Sustainability in commercial laundering processes

Module 3
Washing process

Chapter 1

Sinner’s circle and its effect on washing performance
Content

- Sinner’ circle
- Mechanics and its effect on washing performance
- Chemistry and its effect on washing performance
- Temperature and its effect on washing performance
- Time and its effect on washing performance
Purposes of Washing

- To remove local and general soiling
- To remove stains
- To maintain the whiteness of whitework and the brightness of colour of dyed and printed goods
- To keep or restore the original condition as far as physical characteristics like softness, fluffiness of pile, etc.
- To avoid chemical or physical damage which may unnecessarily shorten the life of the goods
Sinner’s circle

**Temperature** - const.
**Chemical dosing** - const.
**Mechanics** - high
**Time** - shortened

**Temperature** - low
**Chemical dosing** - high
**Mechanics** - weak
**Time** - prolonged
Washer extractors

Basic elements of washer extractors are:

- **Outer case**, immovable liquor tank, fitted with a door through which machine can be loaded and unloaded

- **Perforated cylinder** (inner drum) which is mounted so as to rotate on a horizontal axis within an outer case which holds the wash liquor, it can be sectional or not depending on load capacity, equipped with lifting vanes

- **Reversing mechanism** which allows the cage to make several revolutions in one direction followed by the same number of revolutions in the opposite direction, to avoid the load becoming tangled and knotted

- **Electric drive, heating elements or steam coils, inlet and outlet valves (water, steam), control – steering system.**
## Construction of inner drums

<table>
<thead>
<tr>
<th>Drum diameter [mm]</th>
<th>900</th>
<th>900 - 1400</th>
<th>1400 - 1700</th>
<th>Above 1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marking</td>
<td>O</td>
<td>D</td>
<td>Y</td>
<td>X</td>
</tr>
</tbody>
</table>

- **O**
- **D**
- **Y**
- **X**

![Diagram of drum configurations](image-url)
The movement of the wash in the washer extractor is caused by revolutions of inner drum.

Its intensity depends on peripheral speed of the drum, i.e. number of revolutions per minute.

Depending on peripheral speed the effect of mechanical action is diversified, from low to significant.

If the peripheral speed is a little lower from the speed equilibrating, the wash weight is falling down under the so called *falling angle*, $\alpha$. 


Mechanical factor and its effect on washing performance

Mechanical factor (G) is defined as \( \sin \alpha \)

\[
\sin \alpha = \frac{F_c}{F_g} = \frac{m \omega^2 r}{mg} = G
\]

\[
\sin \alpha = \frac{m \left( \frac{\pi n}{30} \right)^2 D}{2 \ mg} = 0.000555Dn^2 = G
\]

where:

- \( n \) – number of revolutions [rev./min]
- \( D \) – diameter of drum [m]
## The G values for washer extractors

<table>
<thead>
<tr>
<th>Type</th>
<th>Load capacity [kg]</th>
<th>Drum diameter [mm]</th>
<th>Washing revolutions [1/min]</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPSO/HF 205</td>
<td>20.0</td>
<td>760</td>
<td>40</td>
<td>0.68</td>
</tr>
<tr>
<td>D’Hooge/Junior</td>
<td>21.0</td>
<td>700</td>
<td>41</td>
<td>0.66</td>
</tr>
<tr>
<td>Girbau/HS 3022</td>
<td>22.0</td>
<td>740</td>
<td>44</td>
<td>0.80</td>
</tr>
<tr>
<td>Wascator/220</td>
<td>22.0</td>
<td>750</td>
<td>44</td>
<td>0.81</td>
</tr>
<tr>
<td>Dubix/FAS 230</td>
<td>23.0</td>
<td>625</td>
<td>52</td>
<td>0.95</td>
</tr>
<tr>
<td>Primus/F 55</td>
<td>55.0</td>
<td>914</td>
<td>40</td>
<td>0.82</td>
</tr>
<tr>
<td>Luniwash/160</td>
<td>60.0</td>
<td>1120</td>
<td>27</td>
<td>0.46</td>
</tr>
<tr>
<td>Wascator/804</td>
<td>80.0</td>
<td>1120</td>
<td>36</td>
<td>0.81</td>
</tr>
<tr>
<td>D’Hooge/900</td>
<td>90.0</td>
<td>1220</td>
<td>32</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Mechanical factor and its effect on washing performance

• In majority of washer extractors G factor in the range of 0.64-0.77 (for low and medium load capacity) and even 0.5 (for high load capacity) is considered.

• It is caused by an application of such textile goods which require gentle action during the washing process and high mechanical action can damage or shorten the life of the goods.

• The last developments in construction of washer extractors made possible to introduce a continuous regulation of the falling angles of 0.21-0.34. If needed, for the particular textile goods resistant for the mechanical action, the falling angle up to even 0.87 can be increased.
The mechanical action is also affected by:

- **load ratio** (the quotient of an inner drum volume in dm$^3$ to the wash mass) expressed in [dm$^3$/kg] or simply 12:1

- **liquor ratio** (water level in drum) in washing and rinsing processes defined as the quotient of total water volume in the washer extractor to the wash mass expressed in [dm$^3$/kg] or simply 5:1; at the low level of the washing bath due to an increased friction forces the mechanical action is also increased

- **construction of an inner drum**: in sectional drums a decreased mechanical action is observed; an increase in the drum diameter is also associated with an increased mechanical effect
Optimal load ratios for washer extractors determined on practical assessment

- hotel wash (I degree of soiling) – 10:1
- medium soiled wash (II degree of soiling) – 12:1
- heavy soiled wash (III degree of soiling) – 14:1
- curtains and delicate goods – 14:1
- polyester/cotton blends – 20:1
- currently most universal load ratio of 11:1 is applied (ISO 9398 Standard)
### Suggested liquor ratios (dm³/kg) in washing and rinsing processes according to K. Hasenclever and J. Naumann

<table>
<thead>
<tr>
<th>Stage</th>
<th>Type of textiles</th>
<th>Work liquor ratio, [dm³/kg]</th>
<th>Total liquor ratio, [dm³/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing</td>
<td>Cotton</td>
<td>4 – 5</td>
<td>ca 5</td>
</tr>
<tr>
<td></td>
<td>Polyester/cotton</td>
<td>4 – 6</td>
<td>6 – 8</td>
</tr>
<tr>
<td>Rinsing</td>
<td>Cotton</td>
<td>6 – 8</td>
<td>ca 8</td>
</tr>
<tr>
<td></td>
<td>Polyester/cotton</td>
<td>ca 8</td>
<td>8 – 10</td>
</tr>
</tbody>
</table>
Mechanical factor and its effect on washing performance

Dewatering of wash after intermediate and end spinning
The measure of the removal of moisture from textile being washed and rinsed is the dewatering constant $G$ defined as a quotient of the centrifugal acceleration of the washer extractor drum to gravitational acceleration, and expressed as follows:

$$G = \frac{\omega^2 \cdot r}{g}$$

or

$$G = 0,000555 \cdot D \cdot n^2$$

where: $G$ – dewatering constant, $\omega$ – angular speed $= \pi n/30$

$r = D/2$, $g = 9,81 \text{ m/s}^2$, $D$ – inner drum diameter [m]

$n$ – number of spinning revolutions per minute [min$^{-1}$]

$$G = 5,6 \cdot \left( \frac{n}{1000} \right)^2 \cdot D$$

where: $D$ – inner drum diameter [cm]
## Mechanical factor and its effect on washing performance

### Dewatering constant values (G) in washer extractors of different load capacity

<table>
<thead>
<tr>
<th>Type</th>
<th>Load capacity [kg]</th>
<th>Drum diameter [mm]</th>
<th>Spinning revolutions [min⁻¹]</th>
<th>Dewatering constant (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPSO/HFS 205</td>
<td>20.0</td>
<td>760</td>
<td>900</td>
<td>343</td>
</tr>
<tr>
<td>D’Hooge/Junior</td>
<td>21.0</td>
<td>700</td>
<td>1000</td>
<td>390</td>
</tr>
<tr>
<td>Girbau/HS 3022</td>
<td>22.0</td>
<td>740</td>
<td>950</td>
<td>380</td>
</tr>
<tr>
<td>Wascator/220</td>
<td>22.0</td>
<td>750</td>
<td>850</td>
<td>300</td>
</tr>
<tr>
<td>Dubix/FAS 230</td>
<td>23.0</td>
<td>625</td>
<td>926</td>
<td>300</td>
</tr>
<tr>
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<td>914</td>
<td>830</td>
<td>350</td>
</tr>
<tr>
<td>Luniwash/60</td>
<td>60.0</td>
<td>1120</td>
<td>780</td>
<td>380</td>
</tr>
<tr>
<td>D’Hooge/900</td>
<td>90.0</td>
<td>1220</td>
<td>750</td>
<td>383</td>
</tr>
</tbody>
</table>
Influence of different types of textiles on the end humidity after dewatering

<table>
<thead>
<tr>
<th>Type</th>
<th>Surface mass [g/m²]</th>
<th>End humidity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscose fabric</td>
<td>180</td>
<td>54</td>
</tr>
<tr>
<td>Viscose knitted fabric</td>
<td>180</td>
<td>65</td>
</tr>
<tr>
<td>Cotton fabric</td>
<td>180</td>
<td>42</td>
</tr>
<tr>
<td>Cotton knitted fabric</td>
<td>180</td>
<td>48</td>
</tr>
<tr>
<td>Linen fabric</td>
<td>220</td>
<td>40</td>
</tr>
<tr>
<td>Wool knitted fabric</td>
<td>–</td>
<td>27</td>
</tr>
<tr>
<td>Polyamide fabric</td>
<td>100</td>
<td>13</td>
</tr>
<tr>
<td>Polyamide staple fibre</td>
<td>–</td>
<td>15</td>
</tr>
</tbody>
</table>
Chemistry and its effect on washing performance

DREAM OF THE WASHERWOMAN
(R. Berneiser, K. Ueberschär, Lehrbuch der Textilreinigung, VEB Fachbuchverlag, Leipzig 1980)
Chemistry and its effect on washing performance

Water consumption in laundry

**Water consumption in washer-extractors at the considered load (kg) depends on:**

- applied washing technology
- different kinds of textiles to be washed and their soiling degree cause the changes in water consumption
- the main factor affecting the consumption of water in the technological process considered is the liquor ratio in particular phases of the washing process
- the number of these phases requiring the filling of the washing machine with water
# Chemistry and its effect on washing performance

## Water consumption in laundries (dm³/kg of load)

1) pre-wash (2 operations) in separate machine,
2) higher liquor ratio (PET/cotton blend)

## Water Consumption in Laundries (dm³/kg of load)

<table>
<thead>
<tr>
<th>Machines</th>
<th>Technological operations</th>
<th>Total consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wash</td>
<td>Wash¹)</td>
</tr>
<tr>
<td>Traditional washers</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>Old generation washer-extractors</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>New generation washer-extractors</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>(average):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Newborns wash (also overalls)¹)</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>b) 3 fold rinsing²)</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>c) 3 fold rinsing</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>d) 2 fold rinsing</td>
<td>8.5</td>
<td>–</td>
</tr>
<tr>
<td>Tunnel washers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disinfectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sterilizers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing stands for trolleys</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chemistry and its effect on washing performance

Main ingredients of contemporary washing powders:

- Surface active agents (soaps, anionic, non-ionic)
- Sequestering agents (TPPNa, Zeolith A, NTA, EDTA etc.)
- Builders (sodium carbonate, sodium metasilicate, sodium sulphate, sodium perborate etc.)
- Enzymes (proteinases, lipases, cellulases, oxido-reductases) TAED system
- Phosphonates
- Organic copolymers
- Foam stabilizers (alkyl amides)
- NaCMC (sodium salt of carboxymethyl cellulose)
- Fluorescent brightening agents (FBA)
- Fragrance
- Dyestuff (ultramarine)
BLEACHING/DISINFECTING AGENTS

- chlorine-containing bleaching/disinfecting agents (sodium hypochlorite, chloramine, isocyanurates),
- oxygen-containing bleaching/disinfecting agents (hydrogen peroxide, sodium perborate, peracetic acid,

\[
\begin{align*}
\text{H}_2\text{O}_2 + \text{OH}^- & \rightleftharpoons \text{H}_2\text{O} + \text{HOO}^- \\
\text{H}_2\text{O}_2 + \text{CH}_3\text{COOH} & \rightleftharpoons \text{H}_2\text{O} + \text{CH}_3\text{COOOH}
\end{align*}
\]
- activated systems (TAED), modified activated systems (H\textsubscript{2}O\textsubscript{2} /TAED/ACL)
  – for bleaching in tunnel batch washers (wfk)

Chemistry and its effect on washing performance

\[
\text{TAED} + 2 \text{HOO}^- \rightarrow \text{H}_3\text{C} - \text{O} - \text{O}^- + \text{DAED}
\]

TAED - Tetra Acetyl Ethylene Diamine
DAED - Di Acetyl Ethylene Diamine

\[
\text{H}_3\text{C} - \text{O} - \text{O}^- \rightarrow \text{O} + \text{CH}_3\text{COOH}
\]
Bactericidal activity of TAED/PBS system towards *Legionella pneumophila*

*George, I., Proceedings of the 37th wfk-International Detergency Conference, May 21-23, (1996), Krefeld, Germany, pp. 95-98*
Chemistry and its effect on washing performance

The change of protease activity (MAXAPEM) vs pH of washing liquor
Chemistry and its effect on washing performance

Remission of cotton textile treated with various bleaching agents: chemical bleaching (chem), fluorescent brightening agent (FBA), ultramarine (ultra) vs wavelength of light.
Chemistry and its effect on washing performance

Sequestring agents (TPPNa - sodium tripolyphosphate and Zeolite)

\[
\begin{array}{c}
\text{TPPNa} \\
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{Si} - \text{O} - \text{Al}^+ - \text{O} \\
\text{O} \\
\text{Al}^+ - \text{O} - \text{Si} - \text{O} \\
\text{O} \\
\text{O}
\end{array}
\end{array}
\xrightarrow{\text{Ca}^{++}}
\begin{array}{c}
\text{Zeolite} \\
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{Si} - \text{O} - \text{Al}^+ - \text{O} \\
\text{O} \\
\text{Al}^+ - \text{O} - \text{Si} - \text{O} \\
\text{O} \\
\text{O}
\end{array}
\end{array}
\]

Module 3 “Washing process” Chapter 1 “Sinner’s circle and its effects”
Chemistry and its effect on washing performance

Sequestrin agent (nitrile triacetic acid)

\[
\text{NTA} \quad \text{Ca}^{++} \quad \text{Ca} \quad \text{Na}^{+}
\]

\[
\begin{align*}
\text{CH}_2\text{COONa} & \quad \text{CH}_2\text{COONa} \\
\text{CH}_2\text{COONa} & \\
\text{H}_2\text{O} & \\
\text{H}_2\text{O} & \\
\text{H}_2\text{O} & \\
\text{C=O} & \\
\text{O} & \\
\text{O} & \\
\text{O} & \\
\text{O} & \\
\text{N} & \\
\text{Ca} & \\
\text{Ca}^{++} & \\
\text{Na}^{+} & \\
\end{align*}
\]
Chemistry and its effect on washing performance

Scheme of adsorption of carboxymethylcellulose sodium salt on fibre (A) and soil (B)

Module 3 “Washing process” Chapter 1 “Sinner’s circle and its effects”
Temperature and its effect on washing performance

- At elevated temperature the kinetic energy of surfactant ions is increased and the effective removal of dirt is much easier.
- At elevated temperature the sorption velocity of surfactant ions on textiles is increased.
- The problem of the washing temperature in laundries should be considered in relation to disinfection.
- Taking into account the washing quality, the studies done in British laundries and BLRA proved that no distinct changes in dirt removal at 60°C, 65°C, 82°C and even above 92°C were observed.
Temperature and its effect on washing performance

• Our studies with linear alkylbenzene sulphonates proved that the maximum washing efficiency in the temperature range 70°C – 75°C was observed.

• In Poland, in hospital laundries on the basis of the State Hygiene Institute and the Polish Sanitary Inspection directives the main wash should be carried out in temperatures of 92 – 95°C and time 16-18 min.

• What should be the proper washing temperature?
Temperature and its effect on washing performance

Influence of the reaction temperature and the timing of the pH value reduction on the concentration of the formed peracetic acid in the system ACL/H₂O₂; pH-reduction after 60min (10°C), after 40min (20°C) and after 20min (30°C)

Temperature and its effect on washing performance

Number of viable bacteria (*Streptococcus faecalis*) on ½ square inch of textile after rinsing in dependence of main washing temperature

Kelsey, J.C., Path, M.C., Wagg, R.E., BLRA Bulletin, 9 (15), 231 – 236 (1969);
9 (16), 239 – 246 (1969)
Temperature and its effect on washing performance

Number of viable bacteria remaining in washing liquor of various temperatures

<table>
<thead>
<tr>
<th>Test number</th>
<th>Temperature [°C]</th>
<th>Minimal count of bacteria in ml</th>
<th>Maximal count of bacteria in ml</th>
<th>Average count of bacteria in ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>20</td>
<td>1200</td>
<td>10000000</td>
<td>1280000</td>
</tr>
<tr>
<td>14</td>
<td>30</td>
<td>1800</td>
<td>3800000</td>
<td>634271</td>
</tr>
<tr>
<td>14</td>
<td>40</td>
<td>700</td>
<td>2400000</td>
<td>334121</td>
</tr>
<tr>
<td>13</td>
<td>50</td>
<td>100</td>
<td>156000</td>
<td>42293</td>
</tr>
<tr>
<td>13</td>
<td>60</td>
<td>50</td>
<td>10000</td>
<td>1315</td>
</tr>
<tr>
<td>8</td>
<td>70</td>
<td>40</td>
<td>400</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>40</td>
<td>600</td>
<td>192</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>10</td>
<td>300</td>
<td>113</td>
</tr>
</tbody>
</table>

Gruen, L., WRP, (7), 6-10 (1979)
Temperature and its effect on washing performance

Number of viable bacteria on ½ square inch of textile after drum drying for blankets washed in low temperature with addition of disinfection agents: A - oryginal, B - without disinfection agents, C-L – various disinfection agents

The influence of temperature on washing efficiency for washing processes with application of enzymatic detergents.
Time and its effect on washing performance

- Washing time is in reverse proportion to washing agent concentration and applied mechanics.
- Washing agents require a definite contact time to ensure the proper interactions between fibre, dirt, and washing agent.
- With an increased time, the proper balance between the fibre surface and the washing bath is achieved, thus affecting the suspending power of the pigment soil and its redeposition.
- The prolonged time of washing contributes to the bigger redeposition of the pigment soil, causing bigger greying and the mechanical damage of textiles.
Time and its effect on washing performance

• Like temperature, time in which temperature is kept can be also considered as an important factor for disinfection.

• According to the BLRA studies the total time of the main wash should amount to 10 minutes + 4 minutes as “mixing time” at temperature 65°C.

• In washer extractors of a big load capacity 8 minutes as “mixing time” should be added (total 18 minutes).

• An increase in temperature up to 71°C is associated with a decrease in basic time of wash up to 3 minutes with a “mixing time” 4 or 8 minutes, respectively.
Time and its effect on washing performance

The influence of time of washing process on washing efficiency of enzymatic washing agents

Module 3 “Washing process” Chapter 1 “Sinner’s circle and its effects”
### Time and its effect on washing performance

<table>
<thead>
<tr>
<th>No.</th>
<th>Stage</th>
<th>Water</th>
<th>Level</th>
<th>Temperature [°C]</th>
<th>Time [min]</th>
<th>Agent</th>
<th>Amount [g/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>main wash 1</td>
<td>cold</td>
<td>low</td>
<td>40</td>
<td>8</td>
<td>Clax Build, Clax 100 OB</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td>2.</td>
<td>main wash 2</td>
<td>cold</td>
<td>low</td>
<td>85</td>
<td>7</td>
<td>Clax Personril</td>
<td>7.0</td>
</tr>
<tr>
<td>3.</td>
<td>drain</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>rinsing 1</td>
<td>cold</td>
<td>high</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>drain</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>rinsing 2</td>
<td>cold</td>
<td>high</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>drain</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>rinsing 3</td>
<td>cold</td>
<td>medium</td>
<td></td>
<td>3</td>
<td>Clax Divercid I, Clax Combi citric</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>9.</td>
<td>drain</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
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<td>spinning</td>
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- Clax Build, Clax 100 OB – washing agents; Clax Personril – bleaching-disinfecting agent, Clax Divercid I i Clax Combi citric – pH regulating agents in the last rinse

Technology of washing of the hospital whitework, according to Diversey; Milczyński, A., Poradnik pralniczy, Spentex ed., Łódź, 2002 r.