Contents

Foreword ix
Jean-Luc ACHARD

Preface xiii

Acknowledgments xv

Introduction xvii

Chapter 1. Revision of Fluid Mechanics 1

1.1. Euler's equations 1
1.2. Head and Bernoulli's theorem 4
1.3. Hydrostatics and variation of pressure in a direction perpendicular to a streamline 8
1.4. Linear head losses 9
1.5. Singular head losses 12
1.6. Head variation along a streamline 13
1.7. Kinetic energy balance on a fluid volume 14
1.8. Momentum theorem 19
1.9. Angular momentum theorem 22
1.10. Irrotational flows, potential flows 23

Chapter 2. Hydraulic Turbomachines 25

2.1. General information on turbomachinery 25
2.1.1. Turbopumps and turbines 25
2.1.2. Notions of aerodynamics 27
2.1.3. Principle of mechanical conversion: force and power, velocity triangle, fixed reference and mobile reference 29
2.1.4. Rotor and stator 33
2.1.5. Machine with infinite number of blades 34
2.1.6. Similarity of Combe–Rateau 35
2.1.7. Specific speed and classification of roto-dynamic machines 37
2.2. Pump dimensioning 38
2.2.1. Classification of roto-dynamic pumps. 38
2.2.2. Centrifugal pumps 40
2.3. Turbine dimensioning. 42
2.3.1. Classification of roto-dynamic turbines 42
2.3.2. Dimensioning of Pelton turbines 45
2.4. Exercise: centrifugal pump model 50
2.4.1. Solution. 55
2.5. Exercise: radial flow turbine model 67
2.5.1. Solution. 70

Chapter 3. Wind Power 81

3.1. General 81
3.1.1. The wind resource 81
3.1.2. Energy conversion by a wind turbine 82
3.1.3. The development of the wind power sector in France and in Europe 85
3.2. Exercise: flow through a wind turbine – Betz formula 88
3.2.1. Solution. 91
3.3. Exercise: wind turbine rotor model 97
3.3.1. Solution. 101

Chapter 4. Tidal Energy 111

4.1. General information and status of the sector 111
4.2. Exercise: energy model of the Rance plant 118
4.2.1. Solution. 120
4.3. Exercise: sizing a Kaplan turbine 126
4.3.1. Solution. 129

4.4. Exercise: marine current turbines farm and modification of currents . . . 137
4.4.1. Solution. . . . 141

Chapter 5. Hydroelectric Power . . . 151

5.1. Hydroelectric power history and data . . . 151
5.2. Exercise: maximum power provided by a hydroelectric power station . . . 155
5.2.1. Solution. . . . 156
5.3. Exercise: dimensioning of a PSH power plant . . . 160
5.3.1. Part I – turbine study . . . 163
5.3.2. Part II – study of pumping. . . . 163
5.3.3. Part III – production plants and operation of the hydroelectric power station . . . 164
5.3.4. Solution. . . . 166

Chapter 6. Osmotic Energy . . . 175

6.1. The phenomenon of osmosis. . . . 175
6.2. Exercise: sizing an electricity production system using osmotic energy. . . . 177
6.2.1. Solution. . . . 182
6.3. State of the art of osmotic energy technology. . . . 189

Chapter 7. Ocean Thermal Energy Conversion . . . 193

7.1. The OTEC process . . . 193
7.2. Exercise: sizing an OTEC installation using a closed Rankine cycle. . . . 197
7.2.1. Sizing of the closed Rankine cycle. . . . 197
7.2.2. Sizing of heat exchangers . . . 202
7.2.3. Sizing of deep sea water pumping and conclusions . . . 213
7.3. State of play of the OTEC sector . . . 216
7.4. Guide to sizing a heat exchanger . . . 217

Chapter 8. Wave Energy . . . 223

8.1. Surface gravity wave theory . . . 223
8.1.1. General . . . 223
8.1.2. Kinematics of linear surface waves . . . 226
8.1.3. Wave energy and energy flow . . . 230

8.1.4. Reflection of a wave by a vertical wall 233
8.1.5. A laboratory experiment achieving total recovery of the wave energy flow. 234
8.1.6. Recovery of wave energy by an oscillating flap or by a heaving buoy 235
8.2. Exercise: sizing an oscillating flap wave energy converter 237
8.2.1. Solution. 241
8.3. State of play on wave energy recovery. 252

References 259

Index 261