APPENDIX C

SOURCE FORTRAN CODE OF MFREK

AND A SAMPLE INPUT DATA

C.1 MFREK.F

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C-------------------------------------------------------------------------------+
C                MULTIPHASE                                                     |
C                FLOW SIMULATOR WITH                                            |
C                REACTIONS,                                                     |
C                ENERGY EQUATIONS AND                                           |
C                KINETIC THEORY.                                                |
C                                                                               |
C                MODIFIED BY                                                    |
C                YUANXIANG WU & DR. DIMITRI GIDASPOW                            |
C                                                                               |
C                ILLINOIS INSTITUTE OF TECHNOLOGY                               |
C                CHICAGO, ILLINOIS 60616                                        |
C-------------------------------------------------------------------------------+
      PROGRAM MFREK
      INCLUDE 'mfrek.com'
      CHARACTER*10 RESTART
      CHARACTER*80 NAME
      READ(5,'(A)')RESTART
      OPEN(9,FILE=RESTART,FORM='UNFORMATTED',TYPE='UNKNOWN')
      READ(5,'(A)')NAME
      WRITE(6,'(A)')' SIMULATION -  ',NAME
      READ(5,*)(DR(I),I=1,IB2)
      READ(5,*)(DZ(J),J=1,JB2)
      WRITE(6,210)ITC,IB2,JB2,DR(1),DZ(1)
      WRITE(6,215)(DR(I),I=1,IB2)
      WRITE(6,216)(DZ(J),J=1,JB2)
      READ(5,*)(NSL(M),M=1,4)
      WRITE(6,220)(NSL(M),M=1,4)
      WRITE(6,230)NIN,NOUT,NFL,NOBS
      WRITE(6,240)
      DO 5 N=1,NT
      READ(5,*)NSO(N),ITHMF(N),(IOB(M,N),M=1,4)
      WRITE(6,245)NSO(N),(IOB(M,N),M=1,4)
      IF(ITHMF(N).EQ.1)THEN
      READ(5,*)QQ(N),TOBB(N),COEK(N)
      ENDIF
5     CONTINUE
      READ(5,*)(DK(K),K=1,NPHASE)
      READ(5,*)(PHI(K),K=1,NPHASE)
      READ(5,*)(RL(K),K=1,NPHASE)
      READ(5,*)(CL(K),K=1,NPHASE)
      READ(5,*)(VISS(K),K=1,NPHASE)
      READ(5,*)(KIN(K),RLKMIN(K),K=1,NPHASE)
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      WRITE(6,250)
      WRITE(6,255)(DK(K),RL(K),CL(K),PHI(K),K=1,NPHASE)
      READ(5,*)UIO(1),VIO(1),PIO(1),THIO(1),TEMIO(1)
      READ(5,*)(UPIO(K,1),VPIO(K,1),THPIO(K,1),TEMPIO(K,1)
     1,TSKIO(K,1),K=1,NPHASE)
      WRITE(6,260)
      WRITE(6,265)UIO(1),VIO(1),PIO(1),THIO(1),TEMIO(1)
      WRITE(6,270)
      WRITE(6,275)(K,UPIO(K,1),VPIO(K,1),THPIO(K,1),TEMPIO(K,1),K=1
     1,NPHASE)
      WRITE(6,280)
      DO 10 N=2,NO
      READ(5,*)UIO(N),VIO(N),PIO(N),THIO(N),TEMIO(N)
      READ(5,*)(UPIO(K,N),VPIO(K,N),THPIO(K,N),TEMPIO(K,N),
     1TSKIO(K,N),K=1,NPHASE)
10    WRITE(6,285)UIO(N),VIO(N),PIO(N),THIO(N),TEMIO(N)
      WRITE(6,290)
      DO 15 N=2,NO
15    WRITE(6,295)(K,UPIO(K,N),VPIO(K,N),THPIO(K,N),TEMPIO(K,N),
     1K=1,NPHASE)
      READ(5,*)IHEAT,IRXN
      IF(IRXN.EQ.1)THEN
      READ(5,*)(WM(JX),JX=1,JXN)
      WRITE(6,*)
      WRITE(6,*)'MOLECULAR WEIGHT'
      WRITE(6,*)'    CO   CO2  H2  CH4 CH3OH  N2'
      WRITE(6,*)'WM=',(WM(JX),JX=1,JXN)
      WRITE(6,*)
      WRITE(6,*)'REACTION HEAT & STOICHIOMETRIC COEFF.'
      DO 16 K=1,NPHASE+1
      WRITE(6,*)
      READ(5,*)IHO(K),IHE(K)
      WRITE(6,*)'PHASE',K-1,',  # OF HOMO-REACTIONS=',IHO(K),
     1',  # OF HETERO-REACTIONS=',IHE(K)
      IF(IHO(K).NE.0)THEN
      WRITE(6,*)'  HOMO-REACTIONS'
      DO 17 IX=1,IHO(K)
      READ(5,*)HHO(K,IX),(AHO(K,IX,JX),JX=1,JXN)
17    WRITE(6,*)'   REACTION',IX,'  COEF.',(AHO(K,IX,JX),JX=1,JXN)
      ENDIF
      IF(IHE(K).NE.0)THEN
      WRITE(6,*)'  HETERO-REACTIONS'
      DO 21 IX=1,IHE(K)
      READ(5,*)HHE(K,IX),(AHE(K,IX,JX),JX=1,JXN)
21    WRITE(6,*)'   REACTION',IX,'  COEF.',(AHE(K,IX,JX),JX=1,JXN)
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      ENDIF
16    CONTINUE
      WRITE(6,*)
      WRITE(6,*)'COMPOSITIONS'
      WRITE(6,*)
      DO 19 N=1,NO
      DO 19 K=1,NPHASE+1
      READ(5,*)(YIO(K,JX,N),JX=1,JXN)
19    WRITE(6,519)N,K-1,(YIO(K,JX,N),JX=1,JXN)
519   FORMAT(' BLOCK',I2,',  PHASE ',I1,',',6G11.4)
      ENDIF
      READ(5,*)ITD
      READ(5,*)TIME,TSTOP,DT
      READ(5,*)TPR,TDUMP
      WRITE(6,300)ITD,TIME,TSTOP,DT,TPR,TDUMP
      READ(5,*)GRAVX,GRAVY
      WRITE(6,310)GRAVY,GRAVX
      WRITE(6,*)
      DO 30 J=1,JB2
      DO 30 I=1,IB2
      IJ=I+(J-1)*IB2
      TOB(IJ)=0.0
      COE(IJ)=0.0
30    QF(IJ)=0.0
      DO 22 N=1,NT
      IF(ITHMF(N).NE.1)GOTO 22
      DO 23 J=IOB(3,N),IOB(4,N)
      DO 23 I=IOB(1,N),IOB(2,N)
      IJ=I+(J-1)*IB2
      TOB(IJ)=TOBB(N)
      COE(IJ)=COEK(N)
23    QF(IJ)=QQ(N)
22    CONTINUE
      DO 27 N=1,NT
      IF(ITHMF(N).NE.1) GOTO 27
C     WRITE(6,*)'HEAT SOURCE/SINK (T-OBSTACLE/FLUX)'
      DO 24 J=1,JB2
      DO 24 I=1,IB2
      IJ=I+(J-1)*IB2
24    Q(IJ)=QF(IJ)+TOB(IJ)
C     DO 26 IJ=IB2JB2,IB2,-IB2
C26   WRITE(6,25)(Q(IL),IL=IJ-IB1,IJ)
25    FORMAT(6(1X,G12.4))
      GOTO 29
27    CONTINUE
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```
29    CONTINUE
C
      REWIND(9)
      DO 500 K=1,NPHASE
      VISSD(K)=VISS(K)
      DO 500 IJ=1,IB2JB2
500   VISBL(K,IJ)=0.0
      TTIM=0.0
      IF (ITD.EQ.2) CALL TAPERD
      DO 20 K=1,NPHASE
20    ARL(K)=1./RL(K)
      CALL FLIC
      CALL SETUP
      CALL PROG
      STOP
210   FORMAT(/' 1. GEOMETRY'/'  A. COORDINATES
      1(CART=0, CYLIND=1, SPHER=2)
      1=',I3/'  B. MESH SIZE,   IB2=',I3,6X,'JB2=',I3/'
      1C. CELL SIZE'
      2,',   DR=',1PE12.4,'  DZ=',1PE12.4)
215   FORMAT(7X,'DR='/8(2X,F6.3))
216   FORMAT(7X,'DZ='/8(2X,F6.3))
220   FORMAT(/' 2. CELL FLAGS'/'  A. BOUNDARIES (FREE-SLIP=2
      1NO-SLIP=3)'
      1/7X,'BOTTOM=',I3,'  LEFT=',I3,'  TOP=',I3,'  RIGHT=',I3)
230   FORMAT('  B. INLETS =',I3,' OUTLETS =',I3,' FLUIDS =', I3,
      1' OBSTACLES =',I3)
240   FORMAT('    SLIP',10X,'------COORDINATES------')
245   FORMAT(5X,I3,4(4X,I5))
250   FORMAT(/' 3. PARTICULATE PHASE DATA'/7X,'DIAMETER',4X,
      1'MACROSCOPIC',
      1' DENSITY',4X,' HEAT CAPACITY',4X,'SPHERICITY')
255   FORMAT((2(6X,G10.3),13X,G10.3,7X,G10.3))
260   FORMAT(/' 4. INITIAL AND BOUNDARY DATA'/'  A. INITIAL DATA',
      1' (FLUID)'/11X,'UO',13X,'VO',13X,'PO',12X,'THO',11X,'TEMGO')
265   FORMAT((2X,5(4X,1PE11.4)))
270   FORMAT('  B. INITIAL DATA  (SOLID)'/8X,'PHASE',9X,
      1'UKO',11X,'VKO',10X,'THKO',9X,'TEMKO')
275   FORMAT((8X,I3,3X,4(3X,1PE11.4)))
280   FORMAT('  C. INFLOW - OUTFLOW DATA  (FLUID)'/10X,'UIO',12X,
      1'VIO',12X,'PIO',12X,'THIO',11X,'TEMIO')
285   FORMAT((2X,5(4X,1PE11.4)))
290   FORMAT('  D. INFLOW - OUTFLOW DATA  (SOLID)'/8X,'PHASE',9X,
      1'UPIO',11X,'VPIO',10X,'THPIO',9X,'TEMPIO')
295   FORMAT((8X,I3,3X,4(4X,1PE11.4)))
```

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300   FORMAT(/' 5. CONTROL'/ 3X,'A. DUMP AND RESTART,   ITD='
      1,I3/3X,
      1'B. TIME  TSTART=',1PE11.4,'  TSTOP=',1PE11.4,' DT=',
      11PE11.4/
      1'  C. PRINTING AND PLOTTING,  TPR=',1PE11.4,' TDUMP=',
      11PE11.4)
310   FORMAT(/' 6. GRAVITY'/'  A. GRAVY=',1PE15.7,'  GRAVX='
      1,1PE15.7)
      END
C ------------------------------------------------------------------------------------------BDRY
      SUBROUTINE BDRY
      INCLUDE 'mfrek.com'
C
      DO 200 J=2,JB1
      DO 200 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.1) THEN
      RGPN(IJ)=RGP(IJ)
      THN(IJ)=TH(IJ)
      SIEGN(IJ)=SIEG(IJ)
      TG(IJ)=C1+SIEG(IJ)/CG
      IF(IHEAT.EQ.0)TG(IJ)=TEMIO(1)
      CALL ROGY(IJ)
      AKG(IJ)=8.67D5*(TG(IJ)/1400.0)**1.786
      DO 9 K=1,NPHASE
      SIELN(K,IJ)=SIEL(K,IJ)
      IF (RLK(K,IJ).EQ.0.0) THEN
      TL(K,IJ)=0.0
      ELSE
      TL(K,IJ)=C2+SIEL(K,IJ)/CL(K)
      ENDIF
      IF(IHEAT.EQ.0)TL(K,IJ)=TEMPIO(K,1)
      CALL THRCON
      TSKN(K,IJ)=TSK(K,IJ)
9     RLKN(K,IJ)=RLK(K,IJ)
      IPJ=IJ+1
      IJP=IJ+IB2
      IMJ=IJ-1
      IJM=IJ-IB2
      IPJP=IJP+1
      IMJP=IJP-1
      IPJM=IJM+1
      NFLR=IFL(IPJ)
      NFLTR=IFL(IPJP)
      NFLT=IFL(IJP)
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      IF(NFLR.EQ.4.OR.NFLR.GE.7) THEN
      N1=IJ
      N2=IPJ
      IF(NFLR.EQ.4.OR.UG(N1).GT.0.)THEN
      RGFR(N2)=RGFR(N1)
      RGP(N2)=RGP(N1)
      RUG(N2)=RUG(N1)
      TH(N2)=TH(N1)
      TG(N2)=TG(N1)
      DO 14 JX=1,JXN
      YN(1,JX,N2)=YN(1,JX,N1)
14    Y(1,JX,N2)=Y(1,JX,N1)
      DO 15 K=1,NPHASE
      RLFRK(K,N2)=RLFRK(K,N1)
      RLK(K,N2)=RLK(K,N1)
      TSK(K,N2)=TSK(K,N1)
      TSKN(K,N2)=TSK(K,N1)
      RUK(K,N2)=RUK(K,N1)
      DO 13 JX=1,JXN
      YN(K+1,JX,N2)=YN(K+1,JX,N1)
13    Y(K+1,JX,N2)=Y(K+1,JX,N1)
15    TL(K,N2)=TL(K,N1)
      IF(NFLR.GE.7)THEN
      IJ=N2
      CALL CNVERT
      IJ=N1
      ELSE
      P(N2)=P(N1)
      ENDIF
      ENDIF
      IF(NFLTR.GE.4)THEN
      VG(N2)=VG(N1)
      DO 17 K=1,NPHASE
17    VK(K,N2)=VK(K,N1)
      ENDIF
      DO 18 K=1,NPHASE
18    UK(K,N2)=UK(K,N1)
      UG(N2)=UG(N1)
      IF (NFLR.EQ.8)THEN
      DO 20 K=1,NPHASE
      UK(K,N2)=0.0
20    VK(K,N2)=0.0
      ENDIF
      ENDIF
      IF(NFLT.EQ.4.OR.NFLT.GE.7) THEN
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```
      N1=IJ
      N2=IJP
      IF(NFLT.EQ.4.OR.VG(N1).GT.0.)THEN
      RGFT(N2)=RGFT(N1)
      RGP(N2)=RGP(N1)
      RVG(N2)=RVG(N1)
      TH(N2)=TH(N1)
      TG(N2)=TG(N1)
      DO 24 JX=1,JXN
      YN(1,JX,N2)=YN(1,JX,N1)
24    Y(1,JX,N2)=Y(1,JX,N1)
      DO 25 K=1,NPHASE
      RLFTK(K,N2)=RLFTK(K,N1)
      TSK(K,N2)=TSK(K,N1)
      TSKN(K,N2)=TSK(K,N1)
      RLK(K,N2)=RLK(K,N1)
      RVK(K,N2)=RVK(K,N1)
      DO 23 JX=1,JXN
      YN(K+1,JX,N2)=YN(K+1,JX,N1)
23    Y(K+1,JX,N2)=Y(K+1,JX,N1)
25    TL(K,N2)=TL(K,N1)
      IF(NFLT.GE.7)THEN
      IJ=N2
      CALL CNVERT
      IJ=N1
      ELSE
      P(N2)=P(N1)
      ENDIF
      ENDIF
      IF(NFLTR.GE.4) THEN
      UG(N2)=0.0
      DO 27 K=1,NPHASE
27    UK(K,N2)=0.0
      ENDIF
      RGP(N2)=RGP(N1)
      VG(N2)=VG(N1)
C     VG(N2)=RGP(N1)*VG(N1)/RGP(N2)
      DO 28 K=1,NPHASE
28    VK(K,N2)=VK(K,N1)
      IF (NFLT.EQ.8)THEN
      DO 30 K=1,NPHASE
      UK(K,N2)=0.0
30    VK(K,N2)=0.0
      ENDIF
      ENDIF
```

```
C OBSTACLES
      IF(IFL(IJ).EQ.1)THEN
      IF (NFLR .EQ. 2) THEN
      VG(IPJ)=VG(IJ)
      DO 91 K=1,NPHASE
91    VK(K,IPJ)=VK(K,IJ)
      ELSEIF (NFLR .EQ. 3 ) THEN
      VG(IPJ)=0.0
      DO 92 K=1,NPHASE
92    VK(K,IPJ)=0.0
      ENDIF
      IF (NFLT .EQ. 2) THEN
      UG(IJP)=UG(IJ)
      DO 93 K=1,NPHASE
93    UK(K,IJP)=UK(K,IJ)
      ELSEIF (NFLT .EQ. 3) THEN
      UG(IJP)=0.0
      DO 94 K=1,NPHASE
94    UK(K,IJP)=0.0
      ENDIF
      NFLL=IFL(IMJ)
      NFLTL=IFL(IMJP)
      IF (NFLL .EQ. 2) THEN
      VG(IMJ)=VG(IJ)
      DO 95 K=1,NPHASE
95    VK(K,IMJ)=VK(K,IJ)
      ELSEIF (NFLL .EQ. 3) THEN
      VG(IMJ)=0.0
      DO 96 K=1,NPHASE
96    VK(K,IMJ)=0.0
      ENDIF
      NFLB=IFL(IJM)
      NFLBR=IFL(IPJM)
      IF (NFLB .EQ. 2) THEN
      UG(IJM)=UG(IJ)
      DO 97 K=1,NPHASE
97    UK(K,IJM)=UK(K,IJ)
      ELSEIF (NFLB .EQ. 3) THEN
      UG(IJM)=0.0
      DO 98 K=1,NPHASE
98    UK(K,IJM)=0.0
      ENDIF
      ENDIF
      ENDIF
200   CONTINUE
```

```
      RETURN
      END
C -------------------------------------------------------------------------------------BETAS
      SUBROUTINE BETAS
      INCLUDE 'mfrek.com'
C
      PARAMETER (EPSG=1.0D-4)
      DO 10 J=2,JB1
      DO 10 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).NE.1) GOTO 10
      CALL INDXA
      IF(IFL(IPJ).EQ.1.OR.IFL(IPJ).EQ.4.OR.IFL(IPJ).GE.7)THEN
      RIG=RB(I)*(AR(I)*TH(IJ)+BR(I)*TH(IJR))
      ELSE
      RIG=0.
      ENDIF
      IF(IFL(IMJ).NE.2.AND.IFL(IMJ).NE.3.AND.IFL(IMJ).NE.5)THEN
      EFL=RB(I-1)*(BR(I-1)*TH(IJ)+AR(I-1)*TH(IJL))
      ELSE
      EFL=0.
      ENDIF
      IF(IFL(IJP).EQ.1.OR.IFL(IJP).EQ.4.OR.IFL(IJP).GE.7)THEN
      TOP=AZ(J)*TH(IJ)+BZ(J)*TH(IJT)
      ELSE
      TOP=0.
      ENDIF
      IF(IFL(IJM).EQ.1.OR.IFL(IJM).EQ.4.OR.IFL(IJM).EQ.6)THEN
      BOT=BZ(J-1)*TH(IJ)+AZ(J-1)*TH(IJB)
      ELSE
      BOT=0.
      ENDIF
      CONV(IJ)=EPSG*RGP(IJ)
      RBETA=TH(IJ)*ROG(IJ)/P(IJ)+DTODZ(J)*DTODZ(J)*(TOP+BOT)+
      1DTORDR(I)*DTODR(I)*(RIG+EFL)
      ABETA(IJ)=1./RBETA
10    CONTINUE
      RETURN
      END

C -------------------------------------------------------------------------------------CNVERT
      SUBROUTINE CNVERT
      INCLUDE 'mfrek.com'
C
      CALL ROGY(IJ)
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      RGP(IJ)=ROG(IJ)*TH(IJ)
      RGPN(IJ)=RGP(IJ)
      SIEG(IJ)=(TG(IJ)-C1)*CG
      SIEGN(IJ)=SIEG(IJ)
      AKG(IJ)=8.67D5*(TG(IJ)/1400.0)**1.786
      DO 10 K=1,NPHASE
      TSKN(K,IJ)=TSK(K,IJ)
      RLKN(K,IJ)=RLK(K,IJ)
      SIEL(K,IJ)=(TL(K,IJ)-C2)*CL(K)
      SIELN(K,IJ)=SIEL(K,IJ)
10    CONTINUE
      RETURN
      END

C -----------------------------------------------------------------------------------------COMPOS
      SUBROUTINE COMPOS
C  SOLVE THE COMPOSITION FOR EACH PHASE
      INCLUDE 'mfrek.com'
      IF(IRXN.EQ.0)RETURN
      DO 2 J=2,JB1
      DO 2 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).NE.1)GOTO 2
      CALL INDXA
      DO 10 K=1,LT
      K1=K-1
      IF(K.EQ.1)GOTO 6
      IF(RLK(K1,IJ).GT.0.0)GOTO 6
      DO 5 JX=1,JXN
5     Y(K,JX,IJ)=0.0
      GOTO 10
6     CALL RRATE
      IF(K.EQ.1)THEN
C     CALL MASFGY
      IF(UG(IMJ).GE.0.)THEN
      RGFRY(IMJ)=UG(IMJ)*RGP(IJL)*RB(I-1)
      KEY(2)=IJL
      ELSE
      RGFRY(IMJ)=UG(IMJ)*RGP(IJ)*RB(I-1)
      KEY(2)=IJ
      ENDIF
      IF(VG(IJM).GE.0.)THEN
      RGFTY(IJM)=VG(IJM)*RGP(IJB)
      KEY(4)=IJB
      ELSE
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      RGFTY(IJM)=VG(IJM)*RGP(IJ)
      KEY(4)=IJ
      ENDIF
C     ENTRY MASFGAY
      IF(UG(IJ).GE.0.)THEN
      RGFRY(IJ)=UG(IJ)*RGP(IJ)*RB(I)
      KEY(1)=IJ
      ELSE
      RGFRY(IJ)=UG(IJ)*RGP(IJR)*RB(I)
      KEY(1)=IJR
      ENDIF
      IF(VG(IJ).GE.0.)THEN
      RGFTY(IJ)=VG(IJ)*RGP(IJ)
      KEY(3)=IJ
      ELSE
      RGFTY(IJ)=VG(IJ)*RGP(IJT)
      KEY(3)=IJT
      ENDIF
      ELSE
C     CALL MASFKY
      IF(UK(K1,IMJ).GE.0.)THEN
      RLFRKY(K1,IMJ)=UK(K1,IMJ)*RLK(K1,IJL)*RB(I-1)
      KEY(2)=IJL
      ELSE
      RLFRKY(K1,IMJ)=UK(K1,IMJ)*RLK(K1,IJ)*RB(I-1)
      KEY(2)=IJ
      ENDIF
      IF(VK(K1,IJM).GE.0.)THEN
      RLFTKY(K1,IJM)=VK(K1,IJM)*RLK(K1,IJB)
      KEY(4)=IJB
      ELSE
      RLFTKY(K1,IJM)=VK(K1,IJM)*RLK(K1,IJ)
      KEY(4)=IJ
      ENDIF
C
C     ENTRY MASFKAY
      IF(UK(K1,IJ).GE.0.)THEN
      RLFRKY(K1,IJ)=UK(K1,IJ)*RLK(K1,IJ)
      KEY(1)=IJ
      ELSE
      RLFRKY(K1,IJ)=UK(K1,IJ)*RLK(K1,IJR)
      KEY(1)=IJR
      ENDIF
      IF(VK(K1,IJ).GE.0.)THEN
      RLFTKY(K1,IJ)=VK(K1,IJ)*RLK(K1,IJ)
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```
      KEY(3)=IJ
      ELSE
      RLFTKY(K1,IJ)=VK(K1,IJ)*RLK(K1,IJT)
      KEY(3)=IJT
      ENDIF
      ENDIF
      THY=0.0
      DO 25 JX=1,JXN
      DOTMJ(K,JX)=0.0
      DO 30 IX=1,IHO(K)
30    DOTMJ(K,JX)=DOTMJ(K,JX)+RHO(K,IX)*AHO(K,IX,JX)
      DO 27 IX=1,IHE(K)
27    DOTMJ(K,JX)=DOTMJ(K,JX)+RHE(K2,IX)*AHE(K2,IX,JX)
      IF(K.EQ.1)THEN
      SUMN=WM(JX)*DOTMJ(1,JX)*DT+RGPN(IJ)*YN(1,JX,IJ)
      1+DGG(IJ)*YN(1,JX,IJ)
      SUMD=TH(IJ)*ROG(IJ)
      IF(KEY(1).EQ.IJ)THEN
      SUMD=SUMD+DTORDR(I)*RGFRY(IJ)
      ELSE
      SUMN=SUMN-DTORDR(I)*RGFRY(IJ)*YN(1,JX,IJR)
      ENDIF
      IF(KEY(2).EQ.IJ)THEN
      SUMD=SUMD-DTORDR(I)*RGFRY(IMJ)
      ELSE
      SUMN=SUMN+DTORDR(I)*RGFRY(IMJ)*YN(1,JX,IJL)
      ENDIF
      IF(KEY(3).EQ.IJ)THEN
      SUMD=SUMD+DTODZ(J)*RGFTY(IJ)
      ELSE
      SUMN=SUMN-DTODZ(J)*RGFTY(IJ)*YN(1,JX,IJT)
      ENDIF
      IF(KEY(4).EQ.IJ)THEN
      SUMD=SUMD-DTODZ(J)*RGFTY(IJM)
      ELSE
      SUMN=SUMN+DTODZ(J)*RGFTY(IJM)*YN(1,JX,IJB)
      ENDIF
      Y(1,JX,IJ)=SUMN/SUMD
      ELSE
      SUMN=WM(JX)*DOTMJ(K,JX)*DT+RLKN(K1,IJ)*YN(K,JX,IJ)
      SUMD=RLK(K1,IJ)
      IF(KEY(1).EQ.IJ)THEN
      SUMD=SUMD+DTORDR(I)*RLFRKY(K1,IJ)
      ELSE
      SUMN=SUMN-DTORDR(I)*RLFRKY(K1,IJ)*YN(K,JX,IJR)
```

```
      ENDIF
      IF(KEY(2).EQ.IJ)THEN
      SUMD=SUMD-DTORDR(I)*RLFRKY(K1,IMJ)
      ELSE
      SUMN=SUMN+DTORDR(I)*RLFRKY(K1,IMJ)*YN(K,JX,IJL)
      ENDIF
      IF(KEY(3).EQ.IJ)THEN
      SUMD=SUMD+DTODZ(J)*RLFTKY(K1,IJ)
      ELSE
      SUMN=SUMN-DTODZ(J)*RLFTKY(K1,IJ)*YN(K,JX,IJT)
      ENDIF
      IF(KEY(4).EQ.IJ)THEN
      SUMD=SUMD-DTODZ(J)*RLFTKY(K1,IJM)
      ELSE
      SUMN=SUMN+DTODZ(J)*RLFTKY(K1,IJM)*YN(K,JX,IJB)
      ENDIF
      Y(K,JX,IJ)=SUMN/SUMD
      ENDIF
C
      IF(Y(K,JX,IJ).LE.1D-10)Y(K,JX,IJ)=0.0
      THY=THY+Y(K,JX,IJ)
25    CONTINUE
      IF(ABS(THY-1.0).LE.1D-10)GOTO 10
C NORMALIZE THE COMPOSITION,
C PUT THE ERROR TO A MAJOR COMPONENT SUCH AS #6
      IF(K.EQ.1)THEN
      Y(K,6,IJ)=1.0-(THY-Y(K,6,IJ))
      ELSE
      Y(K,6,IJ)=1.0-(THY-Y(K,6,IJ))
      ENDIF
10    CONTINUE
2     CONTINUE
3     DO 9 IJ=1,IB2JB2
      IF(IFL(IJ).NE.1)GOTO 9
      DO 8 K=1,LT
      DO 8 JX=1,JXN
      YN(K,JX,IJ)=Y(K,JX,IJ)
8     CONTINUE
9     CONTINUE
      RETURN
      END

C -------------------------------------------------------------------------------------------FEFLUX
      SUBROUTINE FEFLUX
      INCLUDE 'mfrek.com'
```

```
C
C  CALCULATE FLUCTUATING ENERGY FLUXES OF KINETIC THEORY
C
      TSKCB(K)=(TSKN(K,IJ)-TSKN(K,IJB))
      1*(BZ(J-1)*GCON(K,IJ)+AZ(J-1)*GCON(K,IJB))*RDZP(J-1)
      TSKFB(K,I)=1.5*TSKFB(K,I)-TSKCB(K)
C
      ENTRY FEFLUXA
      IF(IFL(IMJ).NE.1)THEN
      TSKCL(K)=(TSKN(K,IJ)-TSKN(K,IJL))*RB(I-1)
      1*(BR(I-1)*GCON(K,IJ)+AR(I-1)*GCON(K,IJL))*RDRP(I-1)
      TSKFL(K)=1.5*TSKFL(K)-TSKCL(K)
      ENDIF
C
      ENTRY FEFLUXB
      TSKCR(K)=(TSKN(K,IJR)-TSKN(K,IJ))*RB(I)
      1*(BR(I)*GCON(K,IJR)+AR(I)*GCON(K,IJ))*RDRP(I)
      TSKFR(K)=1.5*TSKFR(K)-TSKCR(K)
C
      TSKCT(K)=(TSKN(K,IJT)-TSKN(K,IJ))
      1*(BZ(J)*GCON(K,IJT)+AZ(J)*GCON(K,IJ))*RDZP(J)
      TSKFT(K)=1.5*TSKFT(K)-TSKCT(K)
      RETURN
      END
C -------------------------------------------------------------------------------------FLIC
      SUBROUTINE FLIC
      INCLUDE 'mfrek.com'
      IJ=0
      DO 150 J=1,JB2
      DO 150 I=1,IB2
      IJ=IJ+1
      IFL(IJ)=1
      IF (J.EQ.JB2) THEN
      IFL(IJ)=NSL(3)
      ELSEIF (J.EQ.1) THEN
      IFL(IJ)=NSL(1)
      ENDIF
      IF (I.EQ.1) THEN
      IFL(IJ)=NSL(2)
      ELSEIF (I.EQ.IB2) THEN
      IFL(IJ)=NSL(4)
      ENDIF
150   CONTINUE
      DO 300 N=1,NT
      DO 300 I=IOB(1,N),IOB(2,N)
```

```
      DO 300 J=IOB(3,N),IOB(4,N)
      IJ=I+(J-1)*IB2
      IFL(IJ)=NSO(N)
300   CONTINUE
      IF(IFL(IB1JB2).EQ.4.AND.IFL(IB2JB1).EQ.4)IFL(IB2JB2)=4
      IF(IFL(IB1JB2).EQ.7.AND.IFL(IB2JB1).EQ.7)IFL(IB2JB2)=7
      RETURN
      END

C -------------------------------------------------------------------------------GRNVIS
      SUBROUTINE GRNVIS
      INCLUDE 'mfrek.com'
C
C  CALCULATE NEW GRANULAR TEMPERATURES
C   AND SOLIDS PROPERTIES
C  USING KINETIC THEORY OF GRANULAR SOLIDS
C
      CALL VWORKL
      DO 10 J=2,JB1
      DO 10 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.1)THEN
      IMJ=INDS(IJ,2)
      IJM=INDS(IJ,4)
      DO 5 K=1,NPHASE
      IF(KIN(K).NE.1)GOTO 5
C  GRANULAR KINETIC THEORY IS APPLIED
C  ONLY IF (EF-EF,MIN) > 1.E-10
CWW   IF(RLK(K,IJ).GT.RLKMIN(K).AND.
CWW  1(TH(IJ)-THMIN).GT.1.E-10)THEN
      IF(RLK(K,IJ).GT.RLKMIN(K))THEN
C
      THL(K,IJ)=ARL(K)*RLK(K,IJ)
      TSKS=TSK(K,IJ)**0.5
C  CALCULATE RADIAL DISTRIBUTION FUNCTION & OTHER PARAMETERS
      G0=1.0/(1.0-(THL(K,IJ)/(1.0-THMIN))**(1./3.))
      CS1=(1.0+CRES)*THL(K,IJ)*G0
      CS2=3.0*(1.0-CRES)*RLK(K,IJ)*CS1
C     CS3=RLK(K,IJ)/(RLK(K,IJ)+DMFP(K))
      CS4=2.*VISDIL(K)/((1.+CRES)*G0)
      RSQRTPI=1.0/SQRT(PI)
      GAMMA(K,IJ)=CS2*(4.0*RSQRTPI/DK(K)*TSKS-SILM(K,IJ))
      PS(K,IJ)=RLK(K,IJ)*(1.0+2.0*CS1)
C
      VISCD=CS4*(1.+.8*CS1)**2
```

```
      VISBL(K,IJ)=(4./3.)*RLK(K,IJ)*DK(K)*CS1/PI**0.5
      VISCL(K,IJ)=VISCD+0.6*VISBL(K,IJ)
C
C  GRANULAR CONDUCTIVITY
      GCON(K,IJ)=3.75*CS4*(1.+1.2*CS1)**2*TSKS
     1+1.5*VISBL(K,IJ)*TSKS
      ELSE
      GCON(K,IJ)=0.0
      ENDIF
5     CONTINUE
      ENDIF
10    CONTINUE
C
C  FINAL SOLUTION OF GRANULAR TEMPERATURE
      DO 100 J=2,JB1
      DO 100 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.1)THEN
      CALL INDX
C
      DO 20 K=1,NPHASE
      IF(KIN(K).NE.1)GOTO 20
      CALL GRTEMF
CW    IF(RLK(K,IJ).GT.RLKMIN(K).AND.
CW    1(TH(IJ)-THMIN).GT.1.E-10)THEN
      IF(RLK(K,IJ).GT.RLKMIN(K))THEN
      AP0=-(1.5*RLK(K,IJ)*TSK(K,IJ)-DTODZ(J)*(TSKFT(K)
     1-TSKFB(K,I))-DTORDR(I)*(TSKFR(K)-TSKFL(K)))
      AP1=-(VISCL(K,IJ)*VWLS(K,IJ)+(VISBL(K,IJ)
     1-(2./3.)*VISCL(K,IJ))*VWLM(K,IJ))
CWW   D.G. INDICATES THE DRAG IN THE KINETIC EQS
C     MUST BE ELIMINATED
      AP2=(1.5*RLK(K,IJ)+DT*(3.0*RKPG(K,IJ)*0.00001
     1+PS(K,IJ)*SILM(K,IJ)+GAMMA(K,IJ)))
C
      CALL QESOL(AP0,AP1,AP2,TSKS)
      IF(TSKS.LT.0.0)TSKS=0.0
      IF(TSKS.GT.1000.0)TSKS=1000.0
      TSK(K,IJ)=TSKS*TSKS
C
C  SOLID PHASE BULK AND SHEAR VISCOSITIES
      VISBL(K,IJ)=VISBL(K,IJ)*TSKS
      VISCL(K,IJ)=VISCL(K,IJ)*TSKS
C
C  SOLIDS PHASE PRESSURE
```

```
      PS(K,IJ)=PS(K,IJ)*TSK(K,IJ)
      ELSE
      TSK(K,IJ)=0.0
      VISBL(K,IJ)=0.0
      VISCL(K,IJ)=0.0
      PS(K,IJ)=0.0
      ENDIF
      TSKFL(K)=TSKFR(K)
      TSKFB(K,I)=TSKFT(K)
20    CONTINUE
C
      ENDIF
100   CONTINUE
      RETURN
      END

C -------------------------------------------------------------------------------------GRPROP
      SUBROUTINE GRPROP
      INCLUDE 'mfrek.com'
C
C  INITIALIZE SOLIDS PROPERTIES USING GRANULAR KINETIC THEORY
C
C  GRANULAR KINETIC THEORY IS APPLIED
C  ONLY IF (EF-EF,MIN) > 1.E-10
CWW   IF(RLK(K,IJ).GT.RLKMIN(K).AND.
CWW  1(TH(IJ)-THMIN).GT.1.E-10)THEN
      IF(RLK(K,IJ).GT.RLKMIN(K))THEN
      THL(K,IJ)=ARL(K)*RLK(K,IJ)
      TSKS=TSK(K,IJ)**0.5
      G0=1.0/(1.0-(THL(K,IJ)/(1.0-THMIN))**(1./3.))
      CS1=(1.0+CRES)*THL(K,IJ)*G0
      CS2=3.0*(1.0-CRES)*RLK(K,IJ)*CS1
C     CS3=RLK(K,IJ)/(RLK(K,IJ)+DMFP(K))
      CS4=2.*VISDIL(K)/((1.+CRES)*G0)
      VISCD=CS4*(1.+.8*CS1)**2
      VISBL(K,IJ)=(4./3.)*RLK(K,IJ)*DK(K)*CS1*TSKS/PI**0.5
      VISCL(K,IJ)=VISCD*TSKS+0.6*VISBL(K,IJ)
      PS(K,IJ)=RLK(K,IJ)*(1.0+2.0*CS1)*TSK(K,IJ)
      GCON(K,IJ)=3.75*CS4*(1.+1.2*CS1)**2*TSKS
      1+1.5*VISBL(K,IJ)
      ELSE
      VISBL(K,IJ)=0.0
      VISCL(K,IJ)=0.0
      PS(K,IJ)=0.0
      GCON(K,IJ)=0.0
```

```
      ENDIF
      RETURN
      END

C -------------------------------------------------------------------------------GRTEMF
      SUBROUTINE GRTEMF
      INCLUDE 'mfrek.com'
C
C  CALCULATES GRANULAR TEMPERATURE FLUXES OF KINETIC THEORY
C
      IF(UK(K,IJ).GE.0.)THEN
      TSKFR(K)=RLFRK(K,IJ)*TSKN(K,IJ)
      ELSE
      TSKFR(K)=RLFRK(K,IJ)*TSKN(K,IJR)
      ENDIF
      IF(VK(K,IJ).GE.0.)THEN
      TSKFT(K)=RLFTK(K,IJ)*TSKN(K,IJ)
      ELSE
      TSKFT(K)=RLFTK(K,IJ)*TSKN(K,IJT)
      ENDIF
      IF(IFL(IMJ).NE.1)GOTO 1
      IF(IFL(IJM).NE.1)GOTO 2
      CALL FEFLUXB
      RETURN
C
1     IF(UK(K,IMJ).GE.0.)THEN
      TSKFL(K)=RLFRK(K,IMJ)*TSKN(K,IJL)
      ELSE
      TSKFL(K)=RLFRK(K,IMJ)*TSKN(K,IJ)
      ENDIF
      IF(IFL(IJM).NE.1)GOTO 2
      CALL FEFLUXA
      RETURN
C
2     IF(VK(K,IJM).GE.0.)THEN
      TSKFB(K,I)=RLFTK(K,IJM)*TSKN(K,IJB)
      ELSE
      TSKFB(K,I)=RLFTK(K,IJM)*TSKN(K,IJ)
      ENDIF
      CALL FEFLUX
      RETURN
      END

C -------------------------------------------------------------------------------HEATCG
      SUBROUTINE HEATCG
```

```
      INCLUDE 'mfrek.com'
C
C CALCULATES THE  HEAT FLUXES FROM GAS CONDUCTIVITY
C
      HFGB=(BZ(J-1)*AKG(IJ)+AZ(J-1)*AKG(IJB))*
     1(BZ(J-1)*TH(IJ)+AZ(J-1)*TH(IJB))*
     1(TG(IJ)-TG(IJB))*RDZP(J-1)
      ENTRY HEATGA
      HFGL=RB(I-1)*(BR(I-1)*AKG(IJ)+AR(I-1)*AKG(IJL))
     1*(BR(I-1)*TH(IJ)+AR(I-1)*TH(IJL))*
     1(TG(IJ)-TG(IJL))*RDRP(I-1)
      ENTRY HEATGB
      HFGR=RB(I)*(AR(I)*AKG(IJ)+BR(I)*AKG(IJR))
     1*(AR(I)*TH(IJ)+BR(I)*TH(IJR))*
     1(TG(IJR)-TG(IJ))*RDRP(I)
      HFGT=(AZ(J)*AKG(IJ)+BZ(J)*AKG(IJT))
     1*(AZ(J)*TH(IJ)+BZ(J)*TH(IJT))*
     1(TG(IJT)-TG(IJ))*RDZP(J)
      RETURN
      END

C ----------------------------------------------------------------------------HEATCL
      SUBROUTINE HEATCL
      INCLUDE 'mfrek.com'
C
C CALCULATES THE  HEAT FLUXES FROM SOLIDS CONDUCTIVITY
C
      HFLB(K,I)=(BZ(J-1)*AKL(K,IJ)+AZ(J-1)*AKL(K,IJB))
     1*(BZ(J-1)*RLK(K,IJ)+AZ(J-1)*RLK(K,IJB))*
     1(TL(K,IJ)-TL(K,IJB))*ARL(K)*RDZP(J-1)
      ENTRY HEATLA
      HFLL(K)=RB(I-1)*(BR(I-1)*AKL(K,IJ)+AR(I-1)*AKL(K,IJL))*
     1(BR(I-1)*RLK(K,IJ)+AR(I-1)*RLK(K,IJL))
     1*(TL(K,IJ)-TL(K,IJL))*ARL(K)*RDRP(I-1)
      ENTRY HEATLB
      HFLR(K)=RB(I)*(AR(I)*AKL(K,IJ)+BR(I)*AKL(K,IJR))*
     1(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1*(TL(K,IJR)-TL(K,IJ))*ARL(K)*RDRP(I)
      HFLT(K)=(AZ(J)*AKL(K,IJ)+BZ(J)*AKL(K,IJT))*
     1(AZ(J)*RLK(K,IJ)+BZ(J)*RLK(K,IJT))
     1*(TL(K,IJT)-TL(K,IJ))*ARL(K)*RDZP(J)
      RETURN
      END
C ----------------------------------------------------------------------------ICONV
      SUBROUTINE ICONV
```

```
      INCLUDE 'mfrek.com'
      DIMENSION AI(NP,NP),BI(NP)
C
C  FINAL UPDATING OF THE SPECIFIC ENERGIES ( ENTHALPIES )
C
      IF(IHEAT.EQ.0)RETURN
      DO 100 J=2,JB1
      DO 100 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.1) THEN
      CALL INDXA
      CALL SIEGF
      CALL QRXN
      CALL QFLUX
      AI(1,1)=RGP(IJ)
      BI(1)=RGP(IJ)*SIEG(IJ)-SIEGN(IJ)*(RGP(IJ)-RGPN(IJ))-
      1DTODZ(J)*(EGFT-EGFB(I))-DTORDR(I)*(EGFR-EGFL)
C  FOR INTERNAL ENERGY (MODEL B) <<
CWU    THE WORK DONE BY THE FLUID HAS CONSIDERABLE EFFECT
C      ON ENERGY EQUATION. HERE REDUCE IT TO ITS 10%.
      1-0.1*P(IJ)*(DTODZ(J)*(VG(IJ)-VG(IJM))
      1+DTORDR(I)*(RB(I)*UG(IJ)-RB(I-1)*UG(IMJ)))
      BI(1)=BI(1)+DT*(QGEN(1)+QFLOW(1))
C >>
C  FOR ENTHALPY (MODEL B) <<
C      1+((P(IJ)-PN(IJ))+0.5*DTODZ(J)*(VG(IJ)+VG(IJM))
C      1*((AZ(J)-BZ(J-1))*P(IJ)+BZ(J)*P(IJT)-AZ(J-1)*P(IJB))
C      1+0.5*DTORDR(I)*(UG(IJ)+UG(IMJ))*(RB(I)
C      1*(BR(I)*P(IJR)+AR(I)*P(IJ))
C      1-RB(I-1)*(BR(I-1)*P(IJ)+AR(I-1)*P(IJL))))
C >>
      DO 10 K=1,NPHASE
      CALL SIELF
      KP=K+1
      RHT=-0.5*DT*RHEAT(K,IJ)
      AI(1,KP)=RHT/CL(K)
      AI(KP,1)=RHT/CG
      AI(1,1)=AI(1,1)-AI(KP,1)
      AI(KP,KP)=RLK(K,IJ)-AI(1,KP)
      RIT=(SIEG(IJ)/CG-SIEL(K,IJ)/CL(K)+TL(K,IJ)-TG(IJ))*RHT
      BI(1)=BI(1)-RIT
      BI(KP)=RLK(K,IJ)*SIEL(K,IJ)-SIELN(K,IJ)*(RLK(K,IJ)-
      1RLKN(K,IJ))+
      1RIT-DTODZ(J)*(ELFT(K)-ELFB(K,I))-DTORDR(I)*(ELFR(K)
      1-ELFL(K))
```

```
      BI(KP)=BI(KP)+DT*(QGEN(KP)+QFLOW(KP))
10    CONTINUE
      CALL IINV(NPHS1,AI,BI)
      SIEG(IJ)=BI(1)
      DO 20 K=1,NPHASE
      SIEL(K,IJ)=BI(K+1)
      ELFL(K)=ELFR(K)
20    ELFB(K,I)=ELFT(K)
      EGFB(I)=EGFT
      EGFL=EGFR
      ENDIF
100   CONTINUE
      RETURN
      END
C -------------------------------------------------------------------------------------------IGIL
      SUBROUTINE IGIL
      INCLUDE 'mfrek.com'
      DIMENSION AI(NP,NP),BI(NP)
      IF(IHEAT.EQ.0)RETURN
      CALL QRXN
      CALL QFLUX
      AI(1,1)=RGP(IJ)
      BI(1)=RGP(IJ)*SIEGN(IJ)
      BI(1)=BI(1)+DT*(QGEN(1)+QFLOW(1))
      DO 10 K=1,NPHASE
      KP=K+1
      RHT=-0.5*DT*RHEAT(K,IJ)
      AI(1,KP)=RHT/CL(K)
      AI(KP,1)=RHT/CG
      AI(1,1)=AI(1,1)-AI(KP,1)
      AI(KP,KP)=RLK(K,IJ)-AI(1,KP)
      RIT=(SIEGN(IJ)/CG-SIELN(K,IJ)/CL(K)+TLN(K,IJ)-TGN(IJ))*RHT
      BI(1)=BI(1)-RIT
      BI(KP)=RLK(K,IJ)*SIELN(K,IJ)+RIT
10    BI(KP)=BI(KP)+DT*(QGEN(KP)+QFLOW(KP))
      CALL IINV(NPHS1,AI,BI)
      SIEG(IJ)=BI(1)
      DO 100 K=1,NPHASE
100   SIEL(K,IJ)=BI(K+1)
      RETURN
      END
C -------------------------------------------------------------------------------------------IINV
      SUBROUTINE IINV(NP,A,B)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(NP,NP),B(NP)
```

```
C  INVERSE OF MATRIX WITH NON-ZERO FIRST COLUMN,
C  FIRST ROW & DIAGONAL COLUMN
      DO 10 K=NP,2,-1
      IF (ABS(A(K,K)) .LE. 1.D-6) THEN
      A(1,K)=0.0
      A(K,1)=0.0
      B(K)=0.0
      ELSE
      DIV=1./A(K,K)
      A(K,1)=A(K,1)*DIV
      B(K)=B(K)*DIV
      B(1)=B(1)-A(1,K)*B(K)
      A(1,1)=A(1,1)-A(1,K)*A(K,1)
      ENDIF
10    CONTINUE
      B(1)=B(1)/A(1,1)
      DO 20 K=2,NP
20    B(K)=B(K)-A(K,1)*B(1)
      RETURN
      END
C -------------------------------------------------------------------------------------INDX
      SUBROUTINE INDX
      INCLUDE 'mfrek.com'
C
      IMJP=IJ-1+IB2
      IJTL=IMJP
      IF((IFL(IMJP).EQ.2).OR.(IFL(IMJP).EQ.3)) IJTL=IJ+IB2
      IPJM=IJ+1-IB2
      IJBR=IPJM
      IF((IFL(IPJM).EQ.2).OR.(IFL(IPJM).EQ.3)) IJBR=IJ+1
      IJRR=IJ+2
      IF (I.EQ.IB1) IJRR=IJ+1
      IF((IFL(IJRR).EQ.2).OR.(IFL(IJRR).EQ.3)) IJRR=IJ+1
      IJTT=IJ+IB2+IB2
      IF (J.EQ.JB1) IJTT=IJ+IB2
      IF((IFL(IJTT).EQ.2).OR.(IFL(IJTT).EQ.3)) IJTT=IJ+IB2
      ENTRY INDXA
      IPJ=IJ+1
      IJP=IJ+IB2
      IMJ=IJ-1
      IJM=IJ-IB2
      IPJP=IJP+1
      IJR=INDS(IJ,1)
      IJL=INDS(IJ,2)
      IJT=INDS(IJ,3)
```

```
      IJB=INDS(IJ,4)
      IJTR=INDS(IJ,5)
      RETURN
      END
C ----------------------------------------------------------------------------------------ITER
      SUBROUTINE ITER
      INCLUDE 'mfrek.com'
C
      LOGICAL MUSTIT
      PARAMETER (LMAX=5,OMEGA=1.05)
      DO 5 IJ=1,IB2JB2
      PN(IJ)=P(IJ)
      TGN(IJ)=C1+SIEGN(IJ)/CG
      DO 5 K=1,NPHASE
      IF (RLK(K,IJ).EQ.0.0) THEN
      TLN(K,IJ)=0.0
      ELSE
      TLN(K,IJ)=C2+SIELN(K,IJ)/CL(K)
      ENDIF
5     CONTINUE
      MUSTIT=.FALSE.
      DO 200 NIT=1,200
      DO 100 J=2,JB1
      DO 100 I=2,IB1
      IJ=I+(J-1)*IB2
      IF (IFL(IJ).NE.1) GOTO 100
      LOOP=0
      KROS=-1
      CALL INDXA
      CALL RXN
      DG=RGP(IJ)-RGPN(IJ)+DTORDR(I)*(RGFR(IJ)-RGFR(IMJ))
      1+DTODZ(J)*
      1(RGFT(IJ)-RGFT(IJM))
      DG=DG-DT*DOTM(1)
      ADG=ABS(DG)
      DGORIG=ADG
      IF(ADG.LE.CONV(IJ)) GOTO 78
      MUSTIT=.FALSE.
      D3=DG
      P3=P(IJ)
      IF(NIT.EQ.1)GOTO55
10    IF(D3.GT.0.0)GOTO11
      D2=D3
      P2=P3
      IF(KROS.EQ.-1)KROS=1
```

```
      IF(KROS.EQ.0)KROS=2
      GOTO12
11    D1=D3
      P1=P3
      IF(KROS.EQ.-1)KROS=0
      IF(KROS.EQ.1)KROS=2
12    IF(KROS.EQ.3)GOTO54
      IF(KROS.EQ.2)GOTO13
      DSN=SIGN(1.,D3)
      DP=-D3*ABETA(IJ)
      IF(-DP*DSN.GT.0.25*P3) DP=-0.25*DSN*P3
      P(IJ)=P(IJ)+DP
      GOTO54
13    P(IJ)=(D1*P2-D2*P1)/(D1-D2)
      ABETA(IJ)=(P1-P2)/(D1-D2)
      KROS=3
54    P3=P(IJ)
55    CONTINUE
      CALL IGIL
      TG(IJ)=C1+SIEG(IJ)/CG
      IF(IHEAT.EQ.0)TG(IJ)=TEMIO(1)
      CALL ROGY(IJ)
      DO 83 K=1,NPHASE
      IF (RLK(K,IJ).EQ.0.0) THEN
      TL(K,IJ)=0.0
      ELSE
      TL(K,IJ)=C2+SIEL(K,IJ)/CL(K)
      ENDIF
      IF(IHEAT.EQ.0)TL(K,IJ)=TEMPIO(K,1)
83    CONTINUE
      RGP(IJ)=TH(IJ)*ROG(IJ)
      CALL MATS
      CALL VELSK
      CALL MASFK
      CALL RXN
78    THX=0.0
      DO 79 K=1,NPHASE
      RLK(K,IJ)=RLKN(K,IJ)-DTORDR(I)*(RLFRK(K,IJ)-RLFRK(K,IMJ))
     1-DTODZ(J)*(RLFTK(K,IJ)-RLFTK(K,IJM))
      RLK(K,IJ)=RLK(K,IJ)+DT*DOTM(K+1)
      IF(RLK(K,IJ).LT.1.D-27)RLK(K,IJ)=0.0
79    THX=THX+RLK(K,IJ)*ARL(K)
      TH(IJ)=1.-THX
      RGP(IJ)=ROG(IJ)*TH(IJ)
      IF(ADG.LE.CONV(IJ))GOTO99
```

```
      CALL MASFG
      CALL RXN
      DG=RGP(IJ)-RGPN(IJ)+DTORDR(I)*(RGFR(IJ)-RGFR(IMJ))+DTODZ(J)*
      1(RGFT(IJ)-RGFT(IJM))
      DG=DG-DT*DOTM(1)
      ADG=ABS(DG)
      IF((ADG.LE.CONV(IJ)).AND.(ADG.LT.DGORIG)) GOTO 99
      IF((NIT.EQ.1).AND.(LOOP.EQ.0)) DGORIG=ADG
      D3=DG
      LOOP=LOOP+1
      IF((KROS.LT.2).AND.(LOOP.EQ.LMAX)) ABETA(IJ)=.5
      1*LMAX*ABETA(IJ)
      IF(LOOP.EQ.LMAX) GOTO 99
      IF(KROS.EQ.3)CALL NEWP
      GOTO10
99    DGG(IJ)=DG
100   CONTINUE
      IF(MUSTIT) RETURN
      MUSTIT=.TRUE.
      IF (NIT.EQ.200) WRITE(6,*)'MAX ITERATION AT TIME = ',TIME
200   CONTINUE
      RETURN
      END

C -------------------------------------------------------------------------------KDRAGG
      SUBROUTINE KDRAGG(DRAG,VREL)
      INCLUDE 'mfrek.com'
C
      DRCOE=0.44
      REYN=TH(IJ)*ROG(IJ)*DK(K)*VREL*PHI(K)/VISF
      IF(REYN.LT.0.001)REYN=0.001
      IF(REYN.LE.1000.0) DRCOE=(24.0/REYN)*(1.0+0.15*REYN**0.687)
      DRDVTH=DRCOE*VREL/TH(IJ)**2.65
      IF(DRDVTH.LE.1.0D30) THEN
      DRAG=0.75*RLK(K,IJ)*DRDVTH*ROG(IJ)*ARL(K)/(DK(K)*PHI(K))
      ELSE
      DRAG=1.0D30
      ENDIF
      RETURN
      END

C -------------------------------------------------------------------------------KDRAGS
      SUBROUTINE KDRAGS
      INCLUDE 'mfrek.com'
C
```

```
      DO 130 K=1,NPHASE
      DV=(VG(IJ)-VK(K,IJ)+VG(IJM)-VK(K,IJM))*0.5
      DU=(UG(IJ)-UK(K,IJ)+UG(IMJ)-UK(K,IMJ))*0.5
      VREL=(DU*DU+DV*DV)**0.5
      IF(TH(IJ).GE.0.8) THEN
      CALL KDRAGG(DRAG,VREL)
      ELSE
      DENOM=DK(K)*PHI(K)*TH(IJ)
      DRAG=(150.0*(1.0-TH(IJ))*VISF/DENOM+1.75*ROG(IJ)*VREL)
      1*RLK(K,IJ)/(RL(K)*DENOM)
      ENDIF
      RKPG(K,IJ)=DRAG*RL(K)/(RL(K)-ROG(IJ))
130   CONTINUE
      RETURN
      END

C ----------------------------------------------------------------------------------------MASFG
      SUBROUTINE MASFG
      INCLUDE 'mfrek.com'
C
      IF(UG(IMJ).GE.0.)THEN
      RGFR(IMJ)=UG(IMJ)*RGP(IJL)*RB(I-1)
      ELSE
      RGFR(IMJ)=UG(IMJ)*RGP(IJ)*RB(I-1)
      ENDIF
      IF(VG(IJM).GE.0.)THEN
      RGFT(IJM)=VG(IJM)*RGP(IJB)
      ELSE
      RGFT(IJM)=VG(IJM)*RGP(IJ)
      ENDIF
      ENTRY MASFGA
      IF(UG(IJ).GE.0.)THEN
      RGFR(IJ)=UG(IJ)*RGP(IJ)*RB(I)
      ELSE
      RGFR(IJ)=UG(IJ)*RGP(IJR)*RB(I)
      ENDIF
      IF(VG(IJ).GE.0.)THEN
      RGFT(IJ)=VG(IJ)*RGP(IJ)
      ELSE
      RGFT(IJ)=VG(IJ)*RGP(IJT)
      ENDIF
      RETURN
      END

C ----------------------------------------------------------------------------------------MASFK
```

```
      SUBROUTINE MASFK
      INCLUDE 'mfrek.com'
C
      DO 10 K=1,NPHASE
      IF(UK(K,IMJ).GE.0.)THEN
      RLFRK(K,IMJ)=UK(K,IMJ)*RLK(K,IJL)*RB(I-1)
      ELSE
      RLFRK(K,IMJ)=UK(K,IMJ)*RLK(K,IJ)*RB(I-1)
      ENDIF
      IF(VK(K,IJM).GE.0.)THEN
      RLFTK(K,IJM)=VK(K,IJM)*RLK(K,IJB)
      ELSE
      RLFTK(K,IJM)=VK(K,IJM)*RLK(K,IJ)
      ENDIF
10    CONTINUE
C
      ENTRY MASFKA
      DO 20 K=1,NPHASE
      IF(UK(K,IJ).GE.0.)THEN
      RLFRK(K,IJ)=UK(K,IJ)*RLK(K,IJ)*RB(I)
      ELSE
      RLFRK(K,IJ)=UK(K,IJ)*RLK(K,IJR)*RB(I)
      ENDIF
      IF(VK(K,IJ).GE.0.)THEN
      RLFTK(K,IJ)=VK(K,IJ)*RLK(K,IJ)
      ELSE
      RLFTK(K,IJ)=VK(K,IJ)*RLK(K,IJT)
      ENDIF
20    CONTINUE
      RETURN
      END
C ------------------------------------------------------------------------------MATS
      SUBROUTINE MATS
      INCLUDE 'mfrek.com'
      CALL RXN
      BU1(1)=RUG(IMJ)-DTODRP(I-1)*(P(IJ)-P(IJL))
      BV1(1)=RVG(IJM)-DTODZP(J-1)*(P(IJ)-P(IJB))
      AU1(1,1)=AR(I-1)*(APP(1,IJL)+RGP(IJL))
     1+BR(I-1)*(APP(1,IJ)+RGP(IJ))
      AV1(1,1)=AZ(J-1)*(APP(1,IJB)+RGP(IJB))
     1+BZ(J-1)*(APP(1,IJ)+RGP(IJ))
      AU1(1,1)=AU1(1,1)-DT*DOTM(1)
      AV1(1,1)=AV1(1,1)-DT*DOTM(1)
      DO 130 K=2,NPHS1
      KM1=K-1
```

```
      BU1(K)=RUK(KM1,IMJ)
      BV1(K)=RVK(KM1,IJM)
      DO 110 KK=1,KM1
      KS=K*KM1/2+KK
      AU1(K,KK)=AR(I-1)*APP(KS,IJL)+BR(I-1)*APP(KS,IJ)
      AU1(KK,K)=AU1(K,KK)
      AV1(K,KK)=AZ(J-1)*APP(KS,IJB)+BZ(J-1)*APP(KS,IJ)
      AV1(KK,K)=AV1(K,KK)
110   CONTINUE
      KS=K*(K+1)/2
      AU1(K,K)=AR(I-1)*(APP(KS,IJL)+RLK(KM1,IJL))
     1+BR(I-1)*(APP(KS,IJ)+RLK(KM1,IJ))
      AV1(K,K)=AZ(J-1)*(APP(KS,IJB)+RLK(KM1,IJB))
     1+BZ(J-1)*(APP(KS,IJ)+RLK(KM1,IJ))
      AU1(K,K)=AU1(K,K)-DT*DOTM(K)
      AV1(K,K)=AV1(K,K)-DT*DOTM(K)
130   CONTINUE
      ENTRY MATSA
      CALL RXN
      BU(1)=RUG(IJ)-DTODRP(I)*(P(IJR)-P(IJ))
      BV(1)=RVG(IJ)-DTODZP(J)*(P(IJT)-P(IJ))
      AU(1,1)=AR(I)*(APP(1,IJ)+RGP(IJ))+BR(I)*(APP(1,IJR)+RGP(IJR))
      AV(1,1)=AZ(J)*(APP(1,IJ)+RGP(IJ))+BZ(J)*(APP(1,IJT)+RGP(IJT))
      AU(1,1)=AU(1,1)-DT*DOTM(1)
      AV(1,1)=AV(1,1)-DT*DOTM(1)
      DO 230 K=2,NPHS1
      KM1=K-1
      BU(K)=RUK(KM1,IJ)
      BV(K)=RVK(KM1,IJ)
      DO 210 KK=1,KM1
      KS=K*KM1/2+KK
      AU(K,KK)=AR(I)*APP(KS,IJ)+BR(I)*APP(KS,IJR)
      AU(KK,K)=AU(K,KK)
      AV(K,KK)=AZ(J)*APP(KS,IJ)+BZ(J)*APP(KS,IJT)
      AV(KK,K)=AV(K,KK)
210   CONTINUE
      KS=K*(K+1)/2
      AU(K,K)=AR(I)*(APP(KS,IJ)+RLK(KM1,IJ))
     1+BR(I)*(APP(KS,IJR)+RLK(KM1,IJR))
      AV(K,K)=AZ(J)*(APP(KS,IJ)+RLK(KM1,IJ))
     1+BZ(J)*(APP(KS,IJT)+RLK(KM1,IJT))
      AU(K,K)=AU(K,K)-DT*DOTM(K)
      AV(K,K)=AV(K,K)-DT*DOTM(K)
230   CONTINUE
C
```

```
      RETURN
      END
C ----------------------------------------------------------------------------------------MULTI
      SUBROUTINE MULTI
      INCLUDE 'mfrek.com'
      KS=1
      DO 100 K=1,NPHASE
C     CALCULATE PARTICLE TO PARTICLE INTERACTION
      KS=KS+1
      APP(KS,IJ)=-RKPG(K,IJ)*DT
      DO 98 KK=1,K-1
      KS=KS+1
      DV=(VK(K,IJ)-VK(KK,IJ)+VK(K,IJM)-VK(KK,IJM))*0.5
      DU=(UK(K,IJ)-UK(KK,IJ)+UK(K,IMJ)-UK(KK,IMJ))*0.5
      VREL=(DU*DU+DV*DV)**0.5
98    APP(KS,IJ)=-RLK(K,IJ)*RLK(KK,IJ)*DKF(K,KK)*VREL
100   KS=KS+1
      DO 105 K=1,NPHS1
      SUM=0.0
      DO 101 KK=1,K-1
      KS=K*(K-1)/2+KK
101   SUM=SUM+APP(KS,IJ)
      DO 102 KK=K+1,NPHS1
      KS=KK*(KK-1)/2+K
102   SUM=SUM+APP(KS,IJ)
      KS=K*(K+1)/2
105   APP(KS,IJ)=-SUM
      RETURN
      END
C ----------------------------------------------------------------------------------------NEWP
      SUBROUTINE NEWP
      INCLUDE 'mfrek.com'
C
      IF(D1.NE.D3) THEN
      PA=(D1*P3-D3*P1)/(D1-D3)
      ELSE
      PA=0.5*(P2+P3)
      ENDIF
      IF(D2.NE.D3) THEN
      PB=(D2*P3-D3*P2)/(D2-D3)
      ELSE
      PB=0.5*(P1+P3)
      ENDIF
      IF(D1*D3.GT.0.) THEN
      IF(PA.LT.P2.OR.PA.GT.P3)PA=0.5*(P2+P3)
```

```
      ELSE
      IF(PB.LT.P3.OR.PB.GT.P1)PB=0.5*(P1+P3)
      ENDIF
      P(IJ)=0.5*(PA+PB)
      RETURN
      END
C ------------------------------------------------------------------------------PROD
      SUBROUTINE PROD
      INCLUDE 'mfrek.com'
      TMASSG=0.0
      TMASSS=0.0
      DO 10 J=1,JB2
      KI=0
      DO 9 JX=1,JXN
      AYM(JX,J)=0.0
9     AYMOL(JX,J)=0.0
      FLUX(J)=0.0

      DO 20 I=2,IB2-1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.3)GOTO 20

      CALL ROGY(IJ)
      WMO=0.0
      DO 7 JX=1,JXN
7     WMO=WMO+Y(1,JX,IJ)/WM(JX)
      DO 8 JX1=1,JXN
      AYM(JX1,J)=AYM(JX1,J)+TH(IJ)*ROG(IJ)*VG(IJ)
      1*Y(1,JX1,IJ)*DR(I)*THICK
      YMOL(JX1,IJ)=Y(1,JX1,IJ)/WM(JX1)/WMO
8     AYMOL(JX1,J)=AYMOL(JX1,J)+YMOL(JX1,IJ)
      KI=KI+1
      FLUX(J)=FLUX(J)+TH(IJ)*ROG(IJ)*VG(IJ)*DR(I)*THICK
      IF(J.EQ.1.OR.J.EQ.JB2)GOTO 20
      TMASSG=TMASSG+TH(IJ)*ROG(IJ)*DR(I)*DZ(J)*THICK
      TMASSS=TMASSS+RLK(1,IJ)*DR(I)*DZ(J)*THICK
20    CONTINUE
      DO 11 JX=1,JXN
      AYM(JX,J)=AYM(JX,J)/KI
11    AYMOL(JX,J)=AYMOL(JX,J)/KI
      WMO=0.0
      DO 12 JX=1,JXN
12    WMO=WMO+AYM(JX,J)/WM(JX)
      DO 13 JX=1,JXN
      IF(WMO.EQ.0.0)THEN
```

```
      AYMOL1(JX,J)=AYMOL(JX,J)
      ELSE
      AYMOL1(JX,J)=AYM(JX,J)/WM(JX)/WMO
      ENDIF
13    CONTINUE
10    CONTINUE

      AMIX(1)=TMASSG
      AMIX(2)=TMASSS
      AMIX(3)=FLUX(1)
      AMIX(4)=FLUX(JB2)
      DO 15 JX=1,JXN
15    AMIX(4+JX)=AYMOL(JX,JB2)
      DO 16 JX=1,JXN
16    AMIX(10+JX)=AYMOL1(JX,JB2)
      AMIX(17)=TIME
      RETURN
      END
C -------------------------------------------------------------------------------------PROG
      SUBROUTINE PROG
      INCLUDE 'mfrek.com'
C
      TDUMP1=TIME
      TPRI=TIME
C  SPECIAL APPLICATION
      VJET=4.012
C  END
1     CONTINUE
      CALL BDRY
C  SPECIAL APPLICATION
      CALL PROD
C  END
      TPDT=TIME+0.1*DT
      IF(TPDT.GE.TPRI) THEN
      TPRI=TPRI+TPR
      IF(TIME.GE.0.0)THEN
      WRITE(6,547)TIME
      DO 600 K=1,NPHASE
      IF(KIN(K).EQ.1)THEN
      WRITE(6,*)
      WRITE(6,*)'VISCOSITY',K
      WRITE(6,*)
      DO 323 IJ=IB2JB2,IB2,-IB2
323   WRITE(6,550)(VISCL(1,IL),IL=IJ-IB1,IJ)
      WRITE(6,*)
```

```
      WRITE(6,*)'P-SOLID',K
      WRITE(6,*)
      DO 322 IJ=IB2JB2,IB2,-IB2
322   WRITE(6,550)(PS(1,IL),IL=IJ-IB1,IJ)
      WRITE(6,*)
      WRITE(6,*)'GRANULAR TEMPERATURE',K
      WRITE(6,*)
      DO 324 IJ=IB2JB2,IB2,-IB2
324   WRITE(6,550)(TSK(1,IL),IL=IJ-IB1,IJ)
      ENDIF
600   CONTINUE
      WRITE(6,548)
      DO 325 IJ=IB2JB2,IB2,-IB2
325   WRITE(6,550)(P(IL),IL=IJ-IB1,IJ)
      DO 328 K=1,NPHASE
      WRITE(6,549)K
      DO 328 IJ=IB2JB2,IB2,-IB2
328   WRITE(6,550)(RLK(K,IL)*ARL(K),IL=IJ-IB1,IJ)
      WRITE(6,551)
      DO 331 IJ=IB2JB2,IB2,-IB2
331   WRITE(6,550)(TH(IL),IL=IJ-IB1,IJ)
      WRITE(6,552)
      DO 332 IJ=IB2JB2,IB2,-IB2
332   WRITE(6,550)(VG(IL),IL=IJ-IB1,IJ)
      WRITE(6,553)
      DO 333 IJ=IB2JB2,IB2,-IB2
333   WRITE(6,550)(UG(IL),IL=IJ-IB1,IJ)
      DO 337 K=1,NPHASE
      WRITE(6,556)K
      DO 336 IJ=IB2JB2,IB2,-IB2
336   WRITE(6,550)(VK(K,IL),IL=IJ-IB1,IJ)
      WRITE(6,557)K
      DO 337 IJ=IB2JB2,IB2,-IB2
337   WRITE(6,550)(UK(K,IL),IL=IJ-IB1,IJ)
      IF(IHEAT.EQ.1)THEN
      WRITE(6,554)
      DO 338 IJ=IB2JB2,IB2,-IB2
338   WRITE(6,550)(TG(IL),IL=IJ-IB1,IJ)
      DO 339 K=1,NPHASE
      WRITE(6,555)K
      DO 339 IJ=IB2JB2,IB2,-IB2
339   WRITE(6,550)(TL(K,IL),IL=IJ-IB1,IJ)
      ENDIF
C  SPECIAL APPLICATION
C  OUTPUT COMPOSITIONS (AIR PRODUCTS CASE) (OPTIONAL)
```

```
C       WRITE(6,*)'CO'
C       DO 335 IJ=IB2JB2,IB2,-IB2
C335    WRITE(6,550)(YMOL(1,IL),IL=IJ-IB1,IJ)
C       WRITE(6,*)'CO2'
C       DO 400 IJ=IB2JB2,IB2,-IB2
C400    WRITE(6,550)(YMOL(2,IL),IL=IJ-IB1,IJ)
C       WRITE(6,*)'H2'
C       DO 401 IJ=IB2JB2,IB2,-IB2
C401    WRITE(6,550)(YMOL(3,IL),IL=IJ-IB1,IJ)
C       WRITE(6,*)'N2'
C       DO 402 IJ=IB2JB2,IB2,-IB2
C402    WRITE(6,550)(YMOL(6,IL),IL=IJ-IB1,IJ)
C       WRITE(6,*)'CH3OH'
C       DO 403 IJ=IB2JB2,IB2,-IB2
C403    WRITE(6,550)(YMOL(5,IL),IL=IJ-IB1,IJ)
C       WRITE(6,*)'CH3OH IN LIQUID PHASE (KMOLE/M3)'
C       DO 404 IJ=IB2JB2,IB2,-IB2
C404    WRITE(6,550)(Y(3,5,IL)*1000.0*.70025/WM(5),IL=IJ-IB1,IJ)
C       WRITE(6,*)'H2O IN LIQUID PHASE'
C       DO 405 IJ=IB2JB2,IB2,-IB2
C405    WRITE(6,550)(Y(3,6,IL),IL=IJ-IB1,IJ)
C END
        ENDIF
        ENDIF
        IF(TPDT.GT.TSTOP.OR.TPDT.GT.TDUMP1) THEN
        CALL TAPEWR
        REWIND(9)
C SPECIAL APPLICATION
C GRADULLY INCREASE THE JET VELOCITIES
        IF(ITD.NE.2)THEN
        VJET=VJET+VJET
        IF(VJET.GE.80.24)VJET=80.24
        VG(3)=VJET
        VG(8)=VJET
        VG(13)=VJET
        ENDIF
        WRITE(6,100)AMIX(17),(AMIX(J),J=1,4),AMIX(17)
100     FORMAT(6(G11.5))
C END
        TDUMP1=TDUMP1+TDUMP
        ENDIF
        IF(TPDT.LT.TSTOP) THEN
        TIME=TIME+DT
        CALL TILDE
        CALL BETAS
```

```
      CALL ITER
      DO 11 KNN=1,NPHASE
      IF(KIN(KNN).EQ.1)CALL GRNVIS
11    CONTINUE
      CALL ICONV
      IF(IRXN.EQ.1)CALL COMPOS
      GOTO 1
      ENDIF
      RETURN
547   FORMAT(1X,//,1X,'@ TIME = ',G10.3)
548   FORMAT(1X,/,1X,'P',/)
549   FORMAT(1X,/,1X,'TH',I1,/)
550   FORMAT(6(1X,G11.4))
551   FORMAT(1X,/,1X,'THETA',/)
552   FORMAT(1X,/,1X,'VG',/)
553   FORMAT(1X,/,1X,'UG',/)
554   FORMAT(1X,/,1X,'TG',/)
555   FORMAT(1X,/,1X,'T',I1,/)
556   FORMAT(1X,/,1X,'V',I1,/)
557   FORMAT(1X,/,1X,'U',I1,/)
      END

C ------------------------------------------------------------------------------------QESOL
      SUBROUTINE QESOL(AP0,AP1,AP2,XSOL)
      IMPLICIT REAL*8(A-H,O-Z)
C
C  SOLVE QUADRATIC EQUATION
C
C  SCALING OF COEFFICIENTS
      AAP0=ABS(AP0)
      AAP1=ABS(AP1)
      AAP2=ABS(AP2)
      APMAX=AAP2
      IF(APMAX.LT.AAP1)APMAX=AAP1
      IF(APMAX.LT.AAP0)APMAX=AAP0
      AP0=AP0/APMAX
      AP1=AP1/APMAX
      AP2=AP2/APMAX
C
      ENTRY QESOL1(AP0,AP1,AP2,XSOL)
      IF(AP0.EQ.0.0)THEN
      IF(AP2.EQ.0.0)THEN
      XSOL=0.0
      ELSE
      XSOL=-AP1/AP2
```

```
      IF(XSOL.LT.0.0)XSOL=0.0
      ENDIF
      ELSE
      IF(AP1.EQ.0.0)THEN
      IF(AP2.EQ.0.0)THEN
      XSOL=0.0
      ELSE
      DISC=-AP0/AP2
      IF(DISC.LE.0.0)THEN
      XSOL=0.0
      ELSE
      XSOL=DISC**0.5
      ENDIF
      ENDIF
      ELSE
      IF(AP2.EQ.0.0)THEN
      XSOL=-AP0/AP1
      IF(XSOL.LT.0.0)XSOL=0.0
      ELSE
      GOTO 10
      ENDIF
      ENDIF
      ENDIF
      RETURN
C
      ENTRY QESOL2(AP0,AP1,AP2,XSOL)
10    CONTINUE
      SAP1=AP1*AP1
      DISC=SAP1-4.0*AP0*AP2
      IF(DISC.LT.-1.E-4*SAP1)THEN
      XSOL=0.0
      ELSE
      IF(DISC.LT.0.0)DISC=0.0
      IF(AP1.LT.0.0)THEN
      XSOL=(-AP1+DISC**0.5)/(2.0*AP2)
      ELSE
      XSOL=-2.0*AP0/(AP1+DISC**0.5)
      ENDIF
      ENDIF
      RETURN
      END

C ----------------------------------------------------------------------------------------QFLUX
      SUBROUTINE QFLUX
      INCLUDE 'mfrek.com'
```

```
      DO 5 K=1,LT
5     QFLOW(K)=0.0
      IF(IHEAT.EQ.0)RETURN
      QFL=QF(IJM)+QF(IMJ)+QF(IPJ)+QF(IJP)
      IF(TOB(IJM).NE.0.0)QFLOW(1)=(QFL-(COE(IJM)*(TG(IJ)-TOB(IJM))
      1/DZ(J)))*TH(IJ)
      IF(TOB(IMJ).NE.0.0)QFLOW(1)=(QFL-(COE(IMJ)*(TG(IJ)-TOB(IMJ))
      1/DR(I)))*TH(IJ)
      IF(TOB(IPJ).NE.0.0)QFLOW(1)=(QFL-(COE(IPJ)*(TG(IJ)-TOB(IPJ))
      1/DR(I)))*TH(IJ)
      IF(TOB(IJP).NE.0.0)QFLOW(1)=(QFL-(COE(IJP)*(TG(IJ)-TOB(IJP))
      1/DZ(J)))*TH(IJ)
      DO 10 K=2,LT
      IF(TOB(IJM).NE.0.0)QFLOW(K)=(QFL-(COE(IJM)*(TL(K-1,IJ)-TOB(IJM))
      1/DZ(J)))*RLK(K-1,IJ)*ARL(K-1)
      IF(TOB(IMJ).NE.0.0)QFLOW(K)=(QFL-(COE(IMJ)*(TL(K-1,IJ)-TOB(IMJ))
      1/DR(I)))*RLK(K-1,IJ)*ARL(K-1)
      IF(TOB(IPJ).NE.0.0)QFLOW(K)=(QFL-(COE(IPJ)*(TL(K-1,IJ)-TOB(IPJ))
      1/DR(I)))*RLK(K-1,IJ)*ARL(K-1)
      IF(TOB(IJP).NE.0.0)QFLOW(K)=(QFL-(COE(IJP)*(TL(K-1,IJ)-TOB(IJP))
      1/DZ(J)))*RLK(K-1,IJ)*ARL(K-1)
10    CONTINUE
20    RETURN
      END
C -------------------------------------------------------------------------------------------QRXN
      SUBROUTINE QRXN
C  CALCULATE THE HEAT GENERATION DUE TO REACTIONS
      INCLUDE 'mfrek.com'
      IF(IRXN.EQ.0)RETURN
      CALL RRATE
      DO 10 K=1,LT
      QGEN(K)=0.0
      DO 15 IX=1,IHO(K)
15    QGEN(K)=QGEN(K)+RHO(K,IX)*HHO(K,IX)
      IF(K.NE.1)THEN
      DO 20 IX=1,IHE(K)
20    QGEN(K)=QGEN(K)+RHE(K,IX)*HHE(K,IX)
      ENDIF
10    CONTINUE
      RETURN
      END

C -------------------------------------------------------------------------------------------RHEATS
      SUBROUTINE RHEATS
      INCLUDE 'mfrek.com'
```

```
C
C       INTERPASE HEAT TRANSFER COEFFICIENT
C
        DO 10 K=1,NPHASE
        SP=RLK(K,IJ)*(6./DK(K))*ARL(K)
        DV=(VG(IJ)-VK(K,IJ)+VG(IJM)-VK(K,IJM))*0.5
        DU=(UG(IJ)-UK(K,IJ)+UG(IMJ)-UK(K,IMJ))*0.5
        VREL=SQRT(DU*DU+DV*DV)
        REYN=DK(K)*VREL*ROG(IJ)/VISF
        PR=CG*VISF/AKG(IJ)
C   GUNN MODEL
        CRPR=PR**(1./3.)
        IF (TH(IJ) .GE. 0.8) THEN
        IF(REYN.LE.200.)THEN
        PNU=(2.+1.1*REYN**.6*CRPR)*SP
        ELSEIF(REYN.LE.2000.)THEN
        PNU=.123*(4.*REYN/DK(K))**.83*SP**.17
        ELSE
        PNU=.61*REYN**.67*SP
        ENDIF
        ELSE
        IF(REYN.LE.200.)THEN
        PNU=(2.+0.16*REYN**0.67)*SP
        ELSEIF(REYN.LE.1000.)THEN
        PNU=8.2*REYN**0.6*SP
        ELSE
        PNU=1.06*REYN**0.457*SP
        ENDIF
        ENDIF
        RHEAT(K,IJ)=PNU*AKG(IJ)/DK(K)
10      CONTINUE
        RETURN
        END
C ----------------------------------------------------------------------------------------ROGY
        SUBROUTINE ROGY(MIJ)
C  CALCULATE GAS DENSITY
        INCLUDE 'mfrek.com'
        IF(IRXN.EQ.1)THEN
        WMY=0.0
        DO 10 JX=1,JXN
10      WMY=WMY+Y(1,JX,MIJ)/WM(JX)
        WMY=1.0/WMY
        ELSE
        WMY=WMYGAS
        ENDIF
```

```
      ROG(MIJ)=P(MIJ)*WMY/(C17*TG(MIJ)+C18*P(MIJ))
      RETURN
      END
C
C
C ----------------------------------------------------------------------------RRATE
      SUBROUTINE RRATE
C  DEFINE THE RATE OF REACTIONS AND HEAT OF REACTIONS
      INCLUDE 'mfrek.com'
      IF(IRXN.EQ.0)RETURN
      DO 20 MK=1,LT
      DO 10 IX=1,IHO(MK)
10    RHO(MK,IX)=0.0
      DO 20 IX=1,IHE(MK)
20    RHE(MK,IX)=0.0
      TMO=0.0
      DO 30 JX=1,JXN
30    TMO=TMO+YN(1,JX,IJ)/WM(JX)
      PATM=P(IJ)*1D-6
      PH2=PATM*YN(1,3,IJ)/WM(3)/TMO
      PCO=PATM*YN(1,1,IJ)/WM(1)/TMO
      PME=PATM*YN(1,5,IJ)/WM(5)/TMO
      T=TG(IJ)
      IF(T.LE.430.)T=430.0
      IF(T.GE.630.)T=630.0
      IF(PH2.EQ.0.0.OR.PCO.EQ.0.0)THEN
      RHO(1,1)=0.0
      ELSE
      RK0=8.93D-8*RLK(1,IJ)

C TE CHANG'S KEQ MODEL CORRECTED BY THE DATA FROM DME REPORT
C     RKEQ=1420.8*EXP(21.225+9143.6/T-7.492*LOG(T)
C     1+4.076D-3 *T-7.161D-8*T*T)
      RKEQ=6.249/PATM**2
      RHO(1,1)=RK0*PCO**(1.0/3.0)*PH2**(2.0/3.0)
      1*(1-PME/PCO/PH2**2.0/RKEQ)
      DTO=RGPN(IJ)*TMO
      CCO=RGPN(IJ)*YN(1,1,IJ)/WM(1)
      CH2=RGPN(IJ)*YN(1,3,IJ)/WM(3)
      CME=RGPN(IJ)*YN(1,5,IJ)/WM(5)
C     CALL SOLUTION(RKEQ,DTO,CCO,CH2,CME,RHOX)
C      RHOX=RHOX/DT
      IF(RHO(1,1)*DT.GE.MIN(CCO,2*CH2))
      1RHO(1,1)=0.1*MIN(CCO,2*CH2)/DT
```

```
C       RHO(1,1)=1.98D7*EXP(-RT1)*(PH2**0.4)*(PCO**0.13)
C       1-2.15D10*EXP(-RT2)*(PME**0.13)
C       RHO(1,1)=RHO(1,1)*RLK(1,IJ)/3.6D6
C       CLM=YN(3,5,IJ)*0.70025/WM(5)
C       HME=1.49D6*EXP(-17235.0/8.314/TG(IJ))
C       CLGM=10.0*PME/HME
C       RHE(3,1)=1.2*(CLGM-CLM)*RLK(2,IJ)/0.70025
C       IF(RHE(3,1).LE.0.0)RHE(3,1)=0.0
C       IF(RHO(1,1).LE.0.0)RHO(1,1)=0.0

        ENDIF
        HHO(1,1)=-8.314D8*T*T*(-9143.6/T/T-7.492/T
        1+4.076D-3-7.161D-8*T*2)
        RETURN
        END
C ------------------------------------------------------------------------------------------RXN
        SUBROUTINE RXN
C  CALCULATE PHASE CHANGES
        INCLUDE 'mfrek.com'
        IF(IRXN.EQ.0)RETURN
        CALL RRATE
        DOTM(1)=0.0
        DO 10 K=2,LT
        DOTM(K)=0.0
        DO 20 JX=1,JXN
        DO 20 IX=1,IHE(K)
20      DOTM(K)=DOTM(K)+RHE(K,IX)*WM(JX)*AHE(K,IX,JX)
        DOTM(1)=DOTM(1)-DOTM(K)
10      CONTINUE
        RETURN
        END
C ------------------------------------------------------------------------------------------SETUP
        SUBROUTINE SETUP
        INCLUDE 'mfrek.com'
C
        WRITE(6,660)
        DO 1 I=1,IB1
        DRP(I)=0.5*(DR(I)+DR(I+1))
        RDR(I)=1.0/DR(I)
        RDRP(I)=2.0/(DR(I)+DR(I+1))
        AR(I)=0.5*DR(I+1)*RDRP(I)
1       BR(I)=1.0-AR(I)
        DRP(IB2)=DR(IB2)
        RDR(IB2)=1.0/DR(IB2)
        RDRP(IB2)=RDR(IB2)
```

```
      AR(IB2)=0.5
      BR(IB2)=0.5
      DO 2 J=1,JB1
      DZP(J)=0.5*(DZ(J)+DZ(J+1))
      RDZ(J)=1.0/DZ(J)
      RDZP(J)=2.0/(DZ(J)+DZ(J+1))
      AZ(J)=0.5*DZ(J+1)*RDZP(J)
2     BZ(J)=1.0-AZ(J)
      DZP(JB2)=DZ(JB2)
      RDZ(JB2)=1.0/DZ(JB2)
      RDZP(JB2)=RDZ(JB2)
      AZ(JB2)=0.5
      BZ(JB2)=0.5
      IF(ITC.EQ.0) GO TO 5
      RTC=RST-0.5*DR(1)
      RTB=RST
      R(1)=RTC**ITC
      RB(1)=RTB**ITC
      IF((RTC.LE.0.).AND.(ITC.EQ.2))R(1)=-R(1)
      IF (RB(1).LT.1.D-8) THEN
      RRB(1)=0.0
      ELSE
      RRB(1)=1.0/RB(1)
      ENDIF
      DO 3 I=2,IB2
      RTC=RTB+0.5*DR(I)
      RTB=RTB+DR(I)
      R(I)=RTC**ITC
      RB(I)=RTB**ITC
      RRB(I)=1./RB(I)
3     CONTINUE
      GOTO 10
5     CONTINUE
      DO 8 I=1,IB2
      R(I)=1.
      RB(I)=1.
      RRB(I)=1.
8     CONTINUE
10    CONTINUE
      DO 11 I=1,IB2
      RRIDR(I)=RDR(I)/R(I)
      RRIDRP(I)=RRB(I)*RDRP(I)
      DTODR(I)=DT*RDR(I)
      DTODRP(I)=DT*RDRP(I)
      DTORDR(I)=DT*RRIDR(I)
```

```
      DTOBDR(I)=DT*RRIDRP(I)
11    CONTINUE
      DO 12 J=1,JB2
      DTODZ(J)=DT*RDZ(J)
12    DTODZP(J)=DT*RDZP(J)
      DO 15 IJ2=IB2JB2,IB2,-IB2
      IJ1=IJ2-IB1
15    WRITE(6,650)(IFL(IKPR),IKPR=IJ1,IJ2)
C
      WRITE(6,660)
C   INITIALIZE  SOLID PRESSSURE AND COHESIVE STRENGTH
      DO 20 I=0,1000
      THX=I/1000.
      COHF(I)=10.**(-10.6*THX+5.5)
C     COHF(I)=0.0
C20   GTH(I)=10.**(-8.76*THX+8.49)
20    GTH(I)=10.**(-10.466*THX+8.577)
C   INITIALIZE 'INDS'
      DO 30 J=2,JB1
      DO 30 I=2,IB1
      IJ=I+(J-1)*IB2
      IPJ=IJ+1
      IJR=IPJ
      IJP=IJ+IB2
      IJT=IJP
      IMJ=IJ-1
      IJL=IMJ
      IJM=IJ-IB2
      IJB=IJM
      IPJP=IJP+1
      IJTR=IPJP
      IF((IFL(IPJ).EQ.2).OR.(IFL(IPJ).EQ.3)) IJR=IJ
      IF((IFL(IMJ).EQ.2).OR.(IFL(IMJ).EQ.3)) IJL=IJ
      IF((IFL(IJP).EQ.2).OR.(IFL(IJP).EQ.3)) IJT=IJ
      IF((IFL(IJM).EQ.2).OR.(IFL(IJM).EQ.3)) IJB=IJ
      IF(IJ .EQ. (IB2JB1-1))IJTR=IJ
      GOTO (29,21,21,29,29,29,29),IFL(IPJP)
21    GOTO (22,24,24,22,22,22,22),IFL(IJP)
22    GOTO (25,26,26,25,25,25,25),IFL(IPJ)
24    GOTO (28,25,25,28,28,28,28),IFL(IPJ)
25    IJTR=IJ
      GOTO 29
26    IJTR=IJP
      GOTO 29
28    IJTR=IPJ
```

```
29      CONTINUE
        INDS(IJ,1)=IJR
        INDS(IJ,2)=IJL
        INDS(IJ,3)=IJT
        INDS(IJ,4)=IJB
        INDS(IJ,5)=IJTR
30      CONTINUE
        DO 40 K=1,NPHASE
        DO 40 KK=1,K-1
40      DKF(K,KK)=FAC*DT*(DK(K)+DK(KK))**2/(RL(K)*
        1DK(K)**3+RL(KK)*DK(KK)**3)
        IF(ITD.NE.2)THEN
        DO 60 N=1,NO
        DO 60 J=IOB(3,N),IOB(4,N)
        JJ=(J-1)*IB2
        DO 60 I=IOB(1,N),IOB(2,N)
        IJ=I+JJ
        IF((IFL(IJ).EQ.2).OR.(IFL(IJ).EQ.3))GOTO 60
        P(IJ)=PIO(N)
        TG(IJ)=TEMIO(N)
        TH(IJ)=THIO(N)
        THN(IJ)=TH(IJ)
        UG(IJ)=UIO(N)
        VG(IJ)=VIO(N)
        DO 56 K=1,NPHASE
        IF(KIN(K).EQ.1)TSK(K,IJ)=TSKIO(K,N)
        TL(K,IJ)=TEMPIO(K,N)
        UK(K,IJ)=UPIO(K,N)
        VK(K,IJ)=VPIO(K,N)
        RLK(K,IJ)=RL(K)*THPIO(K,N)
56      RLKN(K,IJ)=RLK(K,IJ)
        DO 55 K=1,LT
        DO 55 JX=1,JXN
        YN(K,JX,IJ)=YIO(K,JX,N)
55      Y(K,JX,IJ)=YIO(K,JX,N)
        CALL ROGY(IJ)
        RGP(IJ)=ROG(IJ)*TH(IJ)
60      CONTINUE
        ENDIF
        DO 65 J=2,JB1
        DO 65 I=2,IB1
        IJ=I+(J-1)*IB2
        IF((IFL(IJ).EQ.2).OR.(IFL(IJ).EQ.3))GOTO 65
        CALL INDXA
C  INITIAL BED PRESSURE
```

```
      IF(ITD.NE.2)THEN
      IF(IPRE.NE.0)THEN
      IF(IJ.EQ.IJB)THEN
      IF(IJ.NE.IJL)THEN
      CALL ROGY(IJL)
      CC=ROG(IJL)
      RLXSUM=TH(IJL)*CC
      DO 61 K=1,NPHASE
61    RLXSUM=RLXSUM+RLK(K,IJL)
      P(IJ)=P(IJL)+GRAVX*DR(I)*RLXSUM
      ENDIF
      ELSE
      CALL ROGY(IJB)
      CC=ROG(IJB)
      RLXSUM=TH(IJB)*CC
      DO 62 K=1,NPHASE
62    RLXSUM=RLXSUM+RLK(K,IJB)
      P(IJ)=P(IJB)+GRAVY*DZ(J)*RLXSUM
      ENDIF
      ENDIF
      ENDIF
C
      CALL CNVERT
      CALL MASFGA
      CALL MASFKA
      THN(IJ)=TH(IJ)
      TG(IJ)=C1+SIEG(IJ)/CG
      IF(IHEAT.EQ.0)TG(IJ)=TEMIO(1)
      CALL ROGY(IJ)
      DO 63 K=1,NPHASE
      IF (RLK(K,IJ).EQ.0.0) THEN
      TL(K,IJ)=0.0
      ELSE
      TL(K,IJ)=C2+SIEL(K,IJ)/CL(K)
      ENDIF
      IF(IHEAT.EQ.0)TL(K,IJ)=TEMPIO(K,1)
      CALL THRCON
      TSKN(K,IJ)=TSK(K,IJ)
      IF(KIN(K).EQ.1)CALL GRPROP
63    RLKN(K,IJ)=RLK(K,IJ)
      CALL KDRAGS
      CALL MULTI
      CALL RHEATS
65    CONTINUE
650   FORMAT(1X,78I1)
```

```
C ----------------------------------------------------------------------------SIELF
      SUBROUTINE SIELF
      INCLUDE 'mfrek.com'
C
C     CALCULATES FLUXES OF SPECIFIC INTERNAL
C     ENERGY DENSITY OF THE LIQ.
C
      IF(UK(K,IJ).GE.0.)THEN
      ELFR(K)=RLK(K,IJ)*SIELN(K,IJ)*UK(K,IJ)*RB(I)
      ELSE
      ELFR(K)=RLK(K,IJR)*SIELN(K,IJR)*UK(K,IJ)*RB(I)
      ENDIF
      IF(VK(K,IJ).GE.0.)THEN
      ELFT(K)=RLK(K,IJ)*SIELN(K,IJ)*VK(K,IJ)
      ELSE
      ELFT(K)=RLK(K,IJT)*SIELN(K,IJT)*VK(K,IJ)
      ENDIF
      IF(IFL(IMJ).NE.1)GOTO 1
      IF(IFL(IJM).NE.1)GOTO 2
      CALL HEATLB
      GOTO 4
1     IF(UK(K,IMJ).GE.0.)THEN
      ELFL(K)=RLK(K,IJL)*SIELN(K,IJL)*UK(K,IMJ)*RB(I-1)
      ELSE
      ELFL(K)=RLK(K,IJ)*SIELN(K,IJ)*UK(K,IMJ)*RB(I-1)
      ENDIF
      IF(IFL(IJM).NE.1)GOTO 2
      CALL HEATLA
      GOTO 3
2     IF(VK(K,IJM).GE.0.)THEN
      ELFB(K,I)=RLK(K,IJB)*SIELN(K,IJB)*VK(K,IJM)
      ELSE
      ELFB(K,I)=RLK(K,IJ)*SIELN(K,IJ)*VK(K,IJM)
      ENDIF
      CALL HEATCL
      ELFB(K,I)=ELFB(K,I)-HFLB(K,I)
      IF(IFL(IMJ).EQ.1)GOTO 4
3     ELFL(K)=ELFL(K)-HFLL(K)
4     ELFT(K)=ELFT(K)-HFLT(K)
      ELFR(K)=ELFR(K)-HFLR(K)
      RETURN
      END
C ----------------------------------------------------------------------------SOLUTION
C NOT IN USE
      SUBROUTINE SOLUTION(DK,DTO,C1,C2,C3,X)
```

```
      A=C1
      IF(C1.GE.2*C2)A=C2/2.0
      B=-C3
C     UNDERFLOW
      COEM=1.0/(C3+A)
      FA=COEM*DK*(C1-A)*(C2-2*A)*(C2-2*A)-
      1COEM*(C3+A)*(DTO-2*A)*(DTO-2*A)
      FB=COEM*DK*(C1-B)*(C2-2*B)*(C2-2*B)-
      1COEM*(C3+B)*(DTO-2*B)*(DTO-2*B)
1     X=(A+B)/2.0
      FX=COEM*DK*(C1-X)*(C2-2*X)*(C2-2*X)-
      1COEM*(C3+X)*(DTO-2*X)*(DTO-2*X)
      IF(ABS(FX/COEM).LE.1D-20)GOTO 10
      IF(FX.LT.0.0)THEN
      A=X
      ELSE
      B=X
      ENDIF
      GOTO 1
10    RETURN
      END
C -------------------------------------------------------------------------------------TAPERD
      SUBROUTINE TAPERD
      INCLUDE 'mfrek.com'
C
      READ(9)TIME,TTIM
      READ(9) (P(IJ),TH(IJ),UG(IJ),VG(IJ),TG(IJ),IJ=1,IB2JB2)
      READ(9)((RLK(K,IJ),UK(K,IJ),VK(K,IJ),TL(K,IJ),
      1TSK(K,IJ),TSKN(K,IJ),K=1,NPHASE),IJ=1,IB2JB2)
      READ(9)(((Y(K,JX,IJ),K=1,LT),JX=1,JXN),IJ=1,IB2JB2)
      READ(9)(((YN(K,JX,IJ),K=1,LT),JX=1,JXN),IJ=1,IB2JB2)
      RETURN
      END
C -------------------------------------------------------------------------------------TAPEWR
      SUBROUTINE TAPEWR
      INCLUDE 'mfrek.com'
      REWIND(9)
C
      WRITE(9)TIME,TTIM
      WRITE(9) (P(IJ),TH(IJ),UG(IJ),VG(IJ),TG(IJ),IJ=1,IB2JB2)
      WRITE(9)((RLK(K,IJ),UK(K,IJ),VK(K,IJ),TL(K,IJ),
      1TSK(K,IJ),TSKN(K,IJ),K=1,NPHASE),IJ=1,IB2JB2)
      WRITE(9)(((Y(K,JX,IJ),K=1,LT),JX=1,JXN),IJ=1,IB2JB2)
      WRITE(9)(((YN(K,JX,IJ),K=1,LT),JX=1,JXN),IJ=1,IB2JB2)
C     WRITE(6,*)'TIME=',TIME
```

```
      RETURN
      END
C ----------------------------------------------------------------------------THRCON
      SUBROUTINE THRCON
      INCLUDE 'mfrek.com'
      PARAMETER (PIC=7.26D-3,RKP=0.3289,RKG=0.0269)
      PARAMETER (APIC=1.-PIC,RF=RKP/RKG)
C
C DAMKOHLER'S EQUIVALENT THERMAL CONDUCTIVITY
C
      IF(TH(IJ).LT.0.99) THEN
      BB=1.25*((1.0-TH(IJ))/TH(IJ))**(10./9.)
      CC=1.0-BB/RF
      RKO=(2./CC)*(BB*(RF-1.)/(CC*CC*RF)*DLOG(RF/BB)-(BB-1.)/CC
      1-(BB+1.)/2.)
      A3=SQRT(1.0-TH(IJ))
      AKL(K,IJ)=(1.-A3)+A3*(PIC*RF+APIC*RKO)*AKG(IJ)
      ELSEIF (TH(IJ).EQ.1.0) THEN
      AKL(K,IJ)=0.0
      ELSE
      AKL(K,IJ)=AKG(IJ)
      ENDIF
      RETURN
      END
C ----------------------------------------------------------------------------TILDE
      SUBROUTINE TILDE
      INCLUDE 'mfrek.com'
C
      DO 10 J=2,JB1
      DO 10 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).NE.1) GOTO 10
      CALL INDX
      CALL UGMOMF
      IGKU=(AR(I)*TH(IJ)+BR(I)*TH(IJR))*1000
      IGKV=(AZ(J)*TH(IJ)+BZ(J)*TH(IJT))*1000
      IGJ=TH(IJ)*1000
      IGT=TH(IJT)*1000
      IGR=TH(IJR)*1000
      RUG(IJ)=(AR(I)*RGP(IJ)+BR(I)*RGP(IJR))*(UG(IJ)+GRAVX*DT)
      1-DTOBDR(I)*(UGFR-UGFL)-DTODZ(J)*(UGFT-UGFB(I))-DT*SUGC*ITC
      UGFL=UGFR
      UGFB(I)=UGFT
      CALL VGMOMF
      RVG(IJ)=(AZ(J)*RGP(IJ)+BZ(J)*RGP(IJT))*(VG(IJ)+GRAVY*DT)
```

```
      DO 20 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).NE.1) GOTO 20
      CALL INDXA
      CALL MATSA
      CALL VELSK2
      CALL MASFGA
      CALL MASFKA
20    CONTINUE
      RETURN
      END
C ------------------------------------------------------------------------------UGMOMF
      SUBROUTINE UGMOMF
      INCLUDE 'mfrek.com'
C
      CS=0.5*(UG(IJ)+UG(IPJ))
      IF (CS.GE.0.) THEN
      UGFR=(AR(I)*RGP(IJ)+BR(I)*RGP(IJR))*UG(IJ)*CS*R(I+1)
      ELSE
      UGFR=(AR(I+1)*RGP(IJR)+BR(I+1)*RGP(IJRR))*UG(IPJ)*CS*R(I+1)
      ENDIF
      CS=AR(I)*VG(IJ)+BR(I)*VG(IPJ)
      IF (CS.GE.0.) THEN
      UGFT=(AR(I)*RGP(IJ)+BR(I)*RGP(IJR))*UG(IJ)*CS
      ELSE
      UGFT=(AR(I)*RGP(IJT)+BR(I)*RGP(IJTR))*UG(IJP)*CS
      ENDIF
      IF(IFL(IMJ).NE.1) GOTO 1
      IF(IFL(IJM).NE.1) GOTO 2
      CALL UGVSB
      GOTO 4
1     CS=0.5*(UG(IJ)+UG(IMJ))
      IF (CS.GE.0.) THEN
      UGFL=(BR(I-1)*RGP(IJ)+AR(I-1)*RGP(IJL))*UG(IMJ)*CS*R(I)
      ELSE
      UGFL=(AR(I)*RGP(IJ)+BR(I)*RGP(IJR))*UG(IJ)*CS*R(I)
      ENDIF
      IF(IFL(IJM).NE.1) GOTO 2
      CALL UGVSA
      GOTO 3
2     CS=(AR(I)*VG(IJM)+BR(I)*VG(IPJM))
      IF (CS.GE.0.) THEN
      UGFB(I)=(AR(I)*RGP(IJB)+BR(I)*RGP(IJBR))*UG(IJM)*CS
      ELSE
      UGFB(I)=(AR(I)*RGP(IJ)+BR(I)*RGP(IJR))*UG(IJ)*CS
```

```
      ENDIF
      CALL UGVS
      UGFB(I)=UGFB(I)-SUGB
      IF(IFL(IMJ).EQ.1)GOTO 4
3     UGFL=UGFL-SUGL
4     UGFT=UGFT-SUGT
      UGFR=UGFR-SUGR
      RETURN
      END
C ------------------------------------------------------------------------------UGVS
      SUBROUTINE UGVS
      INCLUDE 'mfrek.com'
C
      SUGB=VISF*((VG(IPJM)-VG(IJM))*RDRP(I)+(UG(IJ)-UG(IJM))
     1*RDZP(J-1))*
     1(BZ(J-1)*(AR(I)*TH(IJ)+BR(I)*TH(IJR))
     1+AZ(J-1)*(AR(I)*TH(IJB)+BR(I)*TH(IJBR)))
C
      ENTRY UGVSA
      SUGL=VISF*(2.*(UG(IJ)-UG(IMJ))*RDR(I)-(2./3.)
     1*(RRIDR(I)*(RB(I)*
     1UG(IJ)-RB(I-1)*UG(IMJ))+(VG(IJ)-VG(IJM))
     1*RDZ(J)))*TH(IJ)*R(I)
C
      ENTRY UGVSB
      SUGT=VISF*((VG(IPJ)-VG(IJ))*RDRP(I)+(UG(IJP)-
     1UG(IJ))*RDZP(J))*
     1(AZ(J)*(AR(I)*TH(IJ)+BR(I)*TH(IJR))
     1+BZ(J)*(AR(I)*TH(IJT)+BR(I)*TH(IJTR)))
      SUGR=VISF*(2.*(UG(IPJ)-UG(IJ))*RDR(I+1)-(2./3.)*(RRIDR(I+1)
     1*(RB(I+1)*
     1UG(IPJ)-RB(I)*UG(IJ))+(VG(IPJ)-VG(IPJM))*RDZ(J)))
     1*TH(IJR)*R(I+1)
      SUGC=VISF*(2.*RRB(I)*UG(IJ)-(2./3.)*(0.5*RRIDRP(I)*
     1(RB(I+1)*UG(IPJ)-RB(I-1)*UG(IMJ))+
     1(AR(I)*(VG(IJ)-VG(IJM))
     1+BR(I)*(VG(IPJ)-VG(IPJM)))*RDZ(J)))*RRB(I)
     1*(AR(I)*TH(IJ)+BR(I)*TH(IJR))
      RETURN
      END
C ------------------------------------------------------------------------------ULMOMF
      SUBROUTINE ULMOMF
      INCLUDE 'mfrek.com'
C
      CS=0.5*(UK(K,IJ)+UK(K,IPJ))
```

```
      IF (CS.GE.0.) THEN
      ULFR(K)=(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
      1*UK(K,IJ)*CS*R(I+1)
      ELSE
      ULFR(K)=(AR(I+1)*RLK(K,IJR)+BR(I+1)*RLK(K,IJRR))
      1*UK(K,IPJ)*CS*R(I+1)
      ENDIF
      CS=AR(I)*VK(K,IJ)+BR(I)*VK(K,IPJ)
      IF (CS.GE.0.) THEN
      ULFT(K)=(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))*UK(K,IJ)*CS
      ELSE
      ULFT(K)=(AR(I)*RLK(K,IJT)+BR(I)*RLK(K,IJTR))*UK(K,IJP)*CS
      ENDIF
      IF(IFL(IMJ).NE.1) GOTO 1
      IF(IFL(IJM).NE.1) GOTO 2
      CALL ULVSB
      GOTO 4
1     CS=0.5*(UK(K,IJ)+UK(K,IMJ))
      IF (CS.GE.0.) THEN
      ULFL(K)=(BR(I-1)*RLK(K,IJ)+AR(I-1)*RLK(K,IJL))
      1*UK(K,IMJ)*CS*R(I)
      ELSE
      ULFL(K)=(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))*UK(K,IJ)*CS*R(I)
      ENDIF
      IF(IFL(IJM).NE.1)GOTO2
      CALL ULVSA
      GOTO 3
2     CS=AR(I)*VK(K,IJM)+BR(I)*VK(K,IPJM)
      IF (CS.GE.0.) THEN
      ULFB(K,I)=(AR(I)*RLK(K,IJB)+BR(I)*RLK(K,IJBR))*UK(K,IJM)*CS
      ELSE
      ULFB(K,I)=(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))*UK(K,IJ)*CS
      ENDIF
      CALL ULVS
      ULFB(K,I)=ULFB(K,I)-SULB(K)
      IF(IFL(IMJ).EQ.1)GOTO 4
3     ULFL(K)=ULFL(K)-SULL(K)
4     ULFT(K)=ULFT(K)-SULT(K)
      ULFR(K)=ULFR(K)-SULR(K)
      RETURN
      END
C -------------------------------------------------------------------------------------ULVS
      SUBROUTINE ULVS
      INCLUDE 'mfrek.com'
C
```

C USE GAUSS-DOLITTLE METHOD FOR SYMMETRIC MATRIX INVERSION

```
      SULB(K)=((VK(K,IPJM)-VK(K,IJM))*RDRP(I)+(UK(K,IJ)-UK(K,IJM))
     1*RDZP(J-1))*((BZ(J-1)*(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1+AZ(J-1)*(AR(I)*RLK(K,IJB)+BR(I)*RLK(K,IJBR)))
     1*ARL(K)*(VISSD(K)))
C
      ENTRY ULVSA
      SULL(K)=2.*(UK(K,IJ)-UK(K,IMJ))*RDR(I)*R(I)*RLK(K,IJ)*ARL(K)
     1*VISSD(K)+(RRIDR(I)*(RB(I)
     1*UK(K,IJ)-RB(I-1)*UK(K,IMJ))+(VK(K,IJ)-VK(K,IJM))
     1*RDZ(J))*R(I)
     1*(VISBL(K,IJ)-RLK(K,IJ)*ARL(K)*(2./3.)*VISSD(K))
C
      ENTRY ULVSB
      SULT(K)=((VK(K,IPJ)-VK(K,IJ))*RDRP(I)+(UK(K,IJP)-UK(K,IJ))
     1*RDZP(J))
     1*((AZ(J)*(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1+BZ(J)*(AR(I)*RLK(K,IJT)+BR(I)*RLK(K,IJTR)))*ARL(K)*(
     1VISSD(K)))
      SULR(K)=2.*(UK(K,IPJ)-UK(K,IJ))*RDR(I+1)*R(I+1)*
     1*RLK(K,IJR)*ARL(K)*(VISSD(K))+((RRIDR(I+1)
     1*(RB(I+1)*UK(K,IPJ)-RB(I)*UK(K,IJ))+(VK(K,IPJ)-VK(K,IPJM))
     1*RDZ(J)))*R(I+1)*(VISBL(K,IJR)-(2./3.)*RLK(K,IJR)*ARL(K)
     1*(VISSD(K)))
      SULC(K)=(2.*RRB(I)*UK(K,IJ)*(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1*ARL(K)*(VISSD(K)))+((0.5*RRIDRP(I)
     1*(RB(I+1)*UK(K,IPJ)-RB(I-1)*UK(K,IMJ))
     1+(AR(I)*(VK(K,IJ)-VK(K,IJM))
     1+BR(I)*(VK(K,IPJ)-VK(K,IPJM)))*RDZ(J)))*RRB(I)*
     1(VISBL(K,IJ)-(2./3.)*(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1*ARL(K)*(VISSD(K)))
      RETURN
      END
C ------------------------------------------------------------------------------VELINV
      SUBROUTINE VELINV(NH,NP,A,B)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(NP,NP),B(NP)
C
C    USE GAUSS-DOLITTLE METHOD FOR SYMMETRIC MATRIX INVERSION
      DO 136 K=2,NP
      IF(ABS(A(K,K)).GE.1.D-6)GOTO 136
      DO 135 KK=1,NP
      A(K,KK)=0.0
135   A(KK,K)=0.0
      B(K)=0.0
136   CONTINUE
```

```
C
      DO 160 K=1,NP
      IF(A(K,K).EQ.0.0)GOTO 160
      KP1=K+1
      DIV=1./A(K,K)
      DO 140 KJ=KP1,NP
      A(K,KJ)=A(K,KJ)*DIV
140   CONTINUE
      B(K)=B(K)*DIV
      DO 150 KI=KP1,NP
      AMUL=A(KI,K)
      DO 145 KJ=KP1,NP
145   A(KI,KJ)=A(KI,KJ)-AMUL*A(K,KJ)
150   B(KI)=B(KI)-AMUL*B(K)
160   CONTINUE
      DO 170 K=NH,1,-1
      KP1=K+1
      DO 170 KI=KP1,NP
170   B(K)=B(K)-B(KI)*A(K,KI)
      RETURN
      END
C -------------------------------------------------------------------------------------VELSK
      SUBROUTINE VELSK
      INCLUDE 'mfrek.com'
C
      IFLL=IFL(IMJ)
      IF((IFLL.EQ.2).OR.(IFLL.EQ.3).OR.(IFLL.EQ.5))GOTO 200
      CALL VELINV(NPHASE,NPHS1,AU1,BU1)
      UG(IMJ)=BU1(1)
      DO 165 K=2,NPHS1
165   UK(K-1,IMJ)=BU1(K)
200   CONTINUE
      IFLB=IFL(IJM)
      IF((IFLB.EQ.2).OR.(IFLB.EQ.3).OR.(IFLB.EQ.5))GOTO 300
C
      CALL VELINV(NPHASE,NPHS1,AV1,BV1)
      VG(IJM)=BV1(1)
      DO 265 K=2,NPHS1
265   VK(K-1,IJM)=BV1(K)
C
      ENTRY VELSK2
300   CONTINUE
      IFLR=IFL(IPJ)
      IF((IFLR.EQ.2).OR.(IFLR.EQ.3).OR.(IFLR.EQ.5))GOTO 400
      CALL VELINV(NPHASE,NPHS1,AU,BU)
```

```
      UG(IJ)=BU(1)
      DO 365 K=2,NPHS1
365   UK(K-1,IJ)=BU(K)
400   CONTINUE
      IFLT=IFL(IJP)
      IF((IFLT.EQ.2).OR.(IFLT.EQ.3).OR.(IFLT.EQ.5))RETURN
      CALL VELINV(NPHASE,NPHS1,AV,BV)
      VG(IJ)=BV(1)
      DO 465 K=2,NPHS1
465   VK(K-1,IJ)=BV(K)
      RETURN
      END
C -------------------------------------------------------------------------------VGMOMF
      SUBROUTINE VGMOMF
      INCLUDE 'mfrek.com'
C
      CS=0.5*(VG(IJ)+VG(IJP))
      IF (CS.GE.0.) THEN
      VGFT=(AZ(J)*RGP(IJ)+BZ(J)*RGP(IJT))*VG(IJ)*CS
      ELSE
      VGFT=(AZ(J+1)*RGP(IJT)+BZ(J+1)*RGP(IJTT))*VG(IJP)*CS
      ENDIF
      CS=AZ(J)*UG(IJ)+BZ(J)*UG(IJP)
      IF (CS.GE.0.) THEN
      VGFR=(AZ(J)*RGP(IJ)+BZ(J)*RGP(IJT))*VG(IJ)*CS*RB(I)
      ELSE
      VGFR=(AZ(J)*RGP(IJR)+BZ(J)*RGP(IJTR))*VG(IPJ)*CS*RB(I)
      ENDIF
      IF(IFL(IMJ).NE.1) GOTO 1
      IF(IFL(IJM).NE.1) GOTO 2
      CALL VGVSB
      GOTO 4
1     CS=AZ(J)*UG(IMJ)+BZ(J)*UG(IMJP)
      IF (CS.GE.0.) THEN
      VGFL=(AZ(J)*RGP(IJL)+BZ(J)*RGP(IJTL))*VG(IMJ)*CS*RB(I-1)
      ELSE
      VGFL=(AZ(J)*RGP(IJ)+BZ(J)*RGP(IJT))*VG(IJ)*CS*RB(I-1)
      ENDIF
      IF(IFL(IJM).NE.1)GOTO2
      CALL VGVSA
      GOTO 3
2     CS=0.5*(VG(IJM)+VG(IJ))
      IF (CS.GE.0.) THEN
      VGFB(I)=(BZ(J-1)*RGP(IJ)+AZ(J-1)*RGP(IJB))*VG(IJM)*CS
      ELSE
```

```
      VGFB(I)=(AZ(J)*RGP(IJ)+BZ(J)*RGP(IJT))*VG(IJ)*CS
      ENDIF
      CALL VGVS
      VGFB(I)=VGFB(I)-SVGB
      IF(IFL(IMJ).EQ.1)GOTO 4
3     VGFL=VGFL-SVGL
4     VGFT=VGFT-SVGT
      VGFR=VGFR-SVGR
      RETURN
      END
C -------------------------------------------------------------------------------VGVS
      SUBROUTINE VGVS
      INCLUDE 'mfrek.com'
C
      SVGB=VISF*(2./3.)*(2.*(VG(IJ)-VG(IJM))*RDZ(J)
     1-RRIDR(I)*(RB(I)*
     1UG(IJ)-RB(I-1)*UG(IMJ)))*TH(IJ)
C
      ENTRY VGVSA
      SVGL=VISF*((VG(IJ)-VG(IMJ))*RDRP(I-1)+(UG(IMJP)-UG(IMJ))
     1*RDZP(J))*
     1RB(I-1)*(AZ(J)*(BR(I-1)*TH(IJ)+AR(I-1)*TH(IJL))
     1+BZ(J)*(BR(I-1)*TH(IJT)+AR(I-1)*TH(IJTL)))
C
      ENTRY VGVSB
      SVGT=VISF*(2./3.)*(2.*(VG(IJP)-VG(IJ))*RDZ(J+1)-RRIDR(I)
     1*(RB(I)*
     1UG(IJP)-RB(I-1)*UG(IMJP)))*TH(IJT)
      SVGR=VISF*((VG(IPJ)-VG(IJ))*RDRP(I)+(UG(IJP)-UG(IJ))
     1*RDZP(J))*
     1RB(I)*(AZ(J)*(AR(I)*TH(IJ)+BR(I)*TH(IJR))
     1+BZ(J)*(AR(I)*TH(IJT)+BR(I)*TH(IJTR)))
      RETURN
      END
C -------------------------------------------------------------------------------VLMOMF
      SUBROUTINE VLMOMF
      INCLUDE 'mfrek.com'
C
      CS=0.5*(VK(K,IJ)+VK(K,IJP))
      IF (CS.GE.0.) THEN
      VLFT(K)=(AZ(J)*RLK(K,IJ)+BZ(J)*RLK(K,IJT))*VK(K,IJ)*CS
      ELSE
      VLFT(K)=(AZ(J+1)*RLK(K,IJT)+BZ(J+1)*RLK(K,IJTT))
     1*VK(K,IJP)*CS
      ENDIF
```

```
      CS=AZ(J)*UK(K,IJ)+BZ(J)*UK(K,IJP)
      IF (CS.GE.0.) THEN
      VLFR(K)=(AZ(J)*RLK(K,IJ)+BZ(J)*RLK(K,IJT))*VK(K,IJ)*CS*RB(I)
      ELSE
      VLFR(K)=(AZ(J)*RLK(K,IJR)+BZ(J)*RLK(K,IJTR))
     1*VK(K,IPJ)*CS*RB(I)
      ENDIF
      IF(IFL(IMJ).NE.1) GOTO 1
      IF(IFL(IJM).NE.1) GOTO 2
      CALL VLVSB
      GOTO 4
1     CS=AZ(J)*UK(K,IMJ)+BZ(J)*UK(K,IMJP)
      IF (CS.GE.0.) THEN
      VLFL(K)=(AZ(J)*RLK(K,IJL)+BZ(J)*RLK(K,IJTL))
     1*VK(K,IMJ)*CS*RB(I-1)
      ELSE
      VLFL(K)=(AZ(J)*RLK(K,IJ)+BZ(J)*RLK(K,IJT))
     1*VK(K,IJ)*CS*RB(I-1)
      ENDIF
      IF(IFL(IJM).NE.1)GOTO2
      CALL VLVSA
      GOTO 3
2     CS=0.5*(VK(K,IJM)+VK(K,IJ))
      IF (CS.GE.0.) THEN
      VLFB(K,I)=(BZ(J-1)*RLK(K,IJ)+AZ(J-1)*RLK(K,IJB))
     1*VK(K,IJM)*CS
      ELSE
      VLFB(K,I)=(AZ(J)*RLK(K,IJ)+BZ(J)*RLK(K,IJT))*VK(K,IJ)*CS
      ENDIF
      CALL VLVS
      VLFB(K,I)=VLFB(K,I)-SVLB(K)
      IF(IFL(IMJ).EQ.1)GOTO 4
3     VLFL(K)=VLFL(K)-SVLL(K)
4     VLFT(K)=VLFT(K)-SVLT(K)
      VLFR(K)=VLFR(K)-SVLR(K)
      RETURN
      END
C -------------------------------------------------------------------------------------VLVS
      SUBROUTINE VLVS
      INCLUDE 'mfrek.com'
C
      SVLB(K)=(2./3.)*(2.*(VK(K,IJ)-VK(K,IJM))*RDZ(J)-RRIDR(I)
     1*(RB(I)*UK(K,IJ)-RB(I-1)*UK(K,IMJ)))
     1*(RLK(K,IJ)*ARL(K)*(VISSD(K)))
     1+VISBL(K,IJ)*RRIDR(I)*(RB(I)*UK(K,IJ)-RB(I-1)*UK(K,IMJ))
```

```
C
      ENTRY VLVSA
      SVLL(K)=((VK(K,IJ)-VK(K,IMJ))*RDRP(I-1)
     1+(UK(K,IMJP)-UK(K,IMJ))
     1*RDZP(J))*RB(I-1)*((AZ(J)*(BR(I-1)*RLK(K,IJ)+AR(I-1)
     1*RLK(K,IJL))
     1+BZ(J)*(BR(I-1)*RLK(K,IJT)+AR(I-1)*RLK(K,IJTL)))
     1*ARL(K)*(VISSD(K)))
      ENTRY VLVSB
      SVLT(K)=(2./3.)*(2.*(VK(K,IJP)-VK(K,IJ))*RDZ(J+1)-RRIDR(I)
     1*(RB(I)*UK(K,IJP)-RB(I-1)*UK(K,IMJP)))
     1*(RLK(K,IJT)*ARL(K)*(VISSD(K)))
     1+VISBL(K,IJT)*RRIDR(I)*(RB(I)*UK(K,IJP)-RB(I-1)*UK(K,IMJP))
      SVLR(K)=((VK(K,IPJ)-VK(K,IJ))*RDRP(I)+(UK(K,IJP)-UK(K,IJ))
     1*RDZP(J))*RB(I)*((AZ(J)*(AR(I)*RLK(K,IJ)+BR(I)*RLK(K,IJR))
     1+BZ(J)*(AR(I)*RLK(K,IJT)+BR(I)*RLK(K,IJTR)))
     1*ARL(K)*(VISSD(K)))
      RETURN
      END
C ------------------------------------------------------------------------------VWORKL
      SUBROUTINE VWORKL
      INCLUDE 'mfrek.com'
C
C  CALCULATE VISCOUS STRESSES FOR THE WORK TERM IN THE PHASES
C  ENERGY EQUATION (NOTE: VISCOSITY IS MULTIPLIED LATER)
C
      DO 100 J=2,JB1
      DO 100 I=2,IB1
      IJ=I+(J-1)*IB2
      IF(IFL(IJ).EQ.1)THEN
      CALL INDX
C     CALL OBSTACLE
      DO 10 K=1,NPHASE
      IF(KIN(K).NE.1)GOTO 10
      IF(IFL(IPJM).EQ.3)VK(K,IPJM)=0.0
      IF(IFL(IMJM).EQ.3)VK(K,IMJM)=0.0
      IF(IFL(IMJP).EQ.3)UK(K,IMJP)=0.0
      IF(IFL(IMJM).EQ.3)UK(K,IMJM)=0.0
      CS1=0.5*((VK(K,IPJ)+VK(K,IPJM)-VK(K,IMJ)-VK(K,IMJM))
     1/(DRP(I)+DRP(I-1))+(RB(I)*(UK(K,IJP)-UK(K,IJM))
     1+RB(I-1)*(UK(K,IMJP)-UK(K,IMJM)))
     1/(R(I)*(DZP(J)+DZP(J-1))))
      CS2=RDZ(J)*(VK(K,IJ)-VK(K,IJM))
      CS3=RDR(I)*(UK(K,IJ)-UK(K,IMJ))
      CS4=0.5*(RB(I)*UK(K,IJ)+RB(I-1)*UK(K,IMJ))/(R(I)*R(I))
```

```
C
      SILM(K,IJ)=RRIDR(I)*(RB(I)*UK(K,IJ)
      1-RB(I-1)*UK(K,IMJ))+CS2
      SILRZ=CS1
      SILZZ=2.0*CS2
      SILRR=2.0*CS3
      SILPP=2.0*CS4
C
C  CALCULATE VISCOUS WORK FOR THE PHASES
      VWLS(K,IJ)=DT*(SILRZ*CS1+SILZZ*CS2+SILRR*CS3
      1+SILPP*CS4*ITC)
      VWLM(K,IJ)=DT*SILM(K,IJ)*SILM(K,IJ)
10    CONTINUE
      ENDIF
100   CONTINUE
      RETURN
      END
```

C.2 MFREK.COM. The followings are common file for "mfrek.f" and its name must be "mfrek.com" and in same subdirectory as that "mfrek.f" is.

```
    IMPLICIT DOUBLE PRECISION(A-H,O-Z)
    PARAMETER (IB2=18,JB2=60,NPHASE=2,NPHS1=NPHASE+1,LT=NPHS1)
    PARAMETER (NIN=1,NOUT=1,NFL=3,NOBS=6,JXN=6,THICK=44.8564)
    PARAMETER (ITC=0,WMYGAS=28.5,THMIN=0.36,CRES=0.99999)
    PARAMETER (CG=1.80041D7,VISF=1.82D-4)
    PARAMETER (RST=0.,IPRE=0)
    PARAMETER (C17=8.314D7,C18=0.0  )
    PARAMETER (IB=IB2-2,IB1=IB2-1,JB=JB2-2,JB1=JB2-1)
    PARAMETER (IB3=IB2+1,IB4=IB2+2,IB2JB2=IB2*JB2)
    PARAMETER (IB2JB1=IB2JB2-IB2,IB1JB2=IB2JB2-1,
   1IB2JB0=JB*IB2+1)
    PARAMETER (NO=NIN+NOUT+NFL,NT=NO+NOBS)
    PARAMETER (NH=NPHASE,NC=IB2JB2,NI=IB2,NJ=JB2,
   1 NP=NPHS1,NF=NP*(NP+1)/2)
    PARAMETER (PI=3.14159265359)
C  SETC
    PARAMETER (C1=300.,C2=300)
C  COMMON BLOCKS
    COMMON / PARAM1 /  DT,KIN(NH),IRXN,IHEAT,VISS(NH),
   1 DG, D1, D2, D3, P1, P2, P3, GRAVX,GRAVY,NIT,
   1 TIME,  TDUMP, TPR, TSTOP, TARRAY(2), TTIM
    COMMON / PARAM2 /ITHMF(NT), QF(NC),
   1 AYM(JXN,JB2),AYMOL(JXN,JB2),AYMOL1(JXN,JB2),YMOL(JXN,NC),
   1 FLUX(JB2),AMIX(20),
```

```
1 TG(NC), TL(NH,NC), TGN(NC), TLN(NH,NC),
1 SIEG(NC), SIEGN(NC), AKG(NC),
1 SIEL(NH,NC), SIELN(NH,NC), AKL(NH,NC),
1 CL(NH), RHEAT(NH,NC),
1 UGFL, UGFR, UGFT, UGFB(NI),
1 ULFL(NH), ULFR(NH), ULFT(NH), ULFB(NH,NI),
1 VGFL, VGFR, VGFT, VGFB(NI),
1 VLFL(NH), VLFR(NH), VLFT(NH), VLFB(NH,NI),
1 THFL, THFR, THFT, THFB(NI),
1 EGFL, EGFR, EGFT, EGFB(NI),
1 HFGL, HFGR, HFGT, HFGB,
1 ELFL(NH), ELFR(NH), ELFT(NH), ELFB(NH,NI),
1 HFLL(NH), HFLR(NH), HFLT(NH), HFLB(NH,NI),
1 OMTFL(NH), OMTFR(NH), OMTFT(NH), OMTFB(NH,NI),
1 SUGL, SUGR, SUGT, SUGB, SUGC,
1 SULL(NH), SULR(NH),SULT(NH), SULB(NH), SULC(NH),
1 SVGL, SVGR, SVGT, SVGB,
1 SVLL(NH), SVLR(NH),SVLT(NH), SVLB(NH)
 COMMON / PARAM3 /
1 IOB(4,NT), ARL(NH), DK(NH), GTH(0:1000), DKF(NH,NH),
1 C(16), RL(NH),VISSD(NH),IFL(NC),INDS(NC,5), PHI(NH),
1 CPHI(NH), PHILIM(NH,NH), EPSL(NH,NH), EPSU(NH,NH),
1 R(NI), RB(NI), RRB(NI),COHF(0:1000),
1 DR(NI), DZ(NJ), DRP(NI), DZP(NJ),
1 RDR(NI), RDZ(NJ), RDRP(NI), RDZP(NJ),
1 AR(NI), BR(NI), AZ(NJ), BZ(NJ),
1 DTODR(NI), DTODZ(NJ), DTODRP(NI), DTODZP(NJ),
1 RRIDR(NI), RRIDRP(NI), DTOBDR(NI), DTORDR(NI)
 COMMON / PARAMI /
1 I, IJ, IJB, IJBR, IJL, IJM, IJP, IJR,IMJM,
1 IJRR, IJT, IJTL, IJTR, IJTT, IMJ, IMJP, IPJ,
1 IPJM, IPJP, ITD, J, K, NSL(4), NSO(NT)
 COMMON/AREA1/
1 ABETA(NC), CONV(NC), P(NC), PN(NC), TH(NC), THN(NC),
1 RGFR(NC), RGFT(NC), RGP(NC),RGPN(NC), ROG(NC),
1 RGFRY(NC),RGFTY(NC),
1 APP(NF,NC), RUG(NC), RVG(NC),
1 AU1(NP,NP), AV1(NP,NP), AU(NP,NP), AV(NP,NP),
1 BU1(NP), BV1(NP), BU(NP), BV(NP)
 COMMON/AREA2/
1 RLFRK(NH,NC), RLFTK(NH,NC), RKPG(NH,NC),
1 RLFRKY(NH,NC),RLFTKY(NH,NC),
1 RUK(NH,NC), RVK(NH,NC), RLK(NH,NC), RLKN(NH,NC),
1 UG(NC), VG(NC), UK(NH,NC), VK(NH,NC)
 COMMON/INPUT/
```

```
     1 UIO(NO), VIO(NO),   PIO(NO), THIO(NO), TEMIO(NO),
     1 UPIO(NH,NO), VPIO(NH,NO),  THPIO(NH,NO), TEMPIO(NH,NO),
     1 WM(JXN),Q(NC),DOTM(LT),DOTMJ(LT,JXN),YIO(LT,JXN,NO),
     1 QGEN(LT),QFLOW(LT),IHO(LT),IHE(LT),HHO(LT,5),
     1 HHE(LT,5),AHO(LT,5,JXN),AHE(LT,5,JXN),Y(LT,JXN,NC),
     1 RHO(LT,5),RHE(LT,5),TOB(NC),YN(LT,JXN,NC),
     1 KEY(4),AHK(LT,5,JXN),DGG(NC),QQ(NT),TOBB(NT),COEK(NT),
     1 COE(NC),
     1 RLKMIN(NH),TSKIO(NH,NO),TSK(NH,NC),VISBL(NH,NC),
     1 VISCL(NH,NC),VISDIL(NH),PS(NH,NC),TSKN(NH,NC),
     1 SILM(NH,NC),VWLM(NH,NC),VWLS(NH,NC),GCON(NH,NC),
     1 GAMMA(NH,NC),TSKCB(NH),TSKFB(NH,NI),THL(NH,NC),
     1 TSKCL(NH),TSKCT(NH),TSKCR(NH),
     1 TSKFL(NH),TSKFT(NH),TSKFR(NH)
```

C.3 MFREK.D. The followings are a sample input data file named "mfrek.d".

```
mfrek.r
SAMPLE INPUT DATA
18*1.786
60*13.31
5       2       3       3
1       0       2       17      2       13
1       0       2       17      14      31
1       0       2       17      32      59
5       0       2       17      1       1
7       0       2       17      60      60
3       1       12      13      40      42
0       273.15          2.0D6
3       1       12      13      34      36
0       273.15          2.0D6
3       1       12      13      28      30
0       273.15          2.0D6
3       1       12      13      22      24
0       273.15          2.0D6
3       1       12      13      16      18
0       273.15          2.0D6
3       1       12      13      10      12
0       273.15          2.0D6
0.005   0.1
1.0     1.0
3.011   0.70025
4.9D7   3.0D7
5.0     0.089
1       0.1     0       0.1
```

```
0       4.80    5.3129D7        0.050   523.15
0       0                       0.524   523.15          1.0
0       0                       0.426   523.15          1.0
0       4.80    5.2944D7        0.050   523.15
0       0                       0       0               1.0
0       0                       0.950   523.15          1.0
0       0.24    5.2944D7        1.000   523.15
0       0                       0       0               1.0
0       0                       0       0               1.0
0       0.24    5.3349D7        1.000   523.15
0       0                       0       0               1.0
0       0                       0       0               1.0
0       0.24    5.2944D7        1.000   523.15
0       0                       0       0               1.0
0       0                       0       0               1.0
1       1
28      44      2       16      32      28
1       0
0       -1      0       -2      0       1       0
0       0
0       0
0.6806          0.2726          0.0334          0.0000          0.0000          0.0134
0               0               0               0               0               0
0               0               0               0               0               0
0.6806          0.2726          0.0334          0.0000          0.0000          0.0134
0               0               0               0               0               0
0               0               0               0               0               0
0.6806          0.2726          0.0334          0.0000          0.0000          0.0134
0               0               0               0               0               0
0               0               0               0               0               0
0.6806          0.2726          0.0334          0.0000          0.0000          0.0134
0               0               0               0               0               0
0               0               0               0               0               0
0.6806          0.2726          0.0334          0.0000          0.0000          0.0134
0               0               0               0               0               0
0               0               0               0               0               0
0
0       30      1D-4
0.05    0.005
0       -980.62
```