TOUGH
Training Courses

Problem EOS3/4: Heat Pipe

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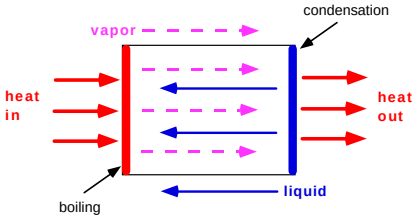
TOUGH2/EOS3: water, air

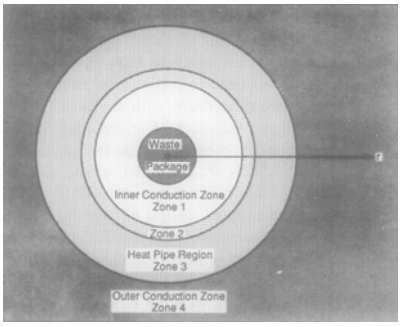
Components	# 1: water # 2: air
Parameter choices	
(NK, NEQ, NPH, NB) =	(2, 3, 2, 6) water and air, nonisothermal (default) (2, 2, 2, 6) water and air, isothermal molecular diffusion can be modeled by setting NB = 8
Primary Variables*	
single-phase conditions	
(P, X, T) - (pressure, air mass fraction, temperature)	
two-phase conditions	
(P_g, S_g + 10, T) - (gas phase pressure, gas saturation plus 10, temperature)	

* By setting MOP(19) = 1, initialization can be made with TOUGH-style variables (P, T, X) for single-phase, (P_g, S_g, T) for two-phase.

2

Heat Pipe in Radial Geometry





- partially-saturated medium (water-air)
- liquid water vaporizes near the heat source
- the vapor is driven away by pressure gradients
- vapor condenses in cooler regions
- capillary pressure gradients draw liquid back towards the heat source
- get counterflow: vapor flows away from the heat source, liquid flows towards it

3

Input File for Heat Pipe Problem (EOS3)

```
*rhp* 1-D RADIAL HEAT PIPE
MESHMAKER1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
RZ2D
RADII
    1
        0.
EQUID
    1             .3
LOGAR
   99           1.E2
LOGAR
   20           1.E4
EQUID
    1            0.0
LAYER----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
    1
       4.5

ROCKS----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
POMED    1     2550.       .10   20.E-15   20.E-15   20.E-15       2.0     800.0
                                        .25

MULTI----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
    2    3    2    6
START----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
----*----1 MOP: 123456789*123456789*1234 ---*----5----*----6----*----7----*----8
PARAM----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
   2 250     250000030000000002 47 1 1                  1.80
          3.15576E8       -1.
     1.E3      9.E3      9.E4      4.E5
    1.E-5     1.E00                                  1.E-7
               1.E5                0.20                18.
diffusivity data are input as follows:
first row water, second row air; first column gas, second column aqueous
DIFFU----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
   2.13e-5     0.e-8
   2.13e-5     0.e-8
RPCAP----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
    7        0.45000    9.6E-4        1.
    7        0.45000    1.0E-3   8.0E-05      5.E8        1.
TIMES----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
    3
 3.15576E7  1.2559E8 3.15576E8
INCON----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8

GENER----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
A1  1HTR 1                          HEAT       3.E3

ENDCY----1----*----2----*----3----*----4----*----5----*----6----*----7----*----8
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Output for Heat Pipe Problem (EOS3)

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A1  1(   1,  2) ST = 0.100000E+04 DT = 0.100000E+04 DX1= 0.145252E+02 DX2= -.151938E-03 T =  19.065 P =   100015. S = 0.199848E+00
A1  1(   2,  3) ST = 0.100000E+05 DT = 0.900000E+04 DX1= 0.759481E+01 DX2= -.129059E-02 T =  27.246 P =   100022. S = 0.198557E+00
A1  1(   3,  4) ST = 0.100000E+06 DT = 0.900000E+05 DX1= 0.981167E+01 DX2= -.352306E-02 T =  63.142 P =   100032. S = 0.195034E+00
A1  1(   4,  7) ST = 0.500000E+06 DT = 0.400000E+06 DX1= 0.455945E+04 DX2= 0.117966E+00 T = 100.883 P =   104591. S = 0.313001E+00
A1  1(   5,  6) ST = 0.900000E+06 DT = 0.400000E+06 DX1= 0.130333E+05 DX2= 0.228700E+00 T = 104.232 P =   117625. S = 0.541701E+00
A1  1(   6,  5) ST = 0.130000E+07 DT = 0.400000E+06 DX1= 0.612673E+04 DX2= 0.670831E-01 T = 105.698 P =   123751. S = 0.608784E+00
A1  1(   7,  4) ST = 0.170000E+07 DT = 0.400000E+06 DX1= 0.427338E+04 DX2= 0.345307E-01 T = 106.686 P =   128025. S = 0.643315E+00
A1  1(   8,  7) ST = 0.250000E+07 DT = 0.800000E+06 DX1= 0.613735E+04 DX2= 0.510356E-01 T = 108.058 P =   134162. S = 0.694350E+00
A1  1(   9,  5) ST = 0.330000E+07 DT = 0.800000E+06 DX1= 0.505059E+04 DX2= 0.720326E-01 T = 109.148 P =   139213. S = 0.766383E+00
A1  1(  10,  5) ST = 0.410000E+07 DT = 0.800000E+06 DX1= 0.335887E+04 DX2= 0.523525E-01 T = 109.855 P =   142572. S = 0.818735E+00
A1  2(  11,  4) ST = 0.490000E+07 DT = 0.800000E+06 DX1= 0.297196E+04 DX2= 0.479447E-01 T = 103.471 P =   114544. S = 0.498481E+00
A1  1(  12,  7) ST = 0.650000E+07 DT = 0.160000E+07 DX1= 0.424798E+04 DX2= 0.511855E-01 T = 111.268 P =   149479. S = 0.906494E+00
A1  1(  13,  6) ST = 0.810000E+07 DT = 0.160000E+07 DX1= 0.359356E+04 DX2= 0.430199E-01 T = 111.982 P =   153072. S = 0.949514E+00
A1  1(  14,  6) ST = 0.970000E+07 DT = 0.160000E+07 DX1= 0.262995E+04 DX2= 0.232522E-01 T = 112.496 P =   155702. S = 0.972766E+00
A1  1(  15,  6) ST = 0.113000E+08 DT = 0.160000E+07 DX1= 0.216556E+04 DX2= 0.120374E-01 T = 112.913 P =   157868. S = 0.984804E+00
A1  1(  16,  8) ST = 0.129000E+08 DT = 0.160000E+07 DX1= 0.222624E+04 DX2= 0.809200E-02 T = 113.338 P =   160094. S = 0.992896E+00
A1  1(  17,  8) ST = 0.145000E+08 DT = 0.160000E+07 DX1= 0.181362E+04 DX2= 0.378796E-02 T = 113.680 P =   161908. S = 0.996684E+00
$$$$$$$$$$$$$ GAS PHASE DISAPPEARS AT ELEMENT *A1  1*  $$$$$      SG = -.821520E+00
$$$$$$$$$$$$$$$$ GAS PHASE EVOLVES AT ELEMENT *A1  1*  $$$$$    XAIR = 0.000000E+00    PX = -.377453E+05   PG = 0.170292E+06
+++++++++ REDUCE TIME STEP AT (  18,  9) ++++++++++++++++   NEW DELT = 0.400000E+06
A1  1(  18,  5) ST = 0.149000E+08 DT = 0.400000E+06 DX1= 0.420592E+03 DX2= 0.539979E-03 T = 113.759 P =   162328. S = 0.997224E+00
A1  1(  19,  5) ST = 0.153000E+08 DT = 0.400000E+06 DX1= 0.398804E+03 DX2= 0.413402E-03 T = 113.834 P =   162727. S = 0.997637E+00
A1  1(  20,  5) ST = 0.157000E+08 DT = 0.400000E+06 DX1= 0.382195E+03 DX2= 0.318097E-03 T = 113.905 P =   163109. S = 0.997955E+00
A1  1(  21,  5) ST = 0.161000E+08 DT = 0.400000E+06 DX1= 0.367970E+03 DX2= 0.244910E-03 T = 113.974 P =   163477. S = 0.998200E+00
A1  1(  22,  5) ST = 0.165000E+08 DT = 0.400000E+06 DX1= 0.355310E+03 DX2= 0.188344E-03 T = 114.040 P =   163833. S = 0.998388E+00
A1  1(  23,  5) ST = 0.169000E+08 DT = 0.400000E+06 DX1= 0.343837E+03 DX2= 0.144592E-03 T = 114.104 P =   164177. S = 0.998533E+00
A1  1(  24,  5) ST = 0.173000E+08 DT = 0.400000E+06 DX1= 0.333323E+03 DX2= 0.110799E-03 T = 114.166 P =   164510. S = 0.998644E+00
A1  1(  25,  5) ST = 0.177000E+08 DT = 0.400000E+06 DX1= 0.323613E+03 DX2= 0.847531E-04 T = 114.226 P =   164833. S = 0.998728E+00
A1  1(  26,  5) ST = 0.181000E+08 DT = 0.400000E+06 DX1= 0.314604E+03 DX2= 0.647274E-04 T = 114.284 P =   165148. S = 0.998793E+00
$$$$$$$$$$ LIQUID PHASE DISAPPEARS AT ELEMENT *A1  1*  $$$$$      SG = 0.105073E+01
A1  1(  27,  5) ST = 0.185000E+08 DT = 0.400000E+06 DX1= -.629120E+03 DX2= -.109988E+02 T = 116.179 P =   164519. S = 0.100000E+01
A1  1(  28,  4) ST = 0.189000E+08 DT = 0.400000E+06 DX1= -.289016E+04 DX2= 0.000000E+00 T = 122.498 P =   161629. S = 0.100000E+01
A1  5(  29,  5) ST = 0.197000E+08 DT = 0.800000E+06 DX1= 0.370136E+03 DX2= 0.960351E-02 T =  99.745 P =   100412. S = 0.188098E+00
A1  1(  30,  5) ST = 0.205000E+08 DT = 0.800000E+06 DX1= -.773602E+04 DX2= -.450431E-17 T = 151.545 P =   146384. S = 0.100000E+01
A1  1(  31,  5) ST = 0.213000E+08 DT = 0.800000E+06 DX1= -.434906E+04 DX2= -.200931E-20 T = 158.807 P =   142035. S = 0.100000E+01
A1  1(  32,  5) ST = 0.221000E+08 DT = 0.800000E+06 DX1= -.124814E+04 DX2= 0.948520E-19 T = 161.649 P =   140787. S = 0.100000E+01
A1  1(  33,  5) ST = 0.229000E+08 DT = 0.800000E+06 DX1= 0.177759E+02 DX2= -.772333E-19 T = 162.649 P =   140805. S = 0.100000E+01
A1  2(  34,  5) ST = 0.237000E+08 DT = 0.800000E+06 DX1= 0.589749E+03 DX2= 0.661802E-02 T = 109.546 P =   141094. S = 0.974051E+00
A1  2(  35,  5) ST = 0.245000E+08 DT = 0.800000E+06 DX1= 0.536789E+03 DX2= 0.523145E-02 T = 109.659 P =   141631. S = 0.979283E+00
A1  2(  36,  5) ST = 0.253000E+08 DT = 0.800000E+06 DX1= 0.502914E+03 DX2= 0.416700E-02 T = 109.764 P =   142134. S = 0.983450E+00
A1  2(  37,  5) ST = 0.261000E+08 DT = 0.800000E+06 DX1= 0.477808E+03 DX2= 0.332475E-02 T = 109.864 P =   142612. S = 0.986774E+00
A1  2(  38,  5) ST = 0.269000E+08 DT = 0.800000E+06 DX1= 0.457283E+03 DX2= 0.264764E-02 T = 109.959 P =   143069. S = 0.989422E+00
A1  2(  39,  5) ST = 0.277000E+08 DT = 0.800000E+06 DX1= 0.439585E+03 DX2= 0.210083E-02 T = 110.050 P =   143509. S = 0.991523E+00
A1  2(  40,  5) ST = 0.285000E+08 DT = 0.800000E+06 DX1= 0.424200E+03 DX2= 0.166067E-02 T = 110.138 P =   143933. S = 0.993184E+00
A1  6(  41,  5) ST = 0.293000E+08 DT = 0.800000E+06 DX1= 0.388974E+03 DX2= 0.964454E-02 T =  99.751 P =   100434. S = 0.185657E+00
A1  2(  42,  5) ST = 0.301000E+08 DT = 0.800000E+06 DX1= 0.507631E+03 DX2= 0.126025E-02 T = 110.344 P =   144932. S = 0.995912E+00
A1  2(  43,  5) ST = 0.309000E+08 DT = 0.800000E+06 DX1= 0.453495E+03 DX2= 0.944158E-03 T = 110.438 P =   145385. S = 0.996856E+00
A1  2(  44,  5) ST = 0.315576E+08 DT = 0.657600E+06 DX1= 0.348608E+03 DX2= 0.571726E-03 T = 110.509 P =   145734. S = 0.997428E+00
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Output for Heat Pipe Problem (EOS3)

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*rhp* 1-D RADIAL HEAT PIPE

        OUTPUT DATA AFTER (  44,  5)-2-TIME STEPS                                                   THE TIME IS  0.36525E+03 DAYS

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

 TOTAL TIME     KCYC   ITER  ITERC   KON        DX1M         DX2M         DX3M         MAX. RES.      NER    KER       DELTEX
 0.31558E+08     44      5    236     2       0.42630E+03  0.11943E-01  0.58034E+00   0.10776E-06      2     1       0.65760E+06

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ELEM.  INDEX      P          T          SG          SL         XAIRG       XAIRL       PER.MOD.    PCAP         DG          DL
                (PA)      (DEG-C)                                                                   (PA)      (KG/M**3)   (KG/M**3)

A1  1      1 0.14573E+06 0.16412E+03 0.10000E+01 0.00000E+00 0.00000E+00 0.00000E+00 0.10000E+01 -.50000E+09 0.72998E+00 0.00000E+00
A1  2      2 0.14573E+06 0.11051E+03 0.99743E+00 0.25724E-02 0.00000E+00 0.00000E+00 0.10000E+01 -.33327E+08 0.83980E+00 0.95030E+03
A1  3      3 0.13007E+06 0.10715E+03 0.86852E+00 0.13148E+00 0.00000E+00 0.00000E+00 0.10000E+01 -.14955E+06 0.75504E+00 0.95285E+03
A1  4      4 0.11877E+06 0.10451E+03 0.61567E+00 0.38433E+00 0.00000E+00 0.00000E+00 0.10000E+01 -.37591E+05 0.69349E+00 0.95482E+03
A1  5      5 0.10974E+06 0.10225E+03 0.41885E+00 0.58115E+00 0.26342E-10 0.29392E-15 0.10000E+01 -.19979E+05 0.64404E+00 0.95649E+03
A1  6      6 0.10204E+06 0.10020E+03 0.22936E+00 0.77064E+00 0.26455E-05 0.27427E-10 0.10000E+01 -.10944E+05 0.60170E+00 0.95798E+03
A1  7      7 0.10004E+06 0.92930E+02 0.17304E+00 0.82696E+00 0.30601E+00 0.34979E-05 0.10000E+01 -.87795E+04 0.67657E+00 0.96312E+03
A1  8      8 0.10004E+06 0.84925E+02 0.17425E+00 0.82575E+00 0.53920E+00 0.68171E-05 0.10000E+01 -.88254E+04 0.76506E+00 0.96850E+03
A1  9      9 0.10004E+06 0.77951E+02 0.17544E+00 0.82456E+00 0.67380E+00 0.90788E-05 0.10000E+01 -.88701E+04 0.83155E+00 0.97294E+03
A1 10     10 0.10004E+06 0.71794E+02 0.17660E+00 0.82340E+00 0.75884E+00 0.10671E-04 0.10000E+01 -.89141E+04 0.88332E+00 0.97665E+03
A1 11     11 0.10004E+06 0.66307E+02 0.17775E+00 0.82225E+00 0.81587E+00 0.11820E-04 0.10000E+01 -.89575E+04 0.92479E+00 0.97978E+03
A1 12     12 0.10004E+06 0.61385E+02 0.17889E+00 0.82111E+00 0.85579E+00 0.12668E-04 0.10000E+01 -.90003E+04 0.95881E+00 0.98245E+03
A1 13     13 0.10004E+06 0.56941E+02 0.18001E+00 0.81999E+00 0.88468E+00 0.13306E-04 0.10000E+01 -.90428E+04 0.98731E+00 0.98474E+03
A1 14     14 0.10004E+06 0.52916E+02 0.18112E+00 0.81888E+00 0.90610E+00 0.13793E-04 0.10000E+01 -.90849E+04 0.10116E+01 0.98671E+03
A1 15     15 0.10004E+06 0.49260E+02 0.18223E+00 0.81777E+00 0.92233E+00 0.14170E-04 0.10000E+01 -.91266E+04 0.10325E+01 0.98840E+03
A1 16     16 0.10004E+06 0.45937E+02 0.18332E+00 0.81668E+00 0.93482E+00 0.14465E-04 0.10000E+01 -.91679E+04 0.10508E+01 0.98987E+03
A1 17     17 0.10004E+06 0.42911E+02 0.18440E+00 0.81560E+00 0.94458E+00 0.14699E-04 0.10000E+01 -.92088E+04 0.10668E+01 0.99114E+03
A1 18     18 0.10004E+06 0.40155E+02 0.18547E+00 0.81453E+00 0.95230E+00 0.14886E-04 0.10000E+01 -.92493E+04 0.10811E+01 0.99223E+03
A1 19     19 0.10004E+06 0.37648E+02 0.18652E+00 0.81348E+00 0.95848E+00 0.15036E-04 0.10000E+01 -.92894E+04 0.10937E+01 0.99318E+03
A1 20     20 0.10004E+06 0.35369E+02 0.18756E+00 0.81244E+00 0.96346E+00 0.15159E-04 0.10000E+01 -.93288E+04 0.11050E+01 0.99399E+03
A1 21     21 0.10004E+06 0.33300E+02 0.18858E+00 0.81142E+00 0.96751E+00 0.15259E-04 0.10000E+01 -.93677E+04 0.11151E+01 0.99470E+03
A1 22     22 0.10004E+06 0.31427E+02 0.18958E+00 0.81042E+00 0.97083E+00 0.15341E-04 0.10000E+01 -.94057E+04 0.11242E+01 0.99531E+03
A1 23     23 0.10004E+06 0.29736E+02 0.19056E+00 0.80944E+00 0.97356E+00 0.15409E-04 0.10000E+01 -.94427E+04 0.11323E+01 0.99583E+03
A1 24     24 0.10004E+06 0.28213E+02 0.19150E+00 0.80850E+00 0.97583E+00 0.15466E-04 0.10000E+01 -.94785E+04 0.11396E+01 0.99628E+03
A1 25     25 0.10004E+06 0.26846E+02 0.19240E+00 0.80760E+00 0.97771E+00 0.15513E-04 0.10000E+01 -.95129E+04 0.11460E+01 0.99667E+03
A1 26     26 0.10004E+06 0.25625E+02 0.19326E+00 0.80674E+00 0.97928E+00 0.15552E-04 0.10000E+01 -.95456E+04 0.11518E+01 0.99700E+03
A1 27     27 0.10004E+06 0.24539E+02 0.19407E+00 0.80593E+00 0.98060E+00 0.15586E-04 0.10000E+01 -.95765E+04 0.11569E+01 0.99728E+03
A1 28     28 0.10004E+06 0.23576E+02 0.19483E+00 0.80517E+00 0.98170E+00 0.15613E-04 0.10000E+01 -.96054E+04 0.11614E+01 0.99752E+03
A1 29     29 0.10004E+06 0.22728E+02 0.19553E+00 0.80447E+00 0.98262E+00 0.15637E-04 0.10000E+01 -.96321E+04 0.11654E+01 0.99772E+03
A1 30     30 0.10004E+06 0.21984E+02 0.19617E+00 0.80383E+00 0.98340E+00 0.15656E-04 0.10000E+01 -.96565E+04 0.11688E+01 0.99789E+03
A1 31     31 0.10004E+06 0.21336E+02 0.19674E+00 0.80326E+00 0.98405E+00 0.15673E-04 0.10000E+01 -.96786E+04 0.11719E+01 0.99804E+03
A1 32     32 0.10004E+06 0.20774E+02 0.19726E+00 0.80274E+00 0.98460E+00 0.15686E-04 0.10000E+01 -.96984E+04 0.11745E+01 0.99816E+03
A1 33     33 0.10004E+06 0.20291E+02 0.19772E+00 0.80228E+00 0.98505E+00 0.15698E-04 0.10000E+01 -.97158E+04 0.11767E+01 0.99826E+03
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6

EOS4: Vapor Pressure Lowering

- Vapor pressure of tightly bound water is reduced

$$P_v(T,S_l) = f_{VPL}(T,S_l)\cdot P_{sat}(T)$$

$$f_{VPL}=\exp\left[\frac{M_w P_c(S_l)}{\rho_l R(T+273.15)}\right]$$

- Vapor pressure lower as capillarity increases
- Prevents full evaporation of water even under above-boiling conditions

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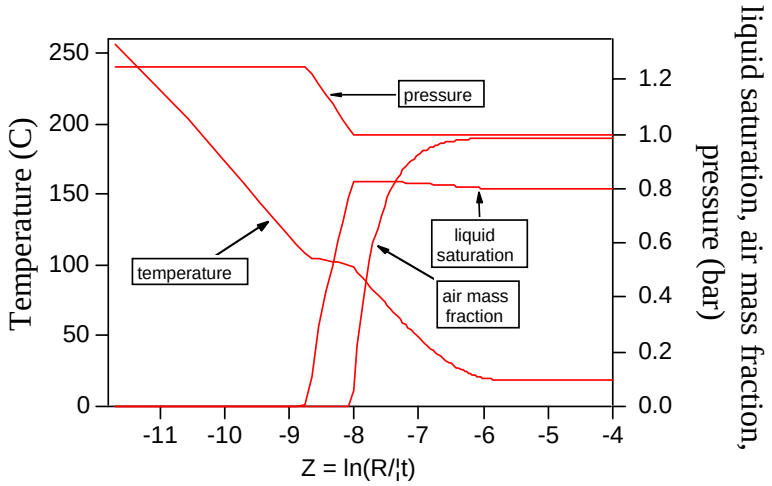
Output for Heat Pipe Problem after t = 10 Years (EOS4)



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