Table of contents

1 Fluid dynamic principles	1
1.1 Flow in the absolute and relative reference frame	1
1.2 Conservation equations	2
1.2.1 Conservation of mass	2
1.2.2 Conservation of energy	3
1.2.3 Conservation of momentum	4
1.3 Boundary layers, boundary layer control	7
1.4 Flow on curved streamlines	11
1.4.1 Equilibrium of forces	
1.4.2 Forced and free vortices	
1.4.3 Flow in curved channels	16
1.5 Pressure losses	18
1.5.1 Friction losses (skin friction)	
1.5.2 Influence of roughness on friction losses	21
1.5.3 Losses due to vortex dissipation (form drag)	25
1.6 Diffusers	27
1.7 Submerged jets	31
1.8 Equalization of non-uniform velocity profiles	33
1.9 Flow distribution in parallel channels, piping networks	34
	20
2 Pump types and performance data	
2.1 Basic principles and components	
2.2 Performance data	
2.2.1 Specific work, head	
2.2.2 Net positive suction head, NPSH	
2.2.3 Power and efficiency	
2.2.4 Pump characteristics	
2.3 Pump types and their applications	
2.3.1 Overview	
2.3.2 Classification of pumps and applications	
2.3.3 Pump types	
2.3.4 Special pump types	
3 Pump hydraulics and physical concepts	69
3.1 One-dimensional calculation with velocity triangles	
3.2 Energy transfer in the impeller, specific work and head	
3.3 Flow deflection caused by the blades. Slip factor	

3.4 Dimensionless coefficients, similarity laws and specific speed	80
3.5 Power balance and efficiencies	
3.6 Calculation of secondary losses	85
3.6.1 Disk friction losses	85
3.6.2 Leakage losses through annular seals	89
3.6.3 Power loss caused by the inter-stage seal	98
3.6.4 Leakage loss of radial or diagonal seals	98
3.6.5 Leakage losses in open impellers	99
3.6.6 Mechanical losses	101
3.7 Basic hydraulic calculations of collectors	102
3.8 Hydraulic losses	107
3.9 Statistical data of pressure coefficients, efficiencies and losses	
3.10 Influence of roughness and Reynolds number	120
3.10.1 Overview	
3.10.2 Efficiency scaling	121
3.10.3 Calculation of the efficiency from loss analysis	123
3.11 Minimization of losses	129
3.12 Compendium of equations for hydraulic calculations	130
4 Performance characteristics	145
4.1 Head-capacity characteristic and power consumption	
4.1.1 Theoretical head curve (without losses)	
4.1.2 Real characteristics with losses	
4.1.3 Component characteristics	
4.1.4 Head and power at operation against closed discharge valve	
4.1.5 Influence of pump size and speed	
4.1.6 Influence of specific speed on the shape of the characteristics	160
4.2 Best efficiency point	
4.3 Prediction of pump characteristics	
4.4 Range charts	
4.5 Modification of the pump characteristics	
4.5.1 Impeller trimming	
4.5.2 Under-filing and over-filing of the blades at the trailing edge.	
4.5.3 Collector modifications	
4.6 Analysis of performance deviations	
4.7 Calculation of modifications of the pump characteristics	
5 Partload operation, impact of 3-D flow phenomena performance	197
5.1 Basic considerations	
5.2 The flow through the impeller	
5.2.1 Overview	
5.2.2 Physical mechanisms	
5.2.3 The combined effect of different mechanisms	
5.2.4 Recirculation at the impeller inlet	
5.2.5 Flow at the impeller outlet	
TIOW At the imperel outlet	,∠∪0

	5.2.6 Experimental detection of the onset of recirculation	207
	5.3 The flow in the collector	
	5.3.1 Flow separation in the diffuser	
	5.3.2 Pressure recovery in the diffuser	
	5.3.3 Influence of approach flow on pressure recovery and stall	
	5.3.4 Flow in the volute casing	
	5.3.5 Flow in annular casings and vaneless diffusers	
	5.4 The effects of flow recirculation	216
	5.4.1 Effects of flow recirculation at the impeller inlet	216
	5.4.2 Effect of flow recirculation at the impeller outlet	
	5.4.3 Effect of outlet recirculation on the flow in the impeller sidewall	gaps
	and on axial thrust	
	5.4.4 Damaging effects of partload recirculation	229
	5.5 Influence of flow separation and recirculation on the Q-H-curve	230
	5.5.1 Types of Q-H-curve instability	230
	5.5.2 Saddle-type instabilities	231
	5.5.3 Type F instabilities	240
	5.6 Means to influence the shape of the Q-H-curve	240
	5.6.1 Introduction	
	5.6.2 Influencing the onset of recirculation at the impeller inlet	
	5.6.3 Influencing the onset of recirculation at the impeller outlet	
	5.6.4 Eliminating a type F instability	242
	5.6.5 Influencing the saddle-type instability of impellers with $n_q < 50$	
	5.6.6 Influencing the saddle-type instability of impellers with $n_q > 50$	
	5.6.7 Influencing the instability of semi-axial and axial impellers	
	5.6.8 Reduction of head and power at shut-off	
	5.7 Flow phenomena in open axial impellers	250
6	Suction capability and cavitation	
	6.1 Cavitation physics	
	6.1.1 Growth and implosion of vapor bubbles in a flowing liquid	
	6.1.2 Bubble dynamics	
	6.2 Cavitation in impeller or diffuser	
	6.2.1 Pressure distribution and cavity length	
	6.2.2 Required NPSH, extent of cavitation, cavitation criteria	
	6.2.3 Scaling laws for cavitating flows	
	6.2.4 The suction specific speed	
	6.2.5 Experimental determination of the required NPSH _R	
	6.2.6 Cavitation in annular seals	
	6.3 Determination of the required NPSH	
	6.3.1 Parameters influencing NPSH _R	
	6.3.2 Calculation of the NPSH _R	
	6.3.3 Estimation of the NPSH ₃ as function of the flow rate	
	6.4 Influence of the fluid properties	
	6.4.1 Thermodynamic effects	294

6.4.2 Non-condensable gases	290
6.4.3 Nuclei content and tensile stresses in the liquid	297
6.5 Cavitation-induced noise and vibrations	300
6.5.1 Excitation mechanisms	300
6.5.2 Cavitation noise measurements	
6.5.3 Frequency characteristics of cavitation noise	304
6.6 Cavitation erosion	305
6.6.1 Testing methods	306
6.6.2 Cavitation resistance	
6.6.3 Prediction of cavitation damage based on cavity length	311
6.6.4 Prediction of cavitation damage based on cavitation noise	
6.6.5 Solid-borne noise measurements for cavitation diagnosis	
6.6.6 Paint erosion tests to determine the location of bubble implosic	n316
6.6.7 Onset of erosion and behavior of material subject to different	
hydrodynamic cavitation intensities	
6.6.8 Summarizing assessment.	
6.7 Selection of the inlet pressure in a plant	
6.8 Cavitation damage: analysis and remedies	
6.8.1 Record damage and operation parameters	
6.8.2 Forms of cavitation and typical cavitation damage patterns	
6.8.3 Reduction or elimination of cavitation damage	
6.9 Insufficient suction capacity: Analysis and remedies	335
7 Design of the hydraulic components	227
7.1 Methods and boundary conditions	337
7.1 Methods and boundary conditions	337 337
7.1 Methods and boundary conditions	337 337 338
7.1 Methods and boundary conditions	337 337 338
7.1 Methods and boundary conditions	337 337 338 341
7.1 Methods and boundary conditions	337 338 339 341
7.1 Methods and boundary conditions	337 338 339 341 350
7.1 Methods and boundary conditions	337 338 341 350 355
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design	337338341350358
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design	337338341350355358
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design	337338341350355358360361
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades	337338341350355358361361
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades 7.3.2 Pumping disks with channels of circular section	337338341350355360361363
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades 7.3.2 Pumping disks with channels of circular section 7.3.3 Impellers with straight radial blades	337338341350355358361363365
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components. 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades 7.3.2 Pumping disks with channels of circular section 7.3.3 Impellers with straight radial blades 7.3.4 Double-acting impeller with straight radial blades	337338341350355361361363365366
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades 7.3.2 Pumping disks with channels of circular section 7.3.3 Impellers with straight radial blades 7.3.4 Double-acting impeller with straight radial blades 7.4 Radial impellers for non-clogging pumps	337338341350355360361363365366368
7.1 Methods and boundary conditions 7.1.1 Methods for the development of hydraulic components. 7.1.2 The hydraulic specification 7.1.3 Calculation models 7.2 Radial impellers 7.2.1 Determination of main dimensions 7.2.2 Impeller design 7.2.3 Criteria for shaping the blades 7.2.4 Criteria for suction impeller design 7.2.5 Exploiting three-dimensional effects in design 7.3 Radial impellers for small specific speeds 7.3.1 Two-dimensional blades 7.3.2 Pumping disks with channels of circular section 7.3.3 Impellers with straight radial blades 7.3.4 Double-acting impeller with straight radial blades	337338341350355368365368368
7.1 Methods and boundary conditions. 7.1.1 Methods for the development of hydraulic components. 7.1.2 The hydraulic specification. 7.1.3 Calculation models. 7.2 Radial impellers. 7.2.1 Determination of main dimensions. 7.2.2 Impeller design. 7.2.3 Criteria for shaping the blades. 7.2.4 Criteria for suction impeller design. 7.2.5 Exploiting three-dimensional effects in design. 7.3 Radial impellers for small specific speeds. 7.3.1 Two-dimensional blades. 7.3.2 Pumping disks with channels of circular section. 7.3.3 Impellers with straight radial blades. 7.3.4 Double-acting impeller with straight radial blades. 7.5 Semi-axial impellers for non-clogging pumps. 7.5 Semi-axial impellers and diffusers. 7.6 Axial impellers and diffusers. 7.6.1 Features.	337338341350355358361361363365368374378
7.1 Methods and boundary conditions. 7.1.1 Methods for the development of hydraulic components. 7.1.2 The hydraulic specification. 7.1.3 Calculation models. 7.2 Radial impellers. 7.2.1 Determination of main dimensions. 7.2.2 Impeller design. 7.2.3 Criteria for shaping the blades. 7.2.4 Criteria for suction impeller design. 7.2.5 Exploiting three-dimensional effects in design. 7.3 Radial impellers for small specific speeds. 7.3.1 Two-dimensional blades. 7.3.2 Pumping disks with channels of circular section. 7.3.3 Impellers with straight radial blades. 7.3.4 Double-acting impeller with straight radial blades. 7.5 Semi-axial impellers. 7.6 Axial impellers and diffusers.	337338341350355358361361363365368374378

	7.6.4 Blade design	389
	7.6.5 Profile selection	393
	7.6.6 Design of axial diffusers	400
	7.7 Inducers	
	7.7.1 Calculation of inducer parameters	
	7.7.2 Design and shaping of an inducer	407
	7.7.3 Matching the inducer to the impeller	409
	7.7.4 Recommendations for inducer application	410
	7.8 Volute casings	412
	7.8.1 Calculation and selection of main dimensions	412
	7.8.2 Design and shaping of volute casings	416
	7.8.3 Influence of the volute shape on hydraulic performance	420
	7.9 Radial diffusers with or without return channels	
	7.9.1 Calculation and selection of main dimensions	422
	7.9.2 Design and shaping of radial diffusers	428
	7.10 Semi-axial diffusers	
	7.11 Volutes combined with a diffuser or stay vanes	
	7.12 Annular casings and vaneless diffusers	
	7.13 Inlet casings for between-bearing pumps	
8	Numerical flow calculations	439
	8.1 Overview	439
	8.2 Quasi-3D-procedures and 3D-Euler-calculations	441
	8.2.1 Quasi-3D- procedures	441
	8.2.2 Three-dimensional Euler-procedures	442
	8.3 Basics of Navier-Stokes calculations	443
	8.3.1 The Navier-Stokes equations	443
	8.3.2 Turbulence models	444
	8.3.3 Treatment of near-wall flows	449
	8.3.4 Grid generation	451
	8.3.5 Numerical procedures and control parameters	454
	8.3.6 Boundary conditions	456
	8.3.7 Initial conditions	
	8.3.8 Possibilities of 3D-Navier-Stokes-calculations	459
	8.4 Averaging and post-processing	462
	8.5 Impeller calculations	
	8.5.1 Global performance at best efficiency flow rate	
	8.5.2 Velocity profiles	
	8.5.3 Influencing parameters	
	8.5.4 Sample calculation	
	8.6 Calculation of collectors and stages	
	8.6.1 Separate calculation of the collector	
	8.6.2 Steady calculations of stages or complete pumps	477
	8.6.3 Unsteady calculations	
	8.7 Two-phase and cavitating flows	

8.8 Calculation strategy, uncertainties, quality issues	482
8.8.1 Uncertainties, sources and reduction of errors	483
8.8.2 CFD quality assurance	485
8.8.3 Comparison between calculation and experiment	496
8.9 Criteria for assessment of numerical calculations	
8.9.1 General remarks	498
8.9.2 Consistence and plausibility of the calculation	499
8.9.3 Will the specified performance be reached?	
8.9.4 Maximization of the hydraulic efficiency	
8.9.5 Stability of the head-capacity curve	502
8.9.6 Unsteady forces	503
8.10 Fundamental considerations on CFD-calculations	503
9 Hydraulic forces	507
9.1 Flow phenomena in the impeller sidewall gaps	
9.2 Axial forces	
9.2.1 General procedure for calculating axial forces	520
9.2.2 Single-stage pumps with single-entry overhung impellers	523
9.2.3 Multistage pumps	527
9.2.4 Double-entry impellers	531
9.2.5 Semi-axial impellers	532
9.2.6 Axial pumps	
9.2.7 Expeller vanes	
9.2.8 Semi-open and open impellers	535
9.2.9 Unsteady axial thrust	536
9.3 Radial forces	536
9.3.1 Definition and scope	
9.3.2 Measurement of radial forces	
9.3.3 Pumps with single volutes	539
9.3.4 Pumps with double volutes	
9.3.5 Pumps with annular casings	
9.3.6 Diffuser pumps	
9.3.7 Radial forces created by non-uniform approach flows	
9.3.8 Axial pumps	547
9.3.9 Radial forces in pumps with single-channel impellers	548
9.3.10 Radial thrust balancing	
9.3.11 Radial thrust prediction	550
10 Noise and Vibrations	
10.1 Unsteady flow at the impeller outlet	
10.2 Pressure pulsations	558
10.2.1 Generation of pressure pulsations	
10.2.2 Noise generation in a fluid	
10.2.3 Influence parameters of the pump	
10.2.4 Influence of the system	561

	10.2.5 Scaling laws	562
	10.2.6 Measurement and evaluation of pressure pulsations	563
	10.2.7 Pressure pulsations of pumps in operation	565
	10.2.8 Damaging effects of pressure pulsations	
	10.2.9 Design guidelines	568
	10.3 Component loading by transient flow conditions	569
	10.4 Radiation of noise	571
	10.4.1 Solid-borne noise	571
	10.4.2 Air-borne noise	572
	10.5 Overview of mechanical vibrations of centrifugal pumps	575
	10.6 Rotor dynamics	
	10.6.1 Overview	577
	10.6.2 Forces in annular seals	578
	10.6.3 Hydraulic impeller interaction	585
	10.6.4 Bearing reaction forces	586
	10.6.5 Eigen values and critical speeds	
	10.6.6 Rotor instabilities	590
	10.7 Hydraulic excitation of vibrations	593
	10.7.1 Interactions between impeller and diffuser blades (RSI)	593
	10.7.2 Rotating stall	600
	10.7.3 Other hydraulic excitation mechanisms	
	10.8 Guidelines for the design of pumps with low sensitivity to vibrations	606
	10.9 Allowable vibrations	609
	10.10 General vibration diagnostics	
	10.10.1 Overview	
	10.10.2 Vibration measurements	
	10.10.3 Vibration diagnostics	
	10.11 Bearing housing vibrations: mechanism, diagnostics, remedies	
	10.11.1 Hydraulic excitation mechanisms	
	10.11.2 Mechanical reaction to hydraulic excitation	
	10.11.3 Hydraulic versus mechanical remedies	630
	10.11.4 Bearing housing vibration diagnostics	
	10.12 Hydraulic and acoustic excitation of pipe vibrations	
	10.12.1 Excitation of pipe vibrations by pumps	
	10.12.2 Excitation of pipe vibrations by components	
	10.12.3 Acoustic resonances in pipelines	
	10.12.4 Hydraulic excitation by vortex streets	650
	10.12.5 Coupling of flow phenomena with acoustics	
	10.12.6 Pipe vibration mechanisms	
	10.13 Torsional vibrations	660
11	Operation of centrifugal pumps	
	11.1 System characteristics, operation in parallel or in series	
	11.2 Pump control	
	11.3 Static and dynamic stability	677

11.4 Start-up and shut-down	679
11.5 Power failure, water hammer	683
11.6 Allowable operation range	684
11.7 The approach flow to the pump	
11.7.1 Suction piping layout	
11.7.2 Transient suction pressure decay	690
11.7.3 Pump intakes and suction from tanks with free liquid level	
11.7.4 Can pumps	711
11.8 Discharge piping	711
12 Turbine operation, general characteristics	715
12.1 Reverse running centrifugal pumps used as turbines	
12.1.1 Theoretical and actual characteristics	
12.1.2 Runaway and resistance characteristics	
12.1.3 Estimation of turbine characteristics from statistical correlation	
12.1.4 Estimation of turbine characteristics from loss models	
12.1.5 Behavior of turbines in plants	
12.2 General characteristics	
13 Influence of the medium on performance	741
13.1 Pumping highly viscous fluids	
13.1.1 Effect of viscosity on losses and performance characteristics	
13.1.2 Estimation of viscous performance from the characteristics n	
with water	748
13.1.3 Influence of viscosity on the suction capacity	754
13.1.4 Start-up of pumps in viscous service	
13.1.5 Viscous pumping applications - recommendations and comm	
13.2 Pumping of gas-liquid mixtures	
13.2.1 Two-phase flow patterns in straight pipe flow	758
13.2.2 Two-phase flow in pumps. Physical mechanisms	761
13.2.3 Calculation of two-phase pump performance	770
13.2.4 Radial pumps operating with two-phase flow	777
13.2.5 Helico-axial multiphase pumps	
13.2.6 System curves	786
13.2.7 Slugs and gas pockets	788
13.2.8 Free gas, dissolved gas and NPSH	790
13.3 Expansion of two-phase mixtures in turbines	791
13.3.1 Calculation of the work transfer	
13.3.2 Prediction of turbine characteristics for two-phase flow	
13.4 Hydraulic transport of solids	796
13.5 Non-Newtonian liquids	804
4 Selection of materials exposed to high flow velocities	809
14.1 Impeller or diffuser fatigue fractures	810
14.2 Corrosion	

14.2.2 Corrosion mechanisms 82 14.2.3 Corrosion in fresh water, cooling water, sewage 82 14.2.4 Corrosion in sea water and produced water 83 14.3 Erosion corrosion in demineralized water 83 14.4 Material selection and allowable flow velocities 84 14.4.1 Definition of frequently encountered fluids 84 14.4.2 Metallic pump materials 84 14.4.3 Impellers, diffusers and casings 85 14.4.5 Shaft materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality criteria 89 15.3.2 Manufacturing quality criter	14.2.1 Corrosion fundamentals	822
14.2.4 Corrosion in sea water and produced water 83 14.3 Erosion corrosion in demineralized water 83 14.4 Material selection and allowable flow velocities 84 14.4.1 Definition of frequently encountered fluids 84 14.4.2 Metallic pump materials 84 14.4.2 Metallic pump materials 85 14.4.3 Impellers, diffusers and casings 85 14.4.5 Shaft materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 <th>14.2.2 Corrosion mechanisms</th> <th>823</th>	14.2.2 Corrosion mechanisms	823
14.3 Erosion corrosion in demineralized water 83: 14.4 Material selection and allowable flow velocities. 84 14.4.1 Definition of frequently encountered fluids 84 14.4.2 Metallic pump materials 84 14.4.3 Impellers, diffusers and casings 85: 14.4.4 Wear ring materials 86: 14.4.5 Shaft materials 86: 14.4.6 Materials for feedwater and condensate pumps 86: 14.4.7 Materials for FGD-pumps 86: 14.5 Hydro-abrasive wear 87: 14.5.1 Influence parameters 87: 14.5.2 Quantitative estimation of hydro-abrasive wear 87: 14.5.3 Material behavior and influence of solids properties 88: 14.5.4 Material selection 88: 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88: 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91	14.2.3 Corrosion in fresh water, cooling water, sewage	827
14.4 Material selection and allowable flow velocities 84 14.4.1 Definition of frequently encountered fluids 84 14.4.2 Metallic pump materials 84 14.4.3 Impellers, diffusers and casings 85 14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 APpendices 91 A1 Units and	14.2.4 Corrosion in sea water and produced water	830
14.4.1 Definition of frequently encountered fluids 84 14.4.2 Metallic pump materials 84 14.4.3 Impellers, diffusers and casings 85 14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5.1 Influence parameters 87 14.5.2 Influence parameters 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 <th>14.3 Erosion corrosion in demineralized water</th> <th>835</th>	14.3 Erosion corrosion in demineralized water	835
14.4.2 Metallic pump materials 84 14.4.3 Impellers, diffusers and casings 85 14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 <th>14.4 Material selection and allowable flow velocities</th> <th>844</th>	14.4 Material selection and allowable flow velocities	844
14.4.3 Impellers, diffusers and casings 85 14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for Fed-pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4.1 Atmospheric pressure 91 A5 So	14.4.1 Definition of frequently encountered fluids	844
14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.5 Abrasive wear in slurry pumps 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92		
14.4.4 Wear ring materials 86 14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.5 Abrasive wear in slurry pumps 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92	14.4.3 Impellers, diffusers and casings	852
14.4.5 Shaft materials 86 14.4.6 Materials for feedwater and condensate pumps 86 14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92	14.4.4 Wear ring materials	863
14.4.7 Materials for FGD-pumps 86 14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 93	14.4.5 Shaft materials	866
14.4.8 Composite materials 86 14.5 Hydro-abrasive wear 87 14.5.1 Influence parameters 87 14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 93	14.4.6 Materials for feedwater and condensate pumps	867
14.5 Hydro-abrasive wear. 870 14.5.1 Influence parameters 870 14.5.2 Quantitative estimation of hydro-abrasive wear. 871 14.5.3 Material behavior and influence of solids properties 881 14.5.4 Material selection 881 14.5.5 Abrasive wear in slurry pumps 881 15 Pump selection and quality considerations 881 15.1 The pump specification 881 15.2 Determination of pump type and size 891 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95	14.4.7 Materials for FGD-pumps	868
14.5 Hydro-abrasive wear. 870 14.5.1 Influence parameters 870 14.5.2 Quantitative estimation of hydro-abrasive wear. 871 14.5.3 Material behavior and influence of solids properties 881 14.5.4 Material selection 881 14.5.5 Abrasive wear in slurry pumps 881 15 Pump selection and quality considerations 881 15.1 The pump specification 881 15.2 Determination of pump type and size 891 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95		
14.5.2 Quantitative estimation of hydro-abrasive wear 87 14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
14.5.3 Material behavior and influence of solids properties 88 14.5.4 Material selection 88 14.5.5 Abrasive wear in slurry pumps 88 15 Pump selection and quality considerations 88 15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93	14.5.2 Quantitative estimation of hydro-abrasive wear	873
14.5.5 Abrasive wear in slurry pumps		
14.5.5 Abrasive wear in slurry pumps		
15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
15.1 The pump specification 88 15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93	15 Pump selection and quality considerations	887
15.2 Determination of pump type and size 89 15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93	15.1 The numn specification	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
15.3 Technical quality criteria 89 15.3.1 Hydraulic criteria 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
15.3.1 Hydraulic criteria. 89 15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
15.3.2 Manufacturing quality 89 15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
15.4 High-energy pumps 90 Appendices 91 A1 Units and unit conversion 91 A2 Properties of saturated water 91 A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
A1 Units and unit conversion		
A1 Units and unit conversion		011
A2 Properties of saturated water		
A3 Solution of gases in water 91 A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
A4 Physical constants 91 A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
A4.1 Atmospheric pressure 91 A4.2 Acceleration due to gravity 91 A5 Sound velocity in liquids 92 A6 Mechanical vibrations - basic notions 92 Index 95 Literature 93		
A4.2 Acceleration due to gravity		
A5 Sound velocity in liquids		
A6 Mechanical vibrations - basic notions		
Index95 Literature93		
Literature93	A6 Mechanical vibrations - basic notions	921
	Index	957
Symbols, abbreviations, definitions	Literature	931
	Symbols, abbreviations, definitions	XXII