Paper and Water: A Guide for Conservators

Gerhard Banik
Irene Bruckle

With contributions by

Vincent Daniels
Stefan Fischer
D. Steven Keller
Joanna M. Kosek
Remhard Lacher
Anthony W. Smith
Alfred Vendl
Gunther Wegele
Paul M. Whitmore

The printing was financially supported by the former Institute of Paper Conservation (IPC), today part of Icon and ICCROM. The project 112 693 “Water in Paper” has been funded with support from the European Commission. This publication reflects the views only of the authors, and neither the Commission, nor other donors can be held responsible for any use which may be made of the information contained therein.
Paper and Water:
A Guide for Conservators

Contents

Foreword from the perspective of the conservator xiv
Kate Colleran

Foreword from the perspective of the conservation scientist xv
Jan Wouters

Introduction xvii
Gerhard Banik and Irene Bruckle

User's Guide xxm

Acknowledgements xxix

1 Relevant Chemistry 1
Gerhard Banik

1.1 Basic principles 2
1.2 Covalent and ionic bonding 9
1.3 Electronegativity 12
1.4 Hydrogen bonding 14
1.5 Van derWaals forces 16
1.6 Carbon and glucose 16
Summary 21

2 Properties of Water 23
Gerhard Banik

2.1 Molecular structure 24
2.2 Surface tension 27
2.3 Viscosity 30
2.4 Volatility 31
2.5 Aggregate states of water 34
Paper and Water

2.6 Dissolution/dissolving ability 36
2.7 Solubility of organic liquids in water 39
2.8 Ionic components in natural water 41
2.9 Hardness of water 43
2.10 Water purification 46
2.11 Purified water in paper conservation 52
Summary 52
Interaction between water molecules (DVD Video 2.1)

3 Dissociation of Water: Acids and Bases 57
Gerhard Banik

3.1 Dissociation of water 58
3.2 Acids and bases 61
3.3 The hydronium ion (H$_3$O$^+$) 64
3.4 Strength of acids and bases 65
3.5 The pH concept 69
3.6 The pH of salt solutions 73
3.7 Buffer solutions - the carbonate buffer 76
Summary 78

4 Structure and Properties of Dry and Wet Paper 81
Irene Brucke

4.1 Cellulose structure 83
4.2 States of water absorption in cellulose 87
4.3 Gel and hysteresis properties of cellulose 94
4.4 The structure of dry and wet paper 97
4.5 The porosity of paper 109
4.6 The strength of paper in relation to its moisture content 111
4.7 Using the paper model 113
Summary 115
The structure of paper (DVD Videos 4.1-4.8)
# 5 Effect of Pulp Processing on Paper-Water Interactions

*Irene Bruckle*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 The native fibre</td>
<td>122</td>
</tr>
<tr>
<td>5.2 Chemical processes</td>
<td>127</td>
</tr>
<tr>
<td>5.3 Effect of chemical processing on fibre composition</td>
<td>130</td>
</tr>
<tr>
<td>5.4 Effect of chemical processing on fibre porosity</td>
<td>133</td>
</tr>
<tr>
<td>5.5 Effect of chemical processing on fibre reactivity</td>
<td>135</td>
</tr>
<tr>
<td>5.6 Beating and refining</td>
<td>138</td>
</tr>
<tr>
<td>Summary</td>
<td>140</td>
</tr>
</tbody>
</table>

Effect of water on different papers *(DVD Videos 5.1-5.5)*

# 6 Effect of Sizing on Paper-Water Interactions

*Gerhard Banik, Irene Bruckle, Remhard Lacher and Gunther Wegele*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Sizingtechnologies</td>
<td>146</td>
</tr>
<tr>
<td>6.2 Surface sizing with gelatine</td>
<td>150</td>
</tr>
<tr>
<td>6.3 Gelatine sizing in relation to paper properties</td>
<td>153</td>
</tr>
<tr>
<td>6.4 Internal sizing with rosin</td>
<td>156</td>
</tr>
<tr>
<td>6.5 Rosin sizing in relation to paper properties</td>
<td>160</td>
</tr>
<tr>
<td>6.6 Internal reactive sizing agents</td>
<td>162</td>
</tr>
<tr>
<td>6.7 Reactive sizing in relation to paper properties</td>
<td>164</td>
</tr>
<tr>
<td>6.8 Properties of sized paper in general</td>
<td>165</td>
</tr>
<tr>
<td>Summary</td>
<td>168</td>
</tr>
</tbody>
</table>

Effect of water on different types of paper *(DVD Videos 6.1-6.7)*

# 7 Paper Drying in the Manufacturing Process

*D. Steven Keller*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7A Water removal in paper manufacturing</td>
<td>175</td>
</tr>
<tr>
<td>7.2 Drying of individual lignocellulosic fibres</td>
<td>184</td>
</tr>
<tr>
<td>7.3 Drying of the fibrous network</td>
<td>190</td>
</tr>
<tr>
<td>7.4 Network shrinkage from fibre shrinkage</td>
<td>190</td>
</tr>
<tr>
<td>7.5 Structural factors that control shrinkage</td>
<td>192</td>
</tr>
</tbody>
</table>

Contents IX
Formation of the paper structure (DVD Videos 7.1-7.3)

8 Paper Ageing and the Influence of Water 219
Paul M. Whitmore

8.1 Major changes in paper with ageing 221
8.2 Cellulose chain-breaking reactions 223
8.3 Discolouration reactions 238
8.4 The study of paper ageing 240
8.5 Stabilization of paper 246
Summary 248

9 The Introduction of Water into Paper 255
Irene Brucke and Gerhard Banik

9.1 Humidity 257
9.2 Humidity and paper 261
9.3 Liquid water and paper 264
9.4 Water transport mechanisms in paper 268
9.5 Paper in humid environments 271
9.6 Water introduction as conservation treatment 273
9.7 Paper and liquid water plus wetting agents 280
9.8 Factors influencing water absorbency of paper objects 282
Summary 285
Response of paper to wetting treatments (DVD Videos 9.1-9.9)

10 The Rate of Discolouration Removal from Paper by Washing 289
Vincent Daniels

10.1 The nature of discoloured material in paper 291
10.2 Paper washing compared with textile washing 292
10.3 Diffusion and mass transfer 294
10.4 Moving discolouration out of paper 297
10.5 Effect of paper thickness on washing rate 299
10.6 Effect of treatment duration on washing rate 301
10.7 Effect of temperature on washing rate 304
10.8 Effect of previous moisture content on washing rate 306
10.9 Effect of surfactants on washing rate 307
10.10 Effect of deacidification on washing rate 309
Summary 310

Methods of controlling water flow (DVD Videos 10.1-10.4)

11 Washing Paper in Conservation 313
Joanna M. Kosek

11.1 Background 315
11.2 Washing principles 317
11.3 Preparatory considerations 320
11.4 Washing treatments 322
11.5 Immersion washing 322
11.6 Floatwashing 324
11.7 Blotter washing 329
11.8 Suction table washing 330
11.9 Combining washing methods 333
11.10 Treatment evaluation 334
Summary 335

Methods of directing water flow (DVD Videos 11.1 -11.4)

12 Aqueous Deacidification of Paper 341
Anthony W. Smith

12.1 Ion-exchange properties of fibres 343
12.2 Deacidification principles 347
12.3 The chemistry of deacidification solutions 351
12.4 The alkalinity of deacidification solutions 373
12.5 Alkaline reserve 375
12.6 Protective effects of alkaline earth carbonates 377
12.7 Specification of aqueous deacidification processes 379
12.8 Practical considerations 380
12.9 Evaluating deacidification treatment 382
Summary 384
The ion-exchange capacity of oxidized cellulose
Neutralization of carboxyl groups (DVD Videos 12.1 and 12.2)

13 Drying Paper in Conservation Practice 389
*Irene Bruckle and Gerhard Banik*

13.1 Water removal in papermaking and conservation 392
13.2 Principles of drying 393
13.3 Effects of free air-drying on sheet dimensional qualities 398
13.4 Preparatory considerations before conservation drying 404
13.5 Restraint-free or air-drying 406
13.6 Modified air-drying 407
13.7 Restraint-drying by pressure in a stack 408
13.8 Restraint-drying by pressure in a stack enforced by friction 410
13.9 Lateral restraint-drying 411
13.10 Restraint-drying by pressure in a stack under enforced airflow 411
13.11 Considerations for drying paper objects 413
Summary 414
Drying of albumen photograph (DVD Video 13.1)

14 Aqueous Treatment in Context 419
*Irene Bruckle*

14.1 Considering risk and benefit of aqueous treatment 420
14.2 Focus on risk factors 423
14.3 Consideration of scientific principles in treatment decision-making 427
14.4 Strategizing conservation decision-making 431
<table>
<thead>
<tr>
<th>Appendices</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Physical quantities and SI units</td>
<td>437</td>
</tr>
<tr>
<td>2. Tables of conversion</td>
<td>440</td>
</tr>
<tr>
<td>3. Measures of concentration</td>
<td>442</td>
</tr>
<tr>
<td>4. Periodic table (extract)</td>
<td>446</td>
</tr>
<tr>
<td>5. Water activity, chemical reactions and biological growth</td>
<td>447</td>
</tr>
<tr>
<td>6. Making proton migration and transfer visible</td>
<td>451</td>
</tr>
<tr>
<td>7. Simplified hygrometric chart</td>
<td>453</td>
</tr>
<tr>
<td>8. Hygrometric chart</td>
<td>454</td>
</tr>
<tr>
<td>9. Relative humidity (RH) over selected salt solutions</td>
<td>455</td>
</tr>
<tr>
<td>10. Setting up workshops</td>
<td>456</td>
</tr>
<tr>
<td>11. Suggested seminar schedule</td>
<td>459</td>
</tr>
<tr>
<td>12. Suggested seminar readings</td>
<td>461</td>
</tr>
<tr>
<td>13. Laboratory safety</td>
<td>464</td>
</tr>
<tr>
<td>14. Suggested seminar experiments</td>
<td>465</td>
</tr>
<tr>
<td>15. Methods for measuring the pH of paper</td>
<td>471</td>
</tr>
<tr>
<td>16. Methods for testing</td>
<td>476</td>
</tr>
<tr>
<td>the water absorption and wetting of paper</td>
<td></td>
</tr>
<tr>
<td>17. Identification of the reducing properties</td>
<td>478</td>
</tr>
<tr>
<td>of deteriorated cellulose</td>
<td></td>
</tr>
<tr>
<td>18. Test for lignin</td>
<td>482</td>
</tr>
<tr>
<td>19. Tests for paper additives</td>
<td>484</td>
</tr>
<tr>
<td>Glossary</td>
<td>491</td>
</tr>
<tr>
<td>Index</td>
<td>527</td>
</tr>
<tr>
<td>About the Authors</td>
<td>539</td>
</tr>
</tbody>
</table>