## Index

accuracy, 43, 176	convergence, 37
adaptation, 60, 178	best-practice guidelines, 175
algebraic slip model, 150	Courant number (CFL), 57, 176
angular momentum, 74	Crank–Nicolson, 56
	Crank–Nicoison, 36
anisotropic, 70, 71 application uncertainty, 175	Dahmköhler number, 118
aspect ratio, 59	dense regime, 144
1	dilatational viscosity, 12
average concentrations, 133	•
average reaction rate, 116, 140	dilute regime, 144
D ( 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	direct numerical simulation (DNS), 79
Batchelor length scale, 119	discrete random walk (DRW), 154
BBO equation, 147 beta-PDF, 122	discretization schemes, 38–46, 176 comparison, 46
boundary conditions, 18-21	dispersed flow, 144
axis, 20	dissipation, 91
best-practice guidelines, 177	dissipative subrange, 73, 76
inlet, 19, 111	drag coefficient, 162
outlet, 19	drag force, 148
periodic, 6	drag models, 161
symmetry, 20	drift velocity, 157
wall functions, 106	dynamic LES, 81
walls, 19	
boundary layers, see turbulent boundary layers	eddy dissipation (ED), 141
boundedness, 40	eddy viscosity, 86
Boussinesq approximation, 85	effective viscosity, 86
bouyancy force, 149	energy cascade, 72
Brownian force, 149	energy-containing subrange, 73, 76
	energy spectrum, 75
calibration, 180	energy transport, 16
capillary number, 160	engulfment, 117
cell-centred, 26	Eötvös number, 162
central differencing, 40	equation of state, 22
chemical energy, 16	equilibrium reaction, 135
chemical reactions, 130–40	Euler–Euler, 150, 155
best-practice guidelines, 178	Euler-Lagrange, 150, 152
collision viscosity, 167	explicit method, 54
combustion, 137	
conditionally bounded, 40	face value, 28
conservativeness, 38	film model, 168
conserved scalar, 119	filtered residual, 80
consistent, 46	filtered velocity, 80
continuity equation, 12	finite differences, 25
control volume, 26	finite elements, 25

finite volumes, 25	look-up table, 134
first-order accurate, 44	low-Reynolds-number models, 108
first-order upwind, 41, 176	•
forces on dispersed particles, 147–9	Mach number, 14
bouyancy force, 149	macromixing, 113
Brownian force, 149	Magnus lift force, 148
drag force, 148	mass transfer, 168
history force, 148	mean concentrations, 133
Magnus lift force, 148	mean free path, 9
pressure force, 148	mesh generation, 58
Saffman lift force, 149	best practice guidelines, 175
shear force, 148	micromixing, 113
thermophoretic force, 149	mixing segregation, 128
turbulence force, 149	mixing timescales, 119
virtual mass force, 148	inertial-convective mixing, 119
four-way coupling, 147	viscous-convective mixing, 120
friction velocity, 103	viscous-diffusive mixing, 120
frictional viscosity, 167	mixture fraction, 119–30, 132
, 1000000, 101	closures, 126
Gauss theorem, 27	instantaneous, 124
Gauss-Seidel, 34	mean, 124
granular flow models, 165	variance, 122, 125
granular temperature, 166	mixture model, 150, 156
granular viscosity, 167	momentum balance, 14
collision, 167	multigrid, 50
friction, 167	multiphase flows
kinetic, 167	characterization, 144
	coupling, 146
heat transfer, 168	loading, 145
hexahedral, 58	particle forces, 147
history force, 148	particle spacing, 145
HRIC scheme, 46	response time, 146
,	Stokes number, 145
implicit method, 55, 177	volume fraction, 144
incompressible flow, 13	multiphase modelling, 149-69
inertial subrange, 73, 76	best-practice guidelines, 178
initial conditions, 20, 34	boundary conditions, 169
best-practice guidelines, 176	Euler–Euler, 150, 155
intensity of segregation, 125	Euler-Lagrange, 150, 152
inter-particle distance, 145	guideline, 172
isotropic, 68, 71, 75	mixture model, 150, 156
	porous-bed model, 150, 160
kinetic energy, 16	turbulence, 153, 156, 160
kinetic energy balance, 16	volume-of-fluid (VOF) model, 150,
kinetic theory of granular flow (KTGF),	158
166	MUSCL scheme, 46
kinetic viscosity, 167	,
Knudsen number, 15, 163	Navier-Stokes equations, 15
Kolmogorov hypotheses, 70	near-wall modelling, 99–110
Kolmogorov spectrum law, 76	Newtonian fluid, 10
Kronecker delta, 12	node-centred, 26
$k-\varepsilon$ model, 89	non-PDF models, 141
$k-\omega$ model, 95	normal stress, 11, 84
	numerical diffusion, 60, 176
large-eddy simulation (LES), 79	numerical errors, 176
law of the wall. 105	Nusselt number, 169

one-way coupling, 146	SIMPLE, 48
	SIMPLEC, 48
particle collisions, 164	SIMPLER, 48
particle interactions, 163	size distribution, 179
particle pressure, 167	skewness, 59, 175
particle response time, 146	slip velocity, 157
particle Reynolds number, 162	slow granular flow, 166
particle spacing, 145	Smagorinsky-Lilly model, 81
particle-particle collisions, 169	species balance, 18
Péclet number, 39	specific dissipation, 95
phase coupling, 146	squish index, 175
PISO, 48	statistical methods, 66
Poisson equation, 13	stoichiometric mixture fraction, 132
porous-bed model, 150, 160	Stokes number, 145
potential energy, 16	strain rate, 10
power-law scheme, 45	stratified flow, 144
Prandtl number, 10	structured grid, 26, 58
Prandtl's mixing length, 105	subgrid stress model, 80
pressure force, 148	subgrid stress tensor, 80
pressure-strain, 98	subgrid viscosity, 81
PRESTO!, 49	substantial operator, 13
presumed PDF, 122	surface-tension model, 159
probability density function (PDF), 120	
	Taylor expansion, 42
QUICK scheme, 45	tensor notation, 8
	tetrahedral, 58
radial distribution function, 167	thermal energy, 16
RANS equations, 82	thermal energy balance, 18
rapid granular flow, 166	thermophoretic force, 149
rarefaction effect, 163	third-order accurate, 46
rate of strain, 10	time step, 177
raw moment, 126	transportiveness, 40
reaction-progress variable, 138	truncation error, 43
realizable $k$ – $\varepsilon$ model, 94	turbulence
residuals, 38	characteristics, 63
restitution coefficient, 164	energy cascade, 72
Reynolds decomposition, 81	energy spectrum, 75
Reynolds number, 69	kinetic energy, 68, 90
Reynolds stress models (RSM), 96	statistics, 66
Reynolds stress tensor, 84	timescales and length scales, 73
Reynolds stresses, 84	transition, 69
RNG $k$ – $\varepsilon$ model, 93	turbulence modelling, 76-99
rotational velocity, 148	best-practice guidelines, 177
	comparison, 99
Saffman lift force, 149	direct numerical simulation (DNS), 79
sample-space variable, 122	energy dissipation, 91
scalar dissipation rate, 127	$k$ – $\omega$ model, 95
scales of segregation, 128	large-eddy simulation (LES), 79
Schmidt number, 9	low-Reynolds-number models, 95, 108
second-order accurate, 44	near-wall region, 107
second-order upwind, 42	realizable $k$ – $\varepsilon$ model, 94
sensitivity analysis, 180	Reynolds stress models (RSM), 96
separated flow, 144	RNG $k$ - $\varepsilon$ model, 93
shear force, 148	standard $k$ – $\varepsilon$ model, 89
shear stress, 11, 84, 101	turbulent viscosity, 85, 86
Sherwood number, 168	zonal modelling, 107

turbulent boundary conditions, 99-112 inlet, 111 unsteady, 20 walls, see wall functions turbulent boundary layers, 101 buffer sub-layer, 102 fully turbulent sub-layer, 102 viscous sub-layer, 101 turbulent diffusivity, 126 turbulent energy dissipation, 91 turbulent intensity, 112 turbulent kinetic energy, 68, 90 turbulent mixer model (TMM), 128 turbulent mixing, 117 turbulent viscosity, 85, 86 two-way coupling, 146

u, 103 unbounded, 46 under-relaxation, 49, 176 universal equilibrium range, 73, 76 unsteady flows, 51, 177 unstructured grid, 58 validation, 180
van Leer scheme, 42
velocity decomposition, 67
verification, 180
virtual mass force, 148
viscosity models, 22
viscous dissipation, 17
viscous stress, 10
volume fraction, 144
volume-of-fluid (VOF) model, 150, 158
von Kármán constant, 81
vortex stretching, 74
vorticity, 74

wall friction velocity, 103
wall functions, 104–7
best-practice guidelines, 177
non-equilibrium, 106
standard, 104
wave number, 75
Weber number, 160

 $y^{+}, 103$