

Contents

<i>Contributors</i>	xi
<i>Preface</i>	xiii
1 Historical development of strategy for steam power	
<i>Seikan Ishigai</i>	1
1.1 The field of steam power	1
1.2 Fundamental characteristics from a technological viewpoint	1
1.3 A brief history of steam power development	4
1.4 Strategy at transition to the new technological era	6
1.5 Three tools of strategy making for technology	7
1.5.1 Intrinsic laws of technology development	7
1.5.2 Transition period theory	8
1.5.3 Recognition of the present state of technology	9
1.6 Position of present technology in historical eras	11
1.6.1 Division of total technology into eras	11
1.6.2 Division of power technology into eras	12
1.6.3 Present power technology in historical eras	12
1.7 Proposed strategy for power technology development	13
1.8 Fossil-fuel-fired steam power technology development	15
1.9 Emergence of intrinsic laws of boiler development through the interplay of natural and social laws of production	16
1.9.1 Introduction	16
1.9.2 From the ancestors to the emergence of the primitive boiler	18
1.9.3 Scale-up of the primitive boiler	20
1.9.4 Emergence of the cylindrical boiler as the first proper class of boiler	21
1.9.5 Transition to the natural circulation water-tube boiler via an intermediate type	23

1.9.6	Initial divergences for meeting the new era of the once-through boiler	29
1.9.7	Challenges by forced-flow groups	30
1.9.8	Transition to the once-through boiler via an intermediate type	35
1.9.9	Concluding remarks	37
1.10	Proposed strategy and suggestions for boiler development	38
	References	41
2	Thermodynamic design of the steam power plant cycle	
	<i>Shigeyasu Nakanishi and Terushige Fujii (Section 2.4)</i>	42
2.1	Thermodynamic fundamentals of assessment of energy conversion	42
2.1.1	Introduction to exergy	42
2.1.2	Principle of assessment of energy conversion process	46
2.2	Thermodynamic analysis of energy conversion in steam power plants	55
2.2.1	General discussion of energy conversion in steam power plants	55
2.2.2	Maximization of exergy efficiency of steam generators	58
2.2.3	Exergy analysis of cogeneration plants	60
2.2.4	Exergy analysis of combined cycle plants	61
2.3	The Rankine cycle	63
2.3.1	General discussion of the Rankine cycle	63
2.3.2	Working fluids for the Rankine cycle	67
2.3.3	Regenerative and reheat cycles	73
2.4	Steam power plants for practical use	87
2.4.1	Classification	87
2.4.2	The saturated steam Rankine cycle	87
2.4.3	The superheated steam Rankine cycle	92
2.4.4	The total flow turbine system	96
2.4.5	The flash turbine system	99
2.4.6	The hybrid system	100
2.4.7	The two-fluid cycle	100
2.4.8	The combined cycle	103
2.4.9	Liquified natural gas (electric) power generation	108
	References	111
3	General planning of the boiler gas-side heat transfer surface	
	<i>Eiichi Nishikawa</i>	113
3.1	The gas-side heat transfer surface and its technological problems	113

3.1.1	Heat recovery section	113
3.1.2	Superheater and reheater	113
3.1.3	Furnace (combustion chamber)	114
3.2	General planning of the boiler furnace	115
3.2.1	Performance limits of boiler furnace design	115
3.2.2	Effects of performance limits on design factors	116
3.2.3	General trend of specific furnace heat release rate q_f	119
3.2.4	Similarity law of the boiler furnace	120
3.2.5	New boiler concepts breaking through the similarity law of conventional boilers	122
3.3	Pollutant control techniques	126
3.3.1	Environmental problems and fossil-fuel-fired boilers	126
3.3.2	General principles of pollution control	128
3.3.3	Low NO _x combustion techniques	129
3.3.4	Coal gasification	139
3.3.5	Removal of pollutants from flue gas	145
3.4	Flow and heat transfer of convective HTS	151
3.4.1	Heat transfer of cross-flow tube banks	151
3.4.2	Extended HTSs	160
3.5	Vibration induced by gas flow	164
3.5.1	Gas column resonance	165
3.5.2	Tube vibration	170
3.6	Gas-side fouling and corrosion	178
3.6.1	The struggle against corrosion	178
3.6.2	Fouling and corrosion of oil-fired boilers	180
3.6.3	Fouling and corrosion of coal-fired boilers	189
3.6.4	Impact of fouling on heat transfer	195
3.6.5	Countermeasures against gas-side fouling and corrosion	197
	References	200
4	Thermal and hydraulic design of steam-generating systems	
	<i>Koji Akagawa</i>	204
4.1	Two-phase flow in steam-generating tubes	204
4.1.1	Flow pattern in vertical and horizontal tubes	204
4.1.2	Prediction method of stratified flow pattern	207
4.1.3	Two-phase flow in vertical serpentine tubes	210
4.2	Boiling heat transfer in steam-generating tubes	215
4.2.1	Axial distributions of wall temperature and heat transfer coefficient	215
4.2.2	Heat transfer in the subcooled boiling region	218

4.2.3	Heat transfer in saturated nucleate boiling and saturated forced convection boiling regions	220
4.2.4	Heat transfer in the post-dryout region	222
4.2.5	Heat transfer at high heat flux	230
4.3	Basic equations and flow characteristics of gas-liquid two-phase flows	238
4.3.1	Conservation equations of mass and momentum	238
4.3.2	Void fraction	240
4.3.3	Pressure drops	242
4.4	Thermohydraulic aspects of the evolution of electricity-generating plants	245
4.5	Thermal and hydraulic design of natural-circulation boilers	250
4.5.1	Principles of natural water circulation and characteristics of circulation velocity	250
4.5.2	Design criteria and typical values for the circulation loop	255
4.6	Thermal and hydraulic design of once-through boilers	259
4.6.1	Constitution of the flow system	259
4.6.2	Design of the furnace water wall	263
4.6.3	Critical heat flux and critical mass flow rate	266
4.6.4	Mass flux and pressure drop in each flow system	270
4.6.5	Small-capacity once-through boilers	272
4.7	Thermal and hydraulic design of forced-circulation boilers	273
4.7.1	Constitution of the flow system	274
4.7.2	Circulation ratio as a design criterion	276
4.7.3	Determination of mass flux in tubes	281
4.8	Thermal and hydraulic design of boiling water reactors	284
4.8.1	System overview and fuel assembly structure	285
4.8.2	Thermal conditions in the reactor core	289
4.8.3	Thermal design principle and evolution of the boiling water reactor	295
4.8.4	Thermal design criteria of reactor core channels	298
4.8.5	Evolution of critical heat flux research and the design criteria of reactor cores	304
4.9	Thermal and hydraulic design of pressurized water reactors	306
4.9.1	System overview of the pressurized water reactor	306
4.9.2	Reactor core structure and thermal conditions	308
4.9.3	Thermal design criteria for the reactor core	312
4.9.4	Steam generators	318
	References	321

5 Flow instability problems in steam-generating tubes	
<i>Mamoru Ozawa</i>	323
5.1 The role of dynamic behavior of thermal hydraulics in steam-generating plant design	323
5.2 Phenomenological description of flow instabilities	324
5.3 Classification of flow instabilities	328
5.4 Flow excursion and flow maldistribution	332
5.5 Pressure drop oscillation	340
5.6 Geysering	346
5.7 Density wave oscillation	347
5.7.1 General feature of density wave oscillation	350
5.7.2 Mechanism of oscillation	353
5.7.3 Block diagram and the role of the pressure-boundary condition	358
5.7.4 Simplified stability criterion	361
5.8 Linear stability analysis of density wave oscillation	363
5.8.1 Model description	364
5.8.2 Dynamic behavior in the single-phase region	365
5.8.3 Dynamic behavior in the two-phase region	366
5.8.4 Boiling-boundary dynamics	369
5.8.5 Dynamic behavior of pressure drop and stability analysis	371
5.8.6 Scaling law in flow stability problems	376
5.9 Nonlinear analysis of flow instability	376
5.10 Computer code for flow stability analysis	379
5.11 Numerical simulation on thermal hydraulics of two-phase flow	380
References	383
<i>Appendix: Exergy–enthalpy diagram of steam</i>	387
<i>Index</i>	391