Odour formation on textiles – Why do textiles accumulate Malodour?

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8th International Fresenius Conference ‘Detergents and Cleaning products’, 12th/13th of February 2014, Mainz
Introduction

Caroline Amberg
- Over 10 years at Swissatest testmateirals ag: laundry hygiene, microbiological testing (disinfectants, products, food), applied R&D (laundry hygiene, biofilm formation in household devices and water supply systems, Odour formation on textiles)

Swissatest Testmaterials ag
- Spin-off company of the swiss federal institute of material testing and research
- Former EMPA Testmaterials ag
- Development, production and sales of testmaterials for detergent and washing machine producers and textile industry + Microbiological lab
Malodour on textiles: What's the problem?

- Known problem on synthetic fibers ('sweat odour')
- Washing at low temperature with a liquid detergent is not sufficient to remove all malodour components
- Malodour accumulation 'old sweat maldour' on textiles

→ Daily life comfort is reduced
→ Lifecycle of the textile is decreased
→ Higher costs and use of resources
Malodour on textiles: Microorganisms

Microbial growth:

a) Microbial growth on the fiber: Bacteria form a biofilm on the fiber. They use sweat and sebum compounds (odorless) as nutrients, and degrade them to odorous volatiles.

c) Microbial degradation of the fiber: Bacteria degrade the fiber, and release odorous substances.

Chemical adsorption:

b) Odorous substances produced by the skin flora are adsorbed to the fiber, and released over time.

A combination of these effects.
Malodours

New and accumulated malodours

plus water

Malodours like sweat, smoke, food, moldy malodours
Malodour in a wash and wear cycle

• Wear the textile:
  • Axilla sweat as primary source of odour on the skin
  • Interaction of volatile substances and microorganisms with the fiber, dye, etc

• Dirty laundry: wet conditions, contact with other textiles, malodours

• Washing process:
  • removal of certain malodour compounds
  • Interaction of detergent and softener with fiber (dye, finishing etc) microorganisms and volatile substances

• Wear: Axilla sweat and body warmth
  • Interaction with microorganism on the textile
  • Interaction with volatile substances already present on the textile
  • Interaction with fiber, dye, finishing etc.
Malodour formation in the axilla
Microorganisms in the axilla

• Sweat is primary on odourless substance and contains ca. 1E+07 CFU/ml

• Sweat is transformed into odorous substances by microorganisms

• *Staphylococcus sp.*, aerobic *Corynebacteria, Micrococi, Propionibacteria* and *Malassezia* (Yeast)

• Significant relation between malodour and number of total aerobes respectively total aerobic *Coryneforms* (James, Casey, Hyliands and Mycock, 2004)

→ Hugh variations within humans of microbial numbers and malodour formation in the axilla
Biotransformation in the axilla

Sources: James, Casey, Hyliands and MyCock, 2004; Austin and Ellis, 2003
Correlation of Malodour and microbial numbers in the axilla


→ Total aerobes and aerobic coryneforms correlate with axillary malodour assessed by probands and panel tests.
Sweat malodour and producers in the axilla

<table>
<thead>
<tr>
<th>Organism</th>
<th>Gram</th>
<th>Odorous substances produced</th>
<th>Selected References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillus licheniformis</td>
<td>+</td>
<td>isobutyric acid, isovaleric acid, 2-methylbutyric acid</td>
<td>Troccaz et al. 2004</td>
</tr>
<tr>
<td>Bacillus subtilis</td>
<td>+</td>
<td>isobutyric acid, isovaleric acid, 2-methylbutyric acid</td>
<td>Ara et al. 2006</td>
</tr>
<tr>
<td>Corynebacterium xerosis</td>
<td>+</td>
<td>5α-androst-2-en-17-one</td>
<td>Obendorf et al. 2007, Dumas et al. 2009</td>
</tr>
<tr>
<td>Corynebacterium tuberculostearicum</td>
<td>+</td>
<td>3-methyl-2-hexenoic acid, 3-methyl-3-hydroxy-hexanoic acid</td>
<td>Troccaz et al. 2004</td>
</tr>
<tr>
<td>Corynebacterium bovis</td>
<td>+</td>
<td>3-methyl-2-hexenoic acid, 3-methyl-3-hydroxy-hexanoic acid</td>
<td>Natsch et al. 2005</td>
</tr>
<tr>
<td>Corynebacterium jeikeium</td>
<td>+</td>
<td>3-methyl-2-hexenoic acid, 3-methyl-3-hydroxy-hexanoic acid, 3-methyl-3-sulfanylhexan-1-ol</td>
<td>Natsch et al. 2005, Bratt &amp; Dayan 2011</td>
</tr>
<tr>
<td>Corynebacterium minutissimum</td>
<td>+</td>
<td></td>
<td>Troccaz et al. 2004</td>
</tr>
<tr>
<td>Corynebacterium striatum</td>
<td>+</td>
<td>5α-androst-2-en-17-one, 3-methyl-2-hexenoic acid, 3-methyl-3-hydroxy-hexanoic acid, 3-methyl-3-sulfanylhexan-1-ol</td>
<td>Obendorf et al. 2007, Natsch et al. 2003, Natsch et al. 2005, Bratt &amp; Dayan 2011</td>
</tr>
<tr>
<td>Propionibacterium acnes</td>
<td>+</td>
<td>propanoic acid, acetic acid</td>
<td>James et al. 2004</td>
</tr>
<tr>
<td>Staphylococcus haemolyticus</td>
<td>+</td>
<td>3-methyl-3-sulfanylhexan-1-ol</td>
<td>Troccaz et al. 2004</td>
</tr>
</tbody>
</table>
Most important compounds / Microorganisms in the axilla

- Odour fingerprint of every individual
- Daily variations
- Key microorganisms are *Corynebacterium sp.*
- Key compounds:
  - 3-methyl-2-hexenoic acid
  - 3-methylobutanoic acid (Isovaleric acid)
  - 3-hydroxy-3-methyl-hexanoic acid
Malodour transfer to the textile
Malodour formation on Textiles

- Odor intensity is highest on Polyester, followed by Cotton on lowest by Wool
- Well, that’s what we experience in our everyday life
- But what are the reasons?

Source: McQueen et al. 2007, Textile Research Journal
Microbial growth on the fabric

- Lower growth of *Staphylococcus sp.* (JIS 1902) within 24 hours on hydrophilic fibers compared to hydrophobic fibers

- Test with probands (field tests):
  - Microflora from the axilla is able to form biofilm on textiles
  - Lower Biofilm-amount on hydrophilic fiber compared to hydrophobic fibers

**Figure 1.** Challenge tests according to JIS L 1902 were used to investigate the growth of *Staphylococcus* sp. on hydrophilic TENCEL® (CLY) and hydrophobic (PES/PP) fibers. Humidity is given as % water added to 100 % dry fibre material

Source: Teufel and Redl, 2006. Lenzinger Berichte

→ Is Hydrophobicity / surface energy crucial for microbial attachment?
→ Is the amount of microorganisms responsible for malodour formation (like in the axilla)?
→ Can we set a malodour limit as critical number of microorganisms?
Microbial adhesion factors on fabrics

- Depending on the microorganisms (charge, hydrophobicity of cell wall)
- Non-specific interaction with the fabric
  - Van der Waals interaction
  - Electrostatic interaction
- Specific interaction (distinct groups in the bacterial cell wall)

→ higher adhesion on hydrophobic, non-polar surfaces: Hydrophobicity is one of the crucial factors of bacterial attachment

Number of Microorganisms = malodour intensity?

- Malodour intensity stays the same over storage time
- Comparable microbial numbers on wool, cotton and Polyester
- Microbial numbers changed over storage time depending on the fabric

➔ Microbial reduction has no influence on malodour intensity

Source: McQueen et al. 2007, Textile Research Journal

Microbial reduction on different fiber types over storage times of 1 day, 7 days and 28 days
Number of Microorganisms = malodour intensity?

Microorganisms in the Axilla

- True for primary odour generated in the axilla

Microorganisms on the fabric

- Not true for the secondary odour developing on the garment in contact with the axilla

→ Bacterial attachment and growth on textiles is probably not the only reason for malodour formation and persistence

Source: Elizabeth A. Grice & Julia A. Segre, Nature Reviews Microbiology 9, 244-253 (April 2011)
Chemical adsorption

Different Fibers have different binding / retention properties for sweat malodour compounds:

• Isovaleric acid on wool, cotton and Polyester: The sweat malodour compound was fast released from Polyester whereas on wool 98% of the isovaleric acid remained bound on the fabric (measured after 3 h incubation)

• Hydrophilic coating of Wool, Cotton and Polyester increasing the retention of isovaleric acid on Cotton and Polyester.

• Panel tests showed a lower odour intensity of the coated PES and Cotton.

Malodour transfer to the textile

- Amount of microorganisms / *Corynebacterium* is not directly related to the malodour intensity of the textile
- Malodour intensity is highly dependent on the fiber type
- Microbial attachment and chemical adsorption seem to be dependent on the hydrophobicity of the textile (beside other textile properties like water sorption etc)

→ Relation between malodour on textiles, microbial interaction and chemical adsorption is not fully understand and subject of further investigation
Malodour removal during a laundry process
Malodour removal during a laundry process

Depending on the cycle:
• Temperature
• Detergent (pH)
• Water / Mechanical action

→ Washing may change the odour profile of the textile

3-methyl-2-hexenoic acid

Isovaleric acid

5α-androst-2-en-17-one

Powder detergent (pH 10 to 11):
• Most carboxylic acid are removed by the washing process
• Androstene??

Liquid detergent (pH 8-9):
• Volatile fatty acids are not totally removed
Malodour compounds on washed textiles

<table>
<thead>
<tr>
<th>Odorous substance</th>
<th>Literature reference</th>
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<tbody>
<tr>
<td>1-hexen-3-one (Ketone)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>1-octen-3-one (Ketone)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>Ethyl-2-methylpropanoate (ester)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>Ethylbutanoate (ester)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>4-heptenal (aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>Octanal (aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>2-octenal (aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>Methional (Aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>2-nonenal (Aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>2,6-nonadienal (Aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>2,4-nonadienal (Aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>2,4-decadienal (Aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>Hexanal (aldehyde)</td>
<td>Chung and Seok (2012)</td>
</tr>
<tr>
<td>Nonanal (aldehyde)</td>
<td>Chung and Seok (2012)</td>
</tr>
<tr>
<td>Decanal (aldehyde)</td>
<td>Takeuchi et al. (2012)</td>
</tr>
<tr>
<td>4-methoxybenzaldehyde (aldehyde)</td>
<td>Munk et al. (2000)</td>
</tr>
<tr>
<td>3-methylbutanoic acid (fatty acid)</td>
<td>Takeuchi et al. (2012)</td>
</tr>
<tr>
<td>4-methyl-3-hexenoic acid (fatty acid)</td>
<td>Kimura et al. (2012)</td>
</tr>
<tr>
<td>5-methyl-4-hexenoic acid (fatty acid)</td>
<td>Takeuchi et al. (2012)</td>
</tr>
<tr>
<td>6-heptenoic acid (fatty acid)</td>
<td>Takeuchi et al. (2012)</td>
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<tr>
<td>4-methyloctanoic acid (fatty acid)</td>
<td>Munk et al. (2001)</td>
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<td>4-ethyloctanoic acid (fatty acid)</td>
<td>Munk et al. (2001)</td>
</tr>
<tr>
<td>Guaiacol</td>
<td></td>
</tr>
</tbody>
</table>

Volatile fatty acids  aldehyds  ketones
Removal of Microorganisms during a laundering process

- water consumption
- washing temperature
- appropriate detergent choice (bleach / no bleach)

→ Low temperature cycles and liquid detergents are not able to remove microorganisms from textiles

Source: IFH report (2013): ‘Effectiveness of laundering processes used in domestic home setting.’

→ Bleach systems are not always adapted to low temperatures
→ Liquids do not contain bleach (not stable)
→ Washing machines do often not reach the stated temperature
Summary

- Malodour formation is a result of microbial transformation of former odourless sweat and sebum compounds.
- Malodour intensity correlates with the number of aerobes and number of Corynebacterium sp.
- On the textile malodour sources are more complex:
  - Microbial activity on the textile itself
  - Chemical adsorption of the volatile substances produced by bacteria on the skin and on the textile
- Chemical adsorption seems to be important and driven by the fiber properties like hydrophobicity.
- The typical sweat odour compound (volatile fatty acids) are removed in a washing test with a powder detergent (high pH) whereas a liquid detergent low temperature cycle is not able to remove them totally.
- After washing, the textiles have different malodour profiles than before washing: Aldehydes and ketones are more prominent after washing.
- A low temperature cycle with a liquid detergent is not able to remove bacteria on textile completely. Further growth after washing is probable.
- Malodour accumulation on textiles seems to be a complex interaction between microbes, volatile substances and the fiber.

Odour projects

CTI-project Nr. 13310.1 PFFLI-NM: ‘Development of new textile coatings reducing bacterial adhesion’ – finished 2013

Cooperation of Swiss federal laboratories for material testing and research (EMPA), SANITIZED AG and Swissatest Testmaterials ag

Follow-up CTI-project Nr. 16190.1 PFN-M-NM: ‘Development of new textile coatings reducing sweat odour’ – start 1th of March 2014

→ Investigations on chemical / microbial / washing process impacts on textile malodour formation
→ Improvement of textile hygiene and malodour prevention

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Thank you for your attention