SMARTCHLOR PROJECT

THE INTELLIGENT CHLORINATION SYSTEM

PROJECT PROGRESS

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National Research, Development and Innovation Office
Hungary

PROJECT FINANCED FROM THE NRDI FUND

MOMENTUM OF INNOVATION

Main aims of the project

- Developing a mathematical model for determining the needed chlorine dose/concentration at different points of the network based on the most important parameters affecting chlorine concentration (water age, flow rates, water quality, type and age of pipelines etc.)
- Developing a methodology for novel process control and adapt the new, patent pending electrochlorination unit
- The first step is collecting base data – YEAR 1.

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Tasks for Year 1.

IW

- Determination of parameters affecting chlorine decay – literature review, evaluation of lab results
- Examination of active chlorine concentration in the distribution system and determination of relationship of parameters describing the change of chlorine concentration

NUPS

- Examination of active chlorine concentration in terms of water quality parameters of raw water

BWW

- Further development of hydraulic model of Budapest drinking water distribution system with the aim of determining the necessary chlorine dose

CQM

- Provide and install lab scale and pilot chlorination devices

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Topics for today

I. Literature summary and conclusions (IW)
   I. Parameters affecting chlorine decay in networks
   II. Approaches of modelling chlorine decay in networks
   III. Our own approach of modelling chlorine decay in networks
II. Laboratory research (NUPS)
   I. Testing the technological parameters of the laboratory scale chlorination device
   II. Laboratory measurements of the effects of referred parameters on chlorine decay
III. Network experiments (BWW)
   I. Installing the pilot network (Engine house)
   II. Assigning sample areas on the real network
IV. Installation of pilot (CQM)
   I. Installing the pilot chlorinator (Engine house)
   II. Education of operators

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LITERATURE SUMMARY AND CONCLUSIONS

BY: INNO-WATER INC.

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Mechanisms affecting chlorine decay

Main reasons for decrease in residual chlorine concentration in networks:

- Contamination from external sources
    - Pipe bursts (breakage)
    - Maintenance
- Natural decay processes in pipelines and tanks
    - Reactions in the bulk water
    - Reactions on the pipe walls
    - Volatilisation

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Parameters affecting chlorine decay in bulk phase

- Inorganic matters concentration
  - Iron, manganese, hydrogen sulphide, cyanides, other inorganic reducing agents
- Organic matters concentration
  - Organic nitrogen compounds, humic substances, phenols, etc.
- Physical parameters
  - Temperature
  - pH
  - Contact time (water age)

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Inorganic compounds I.

Iron

- $HOCl + 2\,H^{+} + 2\,Fe^{2+} \rightleftharpoons 2\,Fe^{3+} + Cl^{-} + H_2O$
- Fast reaction
- Free and combined chlorine show similar reactivity

Manganese

- Reactions similar to that of iron
- Forms insoluable manganese dioxide residue

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Inorganic compounds II.

Ammonium

- $NH_4^+ + HOCl \rightarrow NH_2Cl + H^+ + H_2O$ (monochloro-amin)
- $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ (dichloro-amin)
- $NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ (trichloro-amin)
- End-product formation depends on Cl-N ratio

Hydrogene sulphate

- $2\,H_2S + 5\,Cl_2 + 4\,H_2O = S + 10\,HCl + H_2SO_4$
- Result of biological activity under anaerobic circumstances

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Organic compounds I.

Organic nitrogen compounds

- $HOCl + CH_3NH_2 \rightleftharpoons CH_3NHCl + H_2O$
- Slow reactions except for amino-acids
- Hazard of THM-formation

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Organic compounds II.

Humic substances

- Slow reactions with chlorine
- Reaction rate depends on pH and temperature
- Reaction rates are highly system-specific
- High hazard of THM-formation

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Organic compounds III.

Phenolic compounds

- Compounds containing phenolic groups ($–C_6H_4$ OH)
- Chlorinated phenols cause odour and taste problems
- Modelling is highly problematic

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Physical parameters

Temperature

- Chlorine decay rate increases with temperature
- Lower temperatures result in lower disinfection efficiency

pH

- Chlorine dissociation and $HOCl \leftrightarrow OCl^-$ rate is highly pH-dependent
- Hypochloric acid is more efficient in disinfection (lower pH – corrosion)

Contact time

- Specific compounds have different reaction rates
- High water age usually results in low residual chlorine levels in pipe networks

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Parameters affecting chlorine decay in proximity of pipe walls

- Pipe material and corrosion rate
- Pipe diameter
- Biofilm
- Flow rates

Effects of pipe material and corrosion rate

- Chlorine can react with the material of the pipe wall directly
- Coarse pipe surfaces can endorse biofilm formation
- Pipe wall corrosion affects coarseness and reactions with the pipe wall
- PVC pipes affect chlorine decay the least

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Effects of pipe diameter

- Chlorine decay rates increases with decreasing diameter
- Smaller diameters result in:
  - Increased relative interfacial area
  - Increased opportunity of contact between free chlorine in bulk water and pipe wall

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Effects of biofilm

- Chlorine decay rate increases with biofilm amount
- Residual chlorine reacts with organic compounds of the biofilm but microorganism inactivation rates are lower

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Effects of flow rates

- Increasing flow velocity results in chlorine decay increase (greater shearing force, greater reaction surface)
- The effect of flow rate on decay rates varies with pipe material

Volatilisation

- $Cl^- + H^+ + HClO \leftrightarrows Cl_2 + H_2O$
- Volatilisation occurs mostly in tanks and pump stations
- Depends on:
  - Temperature
  - Water amount
  - Water depth
  - Water surface

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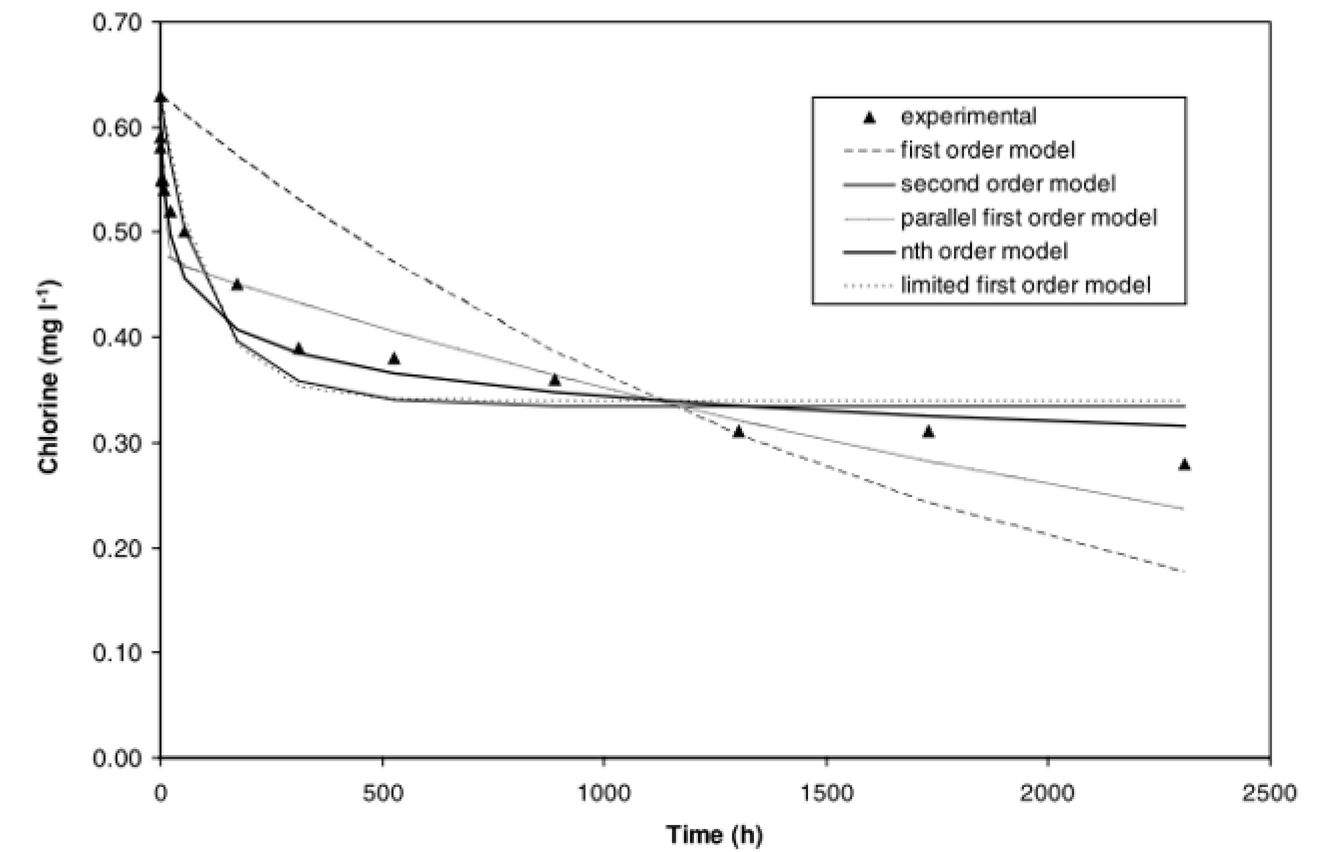
Chlorine decay modelling approaches I.

Title	Governing equation	Parameters
First order	$C = C_0 \exp(-kt)$	k
2nd order	$C = \left(kt + \left(\frac{1}{C_0}\right)^{(1)}\right)^{-1}$	k
3rd order	$C = \left(2kt + \left(\frac{1}{C_0}\right)^{2}\right)^{-\frac{1}{2}}$	k
4th order	$C = \left(3kt + \left(\frac{1}{C_0}\right)^{3}\right)^{-\frac{1}{3}}$	k
Limited first order	$C = C_* + (C_0 - C_*)exp(-kt)$	k
Limited 2nd order	$C = C_* + \left(kt + \left(\frac{1}{C_0 - C_*}\right)\right)^{-1}$	k, C_*
Limited 3rd order	$C = C_* + \left(2kt + \left(\frac{1}{C_0 - C_*}\right)^{2}\right)^{-\frac{1}{2}}$	k, C_*
Limited 4th order	$C = C_* + \left(3kt + \left(\frac{1}{C_0 - C_*}\right)^{3}\right)^{-\frac{1}{3}}$	k, C_*
Parallel first order	$C = x(C_0 - C_*)exp(-k_1 t) + (1 - x)(C_0 - C_*)exp(-k_2 t)$	k_1, k_2, x, C_*

Chlorine decay modelling approaches I.

- First order $\Rightarrow C = C_0 \exp(-kt)$
  - Reaction rate is proportional to chlorine concentration
  - Can't describe first fast reactions
- Limited models $\Rightarrow C = C_* + (C_0 - C_*)exp(-kt)$
  - There is always non-reacted residual chlorine present (C_*)
- Paralel first order
  - Two decay rate constants – for fast and slow reactions

Chlorine decay modelling approaches I.



- First order
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Determination of k values

- $k_t = k_b + k_w$
  - k values are empirical constants for reactions in bulk and on pipe wall
- k_b varies with:
  - Temperature, initial chlorine concentration, TOC, etc.
- k_w varies with:
  - Pipe diameter, pipe material, biofilm properties, flow rates, initial chlorine concentration, etc.

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Determination of k value: an example

Experiments to determine *k* values

- Several experiments, but no standard test
- k_b determined from glass tests (lab)
- k_t is determined from isolated pipe segments over time
- k_w is calculated from k_t and k_b

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Our own approach of modeling chlorine decay in networks

- Identification of the most important parameters affecting chlorine decay;
- Determination of the relations between the compounds and the chlorine consumption (lab experiments) – different *k* values and equations for different parameters;
- Development of a model calculating chlorine consumption by the most important compounds that can be measured on site;
- Validation of the model by field samplings

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Thank you for your attention

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