.31  0.35     28.6   13.19   15.89   14.95 ---- ANNU  621.74
```

## Partial Output (continued)

The link detail report clearly shows the change in two-phase density from 49.9 lb/ft$^3$ to 20.1 lb/ft$^3$ due to the lift gas injection.

LINK "PROD" PROPERTY DETAIL REPORT

VISCOSITY AND DENSITY RESULTS

| DEVICE NAME AND TYPE | SEGM NO | VISCOSITY OIL (CP) | VISCOSITY LIQ (CP) | VISCOSITY VAP (CP) | DENSITY LIQ (LB/CF) | DENSITY VAP (LB/CF) | DENSITY SLIP (LB/CF) | DENSITY NO-SLIP (LB/CF) |
|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | | | | | | | |
| (TBNG) | 0001 | 2.343 | 2.262 | 0.014 | 49.041 | 3.465 | 49.041 | 49.041 |
| | 0002 | 2.326 | 2.245 | 0.014 | 48.976 | 2.952 | 48.976 | 48.976 |
| | 0003 | 2.321 | 2.240 | 0.013 | 49.953 | 2.563 | 49.953 | 49.953 |
| T002 | 0000 | | | | | | | |
| (TBNG) | 0001 | 2.317 | 2.236 | 0.013 | 49.932 | 2.351 | 49.932 | 49.932 |
| | 0002 | 2.314 | 2.233 | 0.013 | 49.917 | 2.200 | **49.917** | 49.917 |
| | 0000 | | | | | | | |
| (GVAL) | 0001 | | | | | | | |
| T002 | 0000 | | | | | | | |
| (TBNG) | 0001 | 2.332 | 2.250 | 0.013 | 49.950 | 1.929 | **20.117** | 20.117 |
| | 0002 | 2.471 | 2.382 | 0.013 | 50.269 | 1.736 | 19.303 | 18.401 |
| | 0003 | 2.625 | 2.529 | 0.013 | 50.588 | 1.550 | 18.688 | 16.673 |
| | 0004 | 2.799 | 2.694 | 0.013 | 50.907 | 1.371 | 18.047 | 14.933 |
| | 0005 | 2.995 | 2.880 | 0.013 | 51.227 | 1.198 | 17.400 | 13.188 |
| | 0006 | 3.217 | 3.092 | 0.013 | 51.548 | 1.030 | 16.685 | 11.448 |
| | 0007 | 3.371 | 3.238 | 0.013 | 51.749 | 0.929 | 16.192 | 10.364 |

FRICTION AND SURFACE TENSION RESULTS

| DEVICE NAME AND TYPE | SEGM NUM. | FRICTION DENSITY (LB/CF) | FRICTION VELO (FPS) | FRICTION ID. (IN) | FRICTION VISCOSITY (CP) | FRIC. FACTOR | REYNOLDS NUMBER | LIQ SURFACE TENSION (DN/CM) |
|---|---|---|---|---|---|---|---|---|
| T001 | 0000 | | | | | | | |
| (TBNG) | 0001 | 49.041 | 5.95 | 3.548 | 2.262 | 0.0221 | 5.6774E4 | 14.90 |
| | 0002 | 48.976 | 5.96 | 3.548 | 2.245 | 0.0221 | 5.7193E4 | 16.37 |
| | 0003 | 49.953 | 5.84 | 3.548 | 2.240 | 0.0221 | 5.7334E4 | 17.64 |
| T002 | 0000 | | | | | | | |
| (TBNG) | 0001 | 49.932 | 4.70 | 3.958 | 2.236 | 0.0223 | 5.1488E4 | 18.36 |
| | 0002 | 49.917 | 4.70 | 3.958 | 2.233 | 0.0223 | 5.1555E4 | 18.91 |
| | 0000 | | | | | | | |
| (GVAL) | 0001 | | | | | | | |
| T002 | 0000 | | | | | | | |
| (TBNG) | 0001 | 20.117 | 12.39 | 3.958 | 0.093 | 0.0168 | 1.3226E6 | 19.59 |
| | 0002 | 17.542 | 13.55 | 3.958 | 0.086 | 0.0167 | 1.4190E6 | 20.43 |
| | 0003 | 14.875 | 14.95 | 3.958 | 0.082 | 0.0167 | 1.4897E6 | 21.29 |
| | 0004 | 12.357 | 16.69 | 3.958 | 0.078 | 0.0167 | 1.5675E6 | 22.19 |
| | 0005 | 9.995 | 18.90 | 3.958 | 0.074 | 0.0167 | 1.6498E6 | 23.13 |
| | 0006 | 7.855 | 21.77 | 3.958 | 0.070 | 0.0167 | 1.7486E6 | 24.07 |

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P20 Gas-lift Study