Hygienic drinking water quality – an ongoing issue

Or: Why do we have to address an issue which we considered to be solved yesterday (i.e. >100 years ago)?

- enhancements of modern drinking water plumbing systems
- New utilisations (showers, whirl pools, ACs)
- in particular: domestic hot water
- changing user profiles, risk groups
- advanced methods of investigation
- new systematic insights concerning the hygiene of drinking water
Principles of drinking water hygiene

- Drinking water is NOT sterile – not achievable
- Therefore: Drinking water may not contain pathogens in concentrations which may impair human health. (German Drinking Water Ordinance § 5,1)
- three criteria to assess health impact of pathogens:
  - Qualitative: pathogenicity
  - Quantitative: concentration
  - Transmissibility through water
- The microorganism needs to reach the drinking water, needs to be able to survive, and needs to be able to reach a human organ from the water which is sensitive to infection
- Drinking water may deteriorate in plumbing systems
Microorganisms multiply in water!

- Drinking water plumbing systems are inhospitable environments
- However even in these aquatic milieus an autochthonous microflora exists
- Including some potentially harmful microorganisms: Legionella, *Pseudomonas aeruginosa*, MOTT (mycobacteria other than tuberculosis)
- Things become more tricky – not sufficient to control microbial pollution entering from outside
Microorganisms multiply in water!

- The indicator principle (*E. coli* etc.) fails!
- A new question arises: Which *ecological conditions* favour survival and growth of these pathogens in DWPS?
  - Temperature, time, nutrients, …?
- Which survival forms are microorganisms able to develop?
- Does this change their pathogenicity?
Legionella spec.

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Legionella spec.

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Biofilms

- slime layers upon surfaces in regular contact with water
- contain microorganisms
- old and successful survival strategy of microorganisms
- Biofilm does not require much: microorganisms, water, some nutrient, a surface
- frame is made of extrapolymer substances (EPS) which are produced by the microorganisms themselves
- organic and inorganic molecules are embedded (liquid, solid, gaseous)
- extremely heterogeneous environment (pH, O₂, nutrients, …)
- cell density exceeds density in the liquid phase (1:10,000)
- 95 % of DWPS microorganisms within the biofilm
Dynamics of biofilms

- Macromolecules attach at the boundary layer and form an initial rough coat – „conditioning film“
- Autochthonous microorganisms attach at the conditioning film, multiply, form and extracellular polymeric substances (EPS) – „the house of biofilm cells“
- Microorganisms grow together and form macro-colonies
- Steady state: decease and multiplication, dynamic exchange
- Increased exchange during transformation periods of physical and/or chemical conditions: nutrients, temperature, pH, toxic substances …
Pathogens in biofilms!

- Quality of materials substantially influences density of microorganisms (Flemming et al 2010)
- Typical biofilm flora is aquatic and not pathogenic, but:
- Availability of nutrients enhances microbiological mass, diversity, probability of pathogens to nest
- Pathogens in DWPS biofilms:
  - Faecal pathogens (e.g. Salmonella)
  - Legionella – even outside of amoebae = extracellular
  - Pseudomonas: pioneer settler
  - MOTT: pioneer settler, can always be isolated
Bacteria disappear from the radar

- Under stress, bacteria lose their ability to multiply, but remain alive, keep their cellular structure, may recover
- 'Viable but not culturable'
- Stressors: lack of nutrients, osmotic pressure, \( O_2 \) pressure, pH, radiation, toxic substances, predators
- Reduced metabolic activity reduces sensitivity against external stressors
- Cultivable microbes: less than 1 %
- VBNC is the normal form of life for the aquatic flora
- amount of VBNC higher in biofilm
VBNC pathogens in DWPS

- *Legionella* are able to migrate into the VBNC status
- Prompted by copper stress, lack of nutrient, ...
- Consequence: cell concentration of pathogens in DWPS is systematically underestimated
- VBNC pathogens can be found also in biofilms
- VBNC is reversible also for pathogens
- VBNC is an important refuge for pathogens
Practical consequences

• Consider ecological aspects already when planning a DWPS

• Avoid temperature optimum of human pathogens (75-130° F) (see WHO GDWQ)

• Ensure water dynamics: water exchange + flow
  – Water exchange controls time for multiplication
  – Turbulent flow reduces laminar boundary layer
    • Enhanced diffusion between biofilm and water
    • Enhanced shearing forces which negatively affects biofilms

• low stagnation, high water exchange!
„Triangle of effects“ for DW quality

- Water exchange rate
  - ≥ 1 time every 3 days
  - ≥ 1 time every 7 days

- Potable water quality

- Temperatures
  - < 77°F
  - > 131°F

- Turbulent flow
  - v (ft/s)
  - pipe-Ø
Microbiological requirements for DW

- According to German Drinking Water Ordinance
- Pathogens below concentrations which impair human health
- Proof traditionally through investigation of indicator bacteria: *E. coli*, enterococci, coliform bacteria, *Clostridium perfringens*
- Reliable, but not comprehensive!
- Further microbiological routine parameters:
  - heterotrophic plate counts (HPC) 72° F, 97° F (regrowth)
  - *Legionella* spec. („Technical Action Value“)
- Additionally and equally ranking: commonly accepted technical standards (CATS) have to be fulfilled
The Biofilm Management Project

Research Question:
Which outlet specific parameters are pertinent for an early prediction of the risk of Legionella contamination above the Technical Action Value (TAV) at single outlets?
Influence of temperature and other risk factors (Logistic Regression)
Consequences

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Critical dimensions for DWPS planning

- 'Room book':
  - complete description of DWPS
  - characterisation of drinking water outlets (place, type, use)
  - exact description of the intended use of the DWPS
  - measures of maintenance
  - qualification of operator
  - temperature regimes (PWC, PWH)

- Temperature: avoid critical range which is preferred by most pathogens (77°F – 131°F): colder or warmer!

- Water dynamics: water exchange and water flow are critical for drinking water quality!

- Nutrients: avoid plumbing materials dispensing organic substances (TOC, DOC, AOC) into the drinking water
Critical dimensions for DWPS constructing

- Protection of surfaces which will be in contact with drinking water against any contamination
- This applies for production, product control, packing, stocking, transport, and processing
- Visual control for contamination
- Basic rules of hand hygiene need to be respected at the construction site
- Operating supplies (for sealing, gliding, cutting, adhering) are potential nutrients
- These substances have to be non-hazardous concerning health, flavour and smell
Critical dimensions for DWPS implementing

- Testing of tightness by use of air or inert gases
- Water may be applied for testing of tightness only if
  - water is filtered
  - water is free of *Pseudomonas aeruginosa*
  - normal operation starts immediately after testing
  - not in buildings with specific hygienic requirements
- Charging = implementing!
- Flushing should be processed and documented
- Hygienic-microbiological controls of representative sample sites immediately after implementing
- Check compliance with temperature limits
Critical dimensions for DWPS operation

- Preconditions for normal operation:
  - maintenance
  - fittings for reflux prevention
  - no connection to Non-DW plumbing systems
  - compliance with temperature limits
  - prevention of stagnation > 3 days

- Measures in case of interruption of operation
  < 4 weeks: complete exchange of water
  < 6 months: additionally cut-off of DWPS areas
  > 6 months: + hygienic-microbiological controls
  > 12 months: complete cut-off of DWPS
Critical dimensions for DWPS maintenance

- Operation instructions and maintenance plans have to be part of detailed engineering.
- Intervention types within maintenance:
  - Preventive service
  - Inspections
  - Repairs
  - Improvements
- Classes of maintenance:
  - A parameter monitoring and repair when defect
  - B regular inspection
  - C regular service
Water Safety Plan

- for principal reasons, **end point control is not sufficient** for quality management of DWPS
- WHO: it is more productive to apply the HACCP concept of food production to drinking
- from source to tap, critical control points need to be defined and surveyed
- process control replaces product control
- new paradigm of WHO for safe drinking water
- the quality targets are health-based
- implementation requires team work
Water Safety Plan
Water Safety Plans for Buildings

- The last meters (= DWPS in buildings) are critical concerning drinking water quality!
- But very often CATS are not completely implemented
- Strong analogies between the German system of technical standards and the concept of WSP
- WSP for buildings follow the common rules of procedure of an iterative process: 
  description – assessment – management – monitoring – verification
- WSPs for Buildings: an organizational frame for the implementation of the system of technical standards
Resume and perspectives

- Human health is the top priority objective
- In order to maintain the high standard of drinking water quality in buildings, the principles of drinking water hygiene need to be adapted and improved
- Thorough planning, constructing, implementing, operating and maintaining of DWPS is critical
- The adjusting screws of the water quality circle: (temperature, water exchange, water flow, nutrients)
- It is not possible to run a DWPS with a zero risk
- The WSP concept provides an appropriate framework to ensure drinking water of high quality