APPENDIX B

ORGANIZATION AND USER MENU OF MFREK

B.1 Program Organization

A flow chart of the program MFREK.f with the various subroutines is given in Figure B.1. An alphabetical listing of the various subroutines and their functions are as follows:

BDRY Sets the boundary conditions - reflects cell centered quantities.

BETAS Calculates the reciprocal derivatives of the mass residuals with respect to pressure $\overline{\beta_{i,j}}=(\partial D/\partial P_g)_{i,j}$ for iteration procedure.

CNVERT Calculates the initial microscopic and macroscopic densities and converts temperature to enthalpies.

COMPOS Calculates composition for each phase.

FEFLUX Calculates fluctuating energy fluxes of kinetic theory of granular solids.

FLIC Sets cell flags based on input data.

GRNVIS Calculates new granular temperature and particulate properties using kinetic theory of granular solids.

GRPROP Initializes particulate properties using kinetic theory of granular solids.

GRTEMF Calculates granular temperature fluxes of kinetic theory.

HEATCG Calculates the heat flux for the gas phase, using the phase conductivities.

HEATCL Calculates the heat flux for the solid and/or liquid phases, using the phase conductivities.

ICONV Updates the specific energies to account for the effects of convection, viscous and pressure work, and conduction.

IGIL Updates the specific energies to account for the effects of mass momentum and energy exchange.

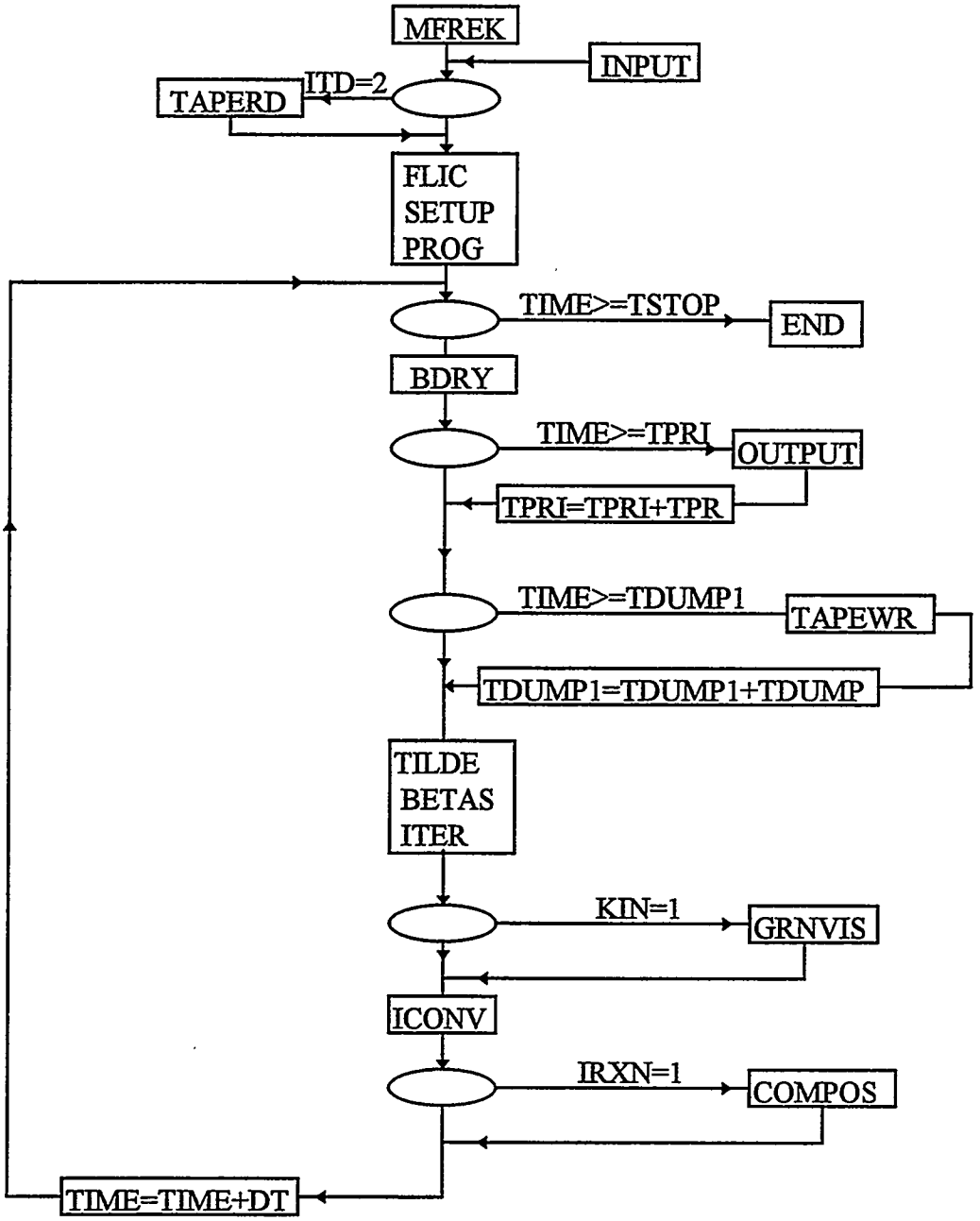

Figure B.1 The Program Flow Chart

IGIL	Updates the specific energies to account for the effects of mass momentum and energy exchange.
IINV	Calculates inverse of matrix with non-zero first column, first row and diagonal column.
INDX	Calculates indices for array quantities.
ITER	Performs the iterative solution of the difference equation of mass momentum and energy equations.
KDRAGG	Calculates gas-solid drag coefficients.
KDRAGS	Calculates gas-solid drag for low or high solid concentration.
MASFG	Calculates mass fluxes for the gas phase.
MASFK	Calculates mass fluxes for the solid and/or liquid phases.
MATS	Calculates the matrix component for velocity calculations.
MULTI	Calculates particle to particle interactions.
NEWP	Calculates a new estimate of advanced time pressure from three (pressure residual) points.
PROD	Calculates the mass flux at inlet and outlet for gas phase.
PROG	Controls the program flow and output.
QESOL	Solves quadratic equation.
QFLUX	Calculates heat flux from heat boundaries (around heat exchangers).
QRXN	Calculates the heat generations due to reactions.
RHEATS	Calculates the value of interface heat transfer coefficient.
RRATE	Defines the rates of reactions and heat generations.

RXN	Calculates phase changes.
SETUP	Defines the initial values of field variables in the fluid, inflow and outflow boundary cells, using the input data.
SIEGF	Calculates fluxes of specific energy for the gas phase.
SIELF	Calculates fluxes of specific energy for the solid and/or phases.
SOLUTION	Identifies rate control step (reaction or mass transfer).
TAPERD	Reads the restart file for initial conditions.
TAPEWR	Writes to a restart file.
THRCON	Calculates the thermal conductivities for the phases.
TILDE	Calculate momenta due to convection, gravity, viscous stress, solids pressure and cohesive stress (tilde quantities).
UGMOMF	Calculates fluxes of radial momentum for the gas phase.
UGVS	Calculates stress tensor terms for the gas phase in radial direction.
ULMOMF	Calculates fluxes of radial momentum for the particulate phases.
ULVS	Calculates stress tensor terms for the particulate phases in radial direction.
VELINV	Uses Gauss-Dolittle method for symmetric matrix inversion.
VELSK	Calculates velocities on the four boundaries of the cell.
VGMOMF	Calculate fluxes of axial momentum for the gas phase.
VGVS	Calculates stress tensor term for the gas phase in axial direction.
VLMOMF	Calculate fluxes of axial momentum for the particulate phases.
VLVS	Calculates stress tensor term for the particulate phases in axial direction.
VWORKL	Calculates the viscous work for the phase specific energy equation.

B.2 Setting up a Program

First of all choose an appropriate coordinate system from rectangular and cylindrical coordinates. Use the symmetries of the problem to reduce the computational region. Properly specify the inflow and outflow coordinates which can be located in any positions.

Non-uniform initial conditions, if any conditions can be programmed by modifying the subroutine SETUP.

Specify dx_i and dy_j according to the degree of resolution required. Sometimes these dimensions are governed BV the size of inflow and outflow openings. However, the ratio between two adjacent increments should be within bounds,

$$\frac{1}{\overline{K}} < \frac{dx_i}{dx_{i+1}} \quad \text{or} \quad \frac{dy_j}{dy_{j+1}} < \overline{K}$$

where $\overline{K}$ is usually a number between 1 and 2 (Noye, 1978; Cebeci and Smith, 1971). The accuracy (and occasional the stability) is sensitive to the value of $\overline{K}$ used. For satisfactory results $\overline{K} < 1.15$ should be used.

The time step is limited by Courant stability condition (Courant et al. 1952),

$$\delta t < \frac{\min(\delta r_i, \delta z_j)}{\max(\text{velocities})}$$

The solution technique is a generalization of the Implicit Continuum Eulerian (ICE) method and hence there is no sonic time step limitation. However, in some cases the time step required for proper convergence could be much less than what is given by the above expression.

B.3 Input Data. A description of the input data file is given below.

B.3.1

RESTART: restart file name (no more than 10 characters).

NAME: case identifier (no more than 80 characters).

(DR(I),I=1,IB2): radial steps.

(DZ(J),J=1,JB2): axial steps.

(NSL(M),M=1,4): cell flag of bottom, left, top and right boundary.

B.3.2

NSL(1), ITHMF(1), (IOB(M,1),M=1,4): cell flag, heat flag (=1 indicate a heat sink/source block, =0 indicate a non-heat sink/source block and skip the following line), coordinates in order of left, right, bottom and top of block for the **first** block. (The following line is optional).

QQ(1), TOBB(1), COEK(1): constant heat flux, constant temperature and heat transfer coefficient of the heat block. One must supply QQ or TOBB and COEK.

NSL(2), ITHMF(2), (IOB(M,2),M=1,4): cell flag, heat flag (=1 indicate heat sink/source block, =0 indicate a non-heat sink/source block and skip the following line), coordinates in order of left, right, bottom and top of block for the **second** block. (The following line is optional).

QQ(2), TOBB(2), COEK(2): constant heat flux, constant temperature and heat transfer coefficient of the heat block. One must supply QQ or TOBB and COEK.

NSL(NT), ITHMF(NT), (IOB(M,NT),M=1,4): cell flag, heat flag (=1 indicate a heat sink/source block, =0 indicate a non-heat sink/source block and skip the

following line), coordinates in order of left, right, bottom and top of block for the **NT-th** block. (The following line is optional).

QQ(NT), TOBB(NT), COEK(NT): constant heat flux, constant temperature and heat transfer coefficient of the heat block. One must supply QQ or TOBB and COEK.

B.3.3

DK(NPHASE): particle diameters of particulate phases.

PHI(NPHASE): sphericity of particles.

RL(NPHASE): density of particulate phases.

CL(NPHASE): specific heat of particulate phases.

VISS(NPHASE): empirical viscosity of particulate phases. Values of VISS must be given even kinetic theory approach is used.

(KIN(K), RLKMIN(K), K=1, NPHASE): KIN=1 use kinetic theory. Kinetic theory is used only when solid concentration is more than RLKMIN.

B.3.4

UIO(1), VIO(1), PIO(1), THIO(1), TEMIO(1): gas velocities in x-direction, y-direction, pressure, volume fraction and temperature of the **first** block.

UPIO(K,1), VPIO(K,1), THPIO(K,1), TEMPIO(K,1): k-phase velocities in x-direction, y-direction, volume fraction and temperature of the **first** block.

UIO(2), VIO(2), PIO(2), THIO(2), TEMIO(2): gas velocities in x-direction, y-direction, pressure, volume fraction and temperature of the **second** block.

UPIO(K,2), VPIO(K,2), THPIO(K,2), TEMPIO(K,2): k-phase velocities in x-direction, y-direction, volume fraction and temperature of the **second** block.

UIO(NO), VIO(NO), PIO(NO), THIO(NO), TEMIO(NO): gas velocities in x-direction, y-direction, pressure, volume fraction and temperature of the **NO-th** block.

UPIO(K,NO), VPIO(K,NO), THPIO(K,NO), TEMPIO(K,NO): k-phase velocities in x-direction, y-direction, volume fraction and temperature of the **NO-th** block.

B.3 5

IHEAT, IRXN: IHEAT=1 for non-isothermal case, IRXN=1 for case with reactions.

B.3 6. If IRXN is not 1, skip this section.

WM(JXN): molecular weights.

IHO(K), IHE(K): # of homogeneous and heterogeneous reactions for phase k (k starts from gas, solid1, solid2, ...)

HHO(K,IX), (AHO(K,IX,JX), JX=1,JXN): reaction heat, stoichiometric coefficients of IX-th homo-reaction in phase k. If IHO(K)=0, skip this line.

HHE(K,IX), (AHE(K,IX,JX), JX=1,JXN): reaction heat, stoichiometric coefficients of IX-th hetero-reaction in phase k (exclude gas). If IHE(K)=0, skip this line.

((YIO(K,JX,1),JX=1,JXN),K=1,NPHS1): initial composition for phase k (gas, solid1, solid2, ...) in the **first** block.

((YIO(K,JX,1),JX=1,JXN),K=1,NPHS1): initial composition for phase k (gas, solid1, solid2, ...) in the **second** block.

((YIO(K,JX,1),JX=1,JXN),K=1,NPHS1): initial composition for phase k (gas, solid1, solid2, ...) in the **NO-th** block.

B.3.7

ITD: =0 no restart; =2 read initial data from a restart file.

TIME, TSTOP, DT: start time, stop time, time interval for simulation.

TPR, TDUMP: time interval for outputting data, time interval for updating restart file.

GRAVY, GRAVX: gravity in x- and y- directions. For inclined bed, they depend on the inclined angle. The other external forces such as electrostatic-force may be added to these terms and modification of GRAVY(K), GRAVX(K) may be needed if these forces are differ from phase to phase.

B.4 Common Block. In addition, some of constants must be given as input data in the INLUDE file "mfrek.com."

Line 2:

IB2=2 + # of radial cells.

JB2=2+ # of axial cells.

NPHASE=# of particulate phases.

Line 3:

NIN=# of inflow blocks.

NOUT=# of outflow blocks.

NFL=# of flow (performing calculation) blocks.

NOBS=# of non-flow blocks.

JXN=# of species. Non-reacting phase such as catalysts may be treated as a specie.

THICK=thichness of the 2-d bed, used for mass balancing and flowrate computing.

Line 4:

ITC=0 Cartesian/1 cylindrical coordinates.

WMYGAS=average molecular weight of continuous phase (gas).

THMIN=minimum volume fraction allowed for continuous phase (gas).

CRES=restitution coefficient used in kinetic theory. It is sensitive to the value of granular temperature.

Line 5:

CG=specific heat of continuous phase (gas).

VISF=viscosity of continuous phase (gas).

Line 6:

RST=left wall position (usually =0).

IPRE=0 uniform initial pressure distribution; =1 weight-depended initial pressure distribution.

Line 7:

C17= 8.314E+7 if gas as continuous phase; =0 if liquid as continuous phase.

C18=0 if gas as continuous phase; =WMYGAS/DENSITY OF LIQUID if liquid as continuous phase.

Important: if modified "mfrek.f," the common variables must be added to the COMMON BLOCKS of "mfrek.com."

B.4 A List of FORTRAN Symbols

In the following list of FORTRAN symbols the array quantities are indicated by an index. They are all part of a common block. The dimensions of array variables needs to be changed when the input data is changed. The indices shown in the following table and the respective dimensions to be used are: I= (1--IB2); J = (1--JB2); IJ = (1--IB2xJB2); JX=(1--JXN) where JXN is total number of species; K = (1--N) where N is total number of particulate phases and M = (1--Nx(N+I)/2. The rest are left unchanged unless otherwise specified.

Symbol	Description
ABETA(IJ)	$1/\beta_{i,j}$
AHE(K,IX,JX)	Stoichiometric coefficient of heterogeneous reaction.
AHO(K,IX,JX)	Stoichiometric coefficient of homogeneous reaction.
AKGO	Reference fluid thermal conductivity.
AKG(IJ)	Thermal conductivity of gas phases.
AKL(K,IJ)	Thermal conductivity of particulate phases.
APP(M,IJ)	$\delta t \sum_{\ell=1}^{N} (\beta_{k\ell})_{i,j}$ as diagonal element.
AR(I)	$dx_{i+1}/2dx_{i+1/2}$.
ARL(K)	Receptacle of phase density.
AU(N,N)	Components of matrix A for cell (i+1/2, j).
AU1(N,N)	Components of matrix A for cell (i-1/2, j).
AV(N,N)	Components of matrix A for cell (i, j+1/2).

AV1(N,N)	Components of matrix A for cell (j, j-1/2).
AH(N,N)	Components of matrix A_h for cell (i, j).
AZ(J)	$dy_{j+1}/2dy_{j+1/2}$.
BR(I)	1-AR(I)
BU(N,N)	Components of vector B_u for cell (i+1/2,j).
BU1(N,N)	Components of vector B_u for cell (i-1/2, j).
BV(N,N)	Components of vector B_y for cell (i, j+1/2).
BV1(N,N)	Components of vector B_y for cell (j, j-1/2).
BH(N,N)	Components of vector B_h for cell(i, j)
BZ(J)	1-AZ(J)
C1--C21	
C1, C2	Reference temperature of gas, particulate phases.
C17	=8.314E+7 if gas as continuous phase; =0 if liquid as continuous phase.
C18	=0 if gas as continuous phase; =WMYGAS/DENSITY OF LIQUID if liquid as continuous phase.
CG	Specific heat of gas phase.
CL(K)	Specific heat of particulate phases.
CPHI(K)	Solids volume fraction at maximum packing.
COE(NC)	Heat conductivity of heat boundary for cell (i,j).
COEK(NT)	Heat conductivity of heat boundary for block N.
COHF(0:1000)	Cohesive stress values.

CONV(IJ)	Pressure iteration convergence criteria computed in BETAS.
CRES	Coefficient of restitution.
D1, D2, D3	Values of $D_{i,j}$.
DG	$D_{i,j}$ - Tolerance in fluid continuity equation.
DGG(IJ)	Store $D_{i,j}$ for composition calculation.
DK(K)	d_k - Characteristic diameter of k-th phase.
DOTM(K)	Phase change.
DOTMJ(K,JX)	Species change in phase k.
DR(I)	dx_i - Variable cell size in x- (or r-) direction at i-th column.
DRP(I)	$dx_{i+1/2}$ - Variable cell size in x- (or r-) direction at i+1/2-th column.
DT	dt - Time increment.
DTOBDR(IJ)	$dt/x_{i+1/2}/dx_{i+1/2}$.
DTODR(IJ)	dt/dx_i .
DTODRP(IJ)	$dt/dx_{i+1/2}$.
DTODZ(IJ)	dt/dy_j.
DTODZP(IJ)	$dt/dy_{j+1/2}$.
DTORDR(IJ)	$dt/x_i/dx_i$.
DZ(J)	dy_j - Variable cell size in y- (or z-) direction at j-th row.
DZP(J)	$dy_{j+1/2}$ - Variable cell size in z-direction at j + 1/2-th row.
DI, D2, D3	Values of $D_{i,j}$.
EGFB(I)	Flux of gas phase specific energy across the bottom boundary of cell (i, j).

EGFL	Flux of gas phase specific energy across left boundary of cell (i,j).
EGFR	Flux of gas phase specific energy across right boundary of cell (i,j).
EGFT	Flux of gas phase specific energy across top boundary of cell (i,j).
ELFB(K,I)	Flux of k-phase specific energy across the bottom boundary of cell (i, j).
ELFL(K)	Flux of k-phase specific energy across left boundary of cell (i,j).
ELFR(K)	Flux of k-phase specific energy across right boundary of cell (i,j).
ELFT(K)	Flux of k-phase specific energy across top boundary of cell (i,j).
EPSG	Value for convergence criteria (default = 10^{-5}).
FLUX	Gas mass flux at outlet.
GAMMA(K,IJ)	Collision energy dissipation rate.
GCDIL(K)	k_{dil} - dilute phase granular conductivity.
GCON(K,IJ)	Granular thermal conductivity for particulate phases.
GRAVX	Gravity in x-direction.
GRAVY	Gravity in y-(or z-) direction.
GTH(IK)	Solids stress values.
HFGB(I)	Conductive heat flux of gas phase across the bottom boundary of cell (i,j).
HFGL	Conductive heat flux of gas phase across left boundary of cell (i,j).
HFGR	Conductive heat flux of gas phase across right boundary of cell (i,j).
HFGT	Conductive heat flux of gas phase across top boundary of cell (i,j).
HFLB(K,I)	Conductive heat flux of k-phase across the bottom boundary of cell (i,j).

HFLL(K)	Conductive heat flux of k-phase across left boundary of cell (i,j).
HFLR(K)	Conductive heat flux of k-phase across right boundary of cell (i,j).
HFLT(K)	Conductive heat flux of k-phase across top boundary of cell (i,j).
HHE	Hetero-reaction heat.
HHO	Homo-reaction heat.
I	I - Computing mesh column index (x- or r- direction).
IB	Number of cell in the radial direction excluding the two fictitious columns along the boundaries; (IB = IB2 -2).
IB1	(IB1 = IB2 -1).
IB2	Total number of cells in the radial direction.
IBlJB2	IB2xJB2 -1.
IB2JBl	IB2x(JB2 - 1) = IB2JB2 - IB2.
IB2JB2	IB2xJB2.
IFL(IJ)	Cell flags set up in FLIC.
IHE	Number of hetero-reactions.
IHEAT	=1 for solving energy equations.
IHO	Number of homo-reactions.
IJ	Index of quantities for cell (i,j), (IJ = I + (J-1) IB2).
IJB	Index of cell centered quantities associated with cell (i,j-1).
IJBR	Index of cell centered quantities associated with cell (i+1,j-1).
IJL	Index of cell centered quantities associated with cell (i-1,j).
IJM	Index of cell (i,j-1).

IJP	Index of cell (i,j+1).
IJR	Index of cell centered quantities associated with cell i+1, j).
IJRR	Index of cell centered quantities associated with cell (i+2,j).
IJT	Index of cell centered quantities associated with cell (i,j+1).
IJTL	Index of cell centered quantities associated with cell (i-1,j+1).
IJTR	Index of cell centered quantities associated with cell (i+1,j+1).
IJTT	Index of cell centered quantities associated with cell (i,j+2).
IMJ	Index of cell i-1,j).
IMJM	Index of cell i-1,j-1).
IMJP	Index of cell (i-1,j+1).
INDC()	Storage of IPJ, IMJ, IJP, IJM, IPJP, IMJP, IPJM, and IMJM for each (i,j).
INDS()	Storage of IJR, IJL, IJT, IJB, IJTR. IJTL, IJBR, IJRR, and IJTT for each (i,j).
IOB(M,N)	Coordinates of nth block.
IPJ	Index of cell (i+1,j).
IPJM	Index of cell (i+1,j-1).
IPJP	Index of cell (i+1,j+1).
IPRES	=0 initial uniform pressure, =1 initial pressure distribution depended on weight of bed.
IRXN	=0 or 1 represented case without or with reactions.
ITD	=0 no restart, =2 read initial data from a restart file.

ITHMF	=0 non heat block, =1 heat sink/source block.
J	Computing mesh index (z-direction).
JB	(JB = JB2 -2).
JBl	(JBl = JB2 -1).
JB2	Total number of cells in the axial direction.
JXN	Total number of species.
K	Index for the particulate phases.
KEY(4)	Used in COMPOS.
Kin(K)	=1 Using kinetic theory for viscosity; =0 Using empirical viscosity.
KV	Index for continuous phase.
LT	=NPHS1 Total number of phases ($\geq$ NPHASE).
MAXIT	Maximum number of iterations.
NAME	Problem identifier.
NC	Total number of cells ($\geq$ IB2JB2).
NF	NPHASEx(NPHASE + 1) / 2.
NFL	Number of fluid blocks.
NPHASE	Number of particulate phases.
NH	Number of inflow openings.
NI	=IB2
NIT	Iteration counter used in ITER.
NJ	=JB2
NOBS	Number of rigid blocks.

NO	Number of inflow, outflow and fluid blocks.
NOUT	Number of outflow exits.
NP	=NPHS1
NPHS1	Total number of phases ($\geq$ NPHASE).
NPHASE	Number of particulate phases.
NS	Total number of solids phases ($\geq$ NSOLID).
NSOLID	Number of particulate phases.
NSL(M)	Boundary flag.
NSO(N)	Block flag.
NT	Number of total blocks.
P(IJ)	Gas pressure in cell (i,j).
Pl, P2, P3	Values of $(P_g)_{i,j}$.
PHI(K)	sphericity of k-th phase.
PI	=3.1415927.
PIO(N)	Initial pressure of block n.
PN(IJ	Gas pressure in cell (i,j) at time level n.
PS(K,ij)	$(P_k)_{i,j}$ Solids Pressure in cell (i,j).
PVISC(K)	Input viscosity.
Q, QF, QFLOW	Heat flux from heat sink/source.
QGEN	Heat flux due to reactions.
R(I)	dx_i - Radial coordinate of the center of cell (i,j).
RB(I)	$dx_{i+1/2}$ - Radial coordinate of the right boundary of cell (i, j).

RDR(I)	$1/dx_i$.
RDRP(I)	$1/dx_{i+1/2}$
RDZ(J)	dy_j .
RDZP(J)	$dy_{j+1/2}$.
RGFRK(K,IJ)	Flux of macroscopic density across the right boundary of cell (i, j).
RGFTK(K.IJ)	Flux of macroscopic density across the top boundary of cell (i, j).
RGFRKY(K,IJ)	Flux of macroscopic density across the right boundary of cell (i, j).
RGFTKY(K.IJ)	Flux of macroscopic density across the top boundary of cell (i, j).
RGP(IJ)	Macroscopic density of the gas for cell (i, j).
RGPN(IJ)	Macroscopic density of the gas for cell (i, j) at time level n.
RHE	Rate of hetero-reaction.
RHO	Rate of homo-reaction.
RHEAT(K,IJ)	Interfacial heat transfer function for gas and particulate phases for cell (i, j).
RKPG(K,IJ)	Gas-particulate phase drag for cell (i, j).
RL(K)	Microscopic particulate phase density.
RLFRK(K,IJ)	Flux of macroscopic density across the right boundary of cell (i, j).
RLFTK(K.IJ)	Flux of macroscopic density across the top boundary of cell (i, j).
RLFRKY(K,IJ)	Flux of macroscopic density across the right boundary of cell (i, j).
RLFTKY(K.IJ)	Flux of macroscopic density across the top boundary of cell (i, j).
RLK(K,IJ)	Phase density for cell (i, j).
RLKN(K,IJ)	Phase density for cell (i, j) at time level n.

RLX(K,IJ)	Mixture density for cell (i, j).
ROG(IJ)	Microscopic density of the gas for cell (i, j).
RRB(I)	$1/x_{i+1/2}$.
RRIDR(I)	$1/x_i/dx_i$.
RRIDRP(I)	$1/x_{i+1/2}/dx_{i+1/2}$.
RST	Radial distance of left boundary from origin.
RUG(IJ)	$\overline{\varepsilon_g \rho_g u_g}$.
RVG(IJ)	$\overline{\varepsilon_g \rho_g v_g}$.
RUK(K,IJ)	$\overline{\varepsilon_k \rho_k u_k}$.
RVK(K.IJ)	$\overline{\varepsilon_k \rho_k v_k}$.
SIEG(IJ)	$(H_g)_{i,j}$ - Specific energy of the gas phases for cell (i,j).
SIEGN(IJ)	$(H_g)_{i,j}^n$ - Specific energy of the gas phases at time level n.
SIEL(K,IJ)	$(H_k)_{i,j}$ - Specific energy of the k-phases for cell (i,j).
SIELN(K,IJ)	$(H_k)_{i,j}^n$ - Specific energy of the k-phases at time level n.
SILM(K,IJ)	$(\text{grad } v_k)_{i,j}$.
SVREL(K)	Square of relative velocity of particulate phase.
SUB	Product of radius, volume fraction, and shear stress.
SUGAR	Product of vol. fraction and azimuthal stress.
SUGL	Product of radius, volume fraction, and radial stress.
SUGR	Same as SUGL, but evaluated at cell location (i+1,j).
SUGT	Same as SUGB, but evaluated at cell location (i+1/2,j+1/2).
SULB(K)	Product of radius, volume fraction, and shear stress.

SULC(K)	Product of vol. fraction and azimuthal stress.
SULL(K)	Product of radius, volume fraction, and radial stress.
SULR(K)	Same as SULL(K), but evaluated at cell location (i+1,j).
SULT(K)	Same as SULB(K), but evaluated at cell location (i+1/2,j+1/2).
SVGB	Product of volume fraction, and axial stress.
SVGL	Product of radius, volume fraction, and axial stress.
SVGR	Same as SVGL, but evaluated at cell (i+1/2, j+1/2).
SVGT	Same as SVGB, but evaluated at cell location (i, j+1).
SVLB(K)	Product of volume fraction, and axial stress.
SVLL(K)	Product of radius, volume fraction, and axial stress.
SVLR(K)	Same as SVLL(K), but evaluated at cell (i+1/2, j+1/2).
SVLT(K)	Same as SVLB(K), but evaluated at cell location (i, j+1).
TARGET	Used in the pressure iteration to provide over or under relaxation.
TDUMP	Time interval for restart file.
TEMIO(K,NT)	Initial temperature of phase k of block n.
TG(IJ)	Gas temperature.
TGN(IJ)	Gas temperature at time level n.
TH(IJ)	Gas volume fractions for cell (i,j).
THICK	Thickness of the 2-d slice (for PROD).
THIO(K,NT)	Initial volume fraction for phase k of block n.
THN(IJ)	Gas volume fractions for cell (i,j) at time level n.
THMIN	Minimum allowed gas volume fraction.

TIME	Initial time.
TL(K,IJ)	$(T_k)_{i,j}$ - Phase k temperature for cell (i,j).
TLN(K,IJ)	$(T_k)_{i,j}$ - Phase k temperature for cell (i,j) at time level n.
TPR	Time interval for output.
TOB(IJ)	Temperature of obstacle cells (i,j).
TOBB(IJ)	Temperature of obstacle block.
TSK(K.IJ)	Granular temperature.
TSKCB(K)	Granular conductive flux across the bottom boundary of cell (i,j).
TSKCL(K)	Granular conductive flux across the left boundary of cell (i,j).
TSKCR(K)	Granular conductive flux across the right boundary of cell (i,j).
TSKCT(K)	Granular conductive flux across the top boundary of cell (i,j).
TSKFB(K)	Flux of granular kinetic energy across the bottom boundary of cell (i,j).
TSKFL(K)	Flux of granular kinetic energy across left boundary of cell (i,j).
TSKFR(K)	Flux of granular kinetic energy across the right boundary of cell (i,j).
TSKFT(K)	Flux of granular kinetic energy across top boundary of cell (i,j).
TSKN(K.IJ)	Granular temperature at time level n.
TSKIO(K,NT)	Initial granular temperature.
TSTOP	Final time.
UG(IJ)	Gas radial velocity.

UGFB (IJ)	Radial momentum flux for the gas phase across the bottom boundary of the radial momentum control volume centered about the point (i+1/2,j).
UGFL(IJ)	Radial momentum flux for the gas phase across the left boundary of the radial momentum control volume centered about the point (i+1/2,j).
UGFR(IJ)	Radial momentum flux for the gas phase across the right boundary of the radial momentum control volume centered about the point (i+1/2,j).
UGFT(IJ)	Radial momentum flux for the gas phase across the top boundary of the radial momentum control volume centered about the point (i+1/2,j).
UIO(NT)	Initial radial gas velocity.
UPIO(K,NT)	Initial radial k-phase velocity.
ULFB (K,IJ)	Radial momentum flux for k-phases across the bottom boundary of the radial momentum control volume centered about the point (i+1/2,j).
ULFL(K,IJ)	Radial momentum flux for k-phases across the left boundary of the radial momentum control volume centered about the point (i+1/2,j).
ULFR(K,IJ)	Radial momentum flux for k-phases across the right boundary of the radial momentum control volume centered about the point (i+1/2,j).

ULFT(K,IJ)	Radial momentum flux for k-phases across the top boundary of the radial momentum control volume centered about the point (i+1/2,j).
VG(IJ)	Gas axial velocity.
VGFB(K,IJ)	Axial momentum flux for gas phase across the bottom boundary of the radial momentum control volume centered about the point (i,j+1/2).
VGFL(K,IJ)	Axial momentum flux for gas phase across the left boundary of the radial momentum control volume centered about the point (i,j+1/2).
VGFR(K,IJ)	Axial momentum flux for gas phase across the right boundary of the radial momentum control volume centered about the point (i,j+1/2).
VGFT(K.IJ)	Axial momentum flux for gas phase across the top boundary of the radial momentum control volume centered about the point (i,j+1/2).
VIO(NT)	Initial gas velocity.
VISBL(K,IJ)	Particulate bulk viscosity for cell (i,j).
VISCL(K,IJ)	Particulate shear viscosity for cell (i,j).
VISDIL(K)	Dilute phase granular viscosity.
VISF	Gas viscosity.
VISS, VISSD	Empirical solid viscosity.
VLFB(K,IJ)	Axial momentum flux for the phases across the bottom boundary of the radial momentum control volume centered about the point (i,j+1/2).

VLFL(K,IJ)	Axial momentum flux for the phases across the left boundary of the radial momentum control volume centered about the point (i,j+1/2).
VLFR(K,IJ)	Axial momentum flux for the phases across the right boundary of the radial momentum control volume centered about the point (i,j+1/2).
VLFT(K.IJ)	Axial momentum flux for the phases across the top boundary of the radial momentum control volume centered about the point (i,j+1/2).
VK(K,IJ)	Axial velocity for cell (i,j).
VPIO(K.NT)	Initial k-phase axial velocity.
VREL(K)	Velocity of solid phase relative to gas phase.
VWLM(K,IJ)	Viscous work generated by symmetric gradient of velocity term.
VWLS(K,IJ)	Viscous work generated by correction term.
WM(JX)	Molecular weight of specie j.
WMYGAS	Average gas or liquid molecular weight (used in no reaction case).
YIO(K,JX,N)	Initial compositions of k-phase.
Y(K,JX,IJ)	Weight fraction of specie j in k-phase.
YN(K,JX,IJ)	Weight fraction of specie j in k-phase at time level n.