The Research and Application of UV Disinfection Technologies in China

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Outlines

- The drives for UV application
- Research review of UV for water and waste water disinfection
- Application of UV technologies in China
- The challenges and prospective
The drives for UV application

Water Pollution
Water Pollution

- China is a country which is short of water resources and with average amount of 2200 m³ water per person, which is 1/4 of the world’s average.
- Of 660 cities all over the country, more than 400 are short of water. 160 million people are influenced by the lack of water.
- More than 190 million people living in rural areas are hard to access safe drinking water.
Seven main watersheds severely polluted

70% of 200 lakes in eastern and southwestern eutrophicated

Half of urban drinking water sources can not meets standards
The drives for UV application

Municipal wastewater treatment

- The number of WWTP
- The Capacity of WWTP


Capacity (m M^3/d):

The Number of WWTP (k Set):
The ratio of municipal wastewater treated

The drives for UV application

![Graph showing the ratio of municipal wastewater treated from 1990 to 2010. The ratio increases from 10% in 1990 to approximately 70% in 2010.](image-url)
The drives for UV application

New standard for municipal waste water discharge

Fecal E. Coli Standards for municipal wastewater Discharge (GB18918-2002)

<table>
<thead>
<tr>
<th>Primary A</th>
<th>Primary B</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000 CFU/L</td>
<td>10,000 CFU/L</td>
<td>10,000 CFU/L</td>
</tr>
</tbody>
</table>

E. Coli Standards for municipal wastewater reused in general purposes (GB18920-2002)

E. coli. <3 CFU/L
The drives for UV application

New standard for reclaimed water

Fecal E. Coli Standards for reclaimed water (GB18921-2002)

<table>
<thead>
<tr>
<th></th>
<th>River and Lake</th>
<th>Waterscape</th>
</tr>
</thead>
<tbody>
<tr>
<td>landscape purpose</td>
<td>10,000 CFU/L</td>
<td>2,000 CFU/L</td>
</tr>
<tr>
<td>(not directly touched by human)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreation purpose</td>
<td>500 CFU/L</td>
<td>Below MDL</td>
</tr>
<tr>
<td>(directly touched by human)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. Coli Standards for reclaimed water used in general purposes (GB18920-2002)

E. coli. <3 CFU/L
The drives for UV application

Outbreak of SARS (Severe Acute Respiratory Syndrome) in 2003

- Before outbreak of SARS, no full-scale WWTP used disinfection process except very few experimental sets
- After outbreak of SARS, the importance of disinfection unanimously recognized by government offices, industry, academia, and public.
- Because of some disadvantages of UV technologies, UV disinfection became the first choice of the disinfection process
UV disinfection used in WWTP

- More than 600 sets of the capacity above 50,000m³/d installed
- Manufactures from both inside and outside China
The drives for UV application

UV disinfection for drinking water

- Much stringent standards for drinking water quality was promulgated in 2006

  - Old standards: 35 parameters (GB 5749-85)
  - New standards: 106 parameters (GB 5749-2006), have been effective from 1st, July, 2007
UV disinfection for drinking water

Comparison of two version standards

71 new parameters:
Microbiological: 2 → 6
Disinfectants: 1 → 4
Toxicological: Inorganic: 10 → 21
Organic: 5 → 53
Aesthetical: 15 → 20

8 parameters modified:
Total coliform: 3 CFU/L → no detected (CFU/100 mL)
As: 0.05mg/L → 0.01mg/L
Cd: 0.01mg/L → 0.005mg/L
Pb: 0.05 mg/l → 0.01mg/L
Nitrate: 20 mg/L → 10mg/L
CCl4: 0.003mg/L → 0.002mg/L
Turbidity: 3 NTU → 1 NTU
Total α radioactivity: 0.1 Bq/L → 0.5 Bq/L.
The drives for UV application

The drive from new standards

Biological parameters

- Cryptosporidium oocysts and giardia cysts
  - < 1/10L)
- Total coliform: < MDL/100mL
- E. coli: < MDL/100mL
- Fecal coli: < MDL/100mL
- Total bacterial count: < 100cfu/mL
The drives for UV application

DBP regulations

<table>
<thead>
<tr>
<th></th>
<th>THMs (mg/L)</th>
<th>HAA5 (mg/L)</th>
<th>Chlorine (mg/L)</th>
<th>Chlorammines (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>0.080</td>
<td>0.060</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>China</td>
<td>0.100</td>
<td>0.060</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ClO₂ (mg/L)</th>
<th>Chlorite (mg/L)</th>
<th>Bromate (mg/L)</th>
<th>Acetaldehyde (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>0.8</td>
<td>1.0</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td>China</td>
<td>0.8</td>
<td>0.7</td>
<td>0.01</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Ensure water safe for drinking

To provide drinking water safe for direct drinking

- Traditionally, Chinese are used to drink tea or boiled water
- Up to now, no city provides drinking water be directly drank at POU
- New standard requires drinking water safe for all users, including urban residents and rural residents.
Research of UV disinfection for drinking water treatment

- Validate the efficiency of UV for different organisms
- Investigate the options to control the bio-stability in distribution systems following UV disinfection
- Evaluate the mutagenicity of water from different disinfection technologies.
- Assess the cost-effective feasibility
A 20-25 m³/h and a 5 m³/h pilot UV disinfection systems were installed in two WTPs at 2006 and 2007, respectively.

TBC, E. coli, B. subtilis and MS₂ were chosen as the index organisms

Coffee was used to adjust the transmittance

Filtered water from conventional process was used to be disinfected.
Water tank

Coffee organism
UV reactor and simulated clearwell
Facility layout
Collimated beam
The TBC number from UV reactor were far fewer than the drinking water standard of China (100CFU/ mL).
The total coliform number were below MDL in 100 days of 102 day sampling.
The water temperature could impact on the influent bacteria concentration, but it did not change the UV disinfection effect.
In most situations, UVI were above the deadline.
UV inactivation for the challenge organism in the pilot

E. coli

TBC

B. subtilis

MS2

$y = 0.044x + 0.038$

$R^2 = 0.941$

$y = 0.046x + 0.282$

$R^2 = 0.983$
Comparison of MS2 response curve

Under collimated beam test, the MS2 response curve was similar for different water.
Bioassay curve for Beijing No 9

- Designed dose: 40mJ/cm² when flow rate was 10m³/h,
- Bioassay dose: 46±1mJ/cm² when flow rate was 10m³/h, 12.5% safe margin.
Comparison for bioassay curve of two pilots

The bioassay curve of Beijing and Dongguan is in consistence. It was confirmed that UVT was an important factor for UV disinfection effect.
Cleaning
Control bio-stability following UV

- Hydraulic retention time of distribution system,
- Disinfectant (chlorine or chloramine) residual
- AOC level
- Pipe materials
- UV dose
Control bio-stability following UV

Water tank

UV reactor

BAR
The influent water quality

<table>
<thead>
<tr>
<th>Parameter</th>
<th>level</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.2~7.8</td>
</tr>
<tr>
<td>UV254 (cm⁻¹)</td>
<td>0.01~0.02</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>0.1~0.2</td>
</tr>
<tr>
<td>UVT</td>
<td>95%~98%</td>
</tr>
<tr>
<td>TOC (mg L⁻¹)</td>
<td>0.6~0.8</td>
</tr>
<tr>
<td>AOC (μg L⁻¹)</td>
<td>50~70</td>
</tr>
<tr>
<td>Temperature (℃)</td>
<td>15-17</td>
</tr>
</tbody>
</table>
Impacts of UV dose on HPC on coupon

Biofilm densities on steel coupons are much less than PVC coupons.
The impact of UV dose on the biofilm densities

AOC=50µg/ L; Temperature=16℃; Chorine residual=0

The steady-state biofilm density had no obviously changing
The relationship of fluid HPC and chlorine residual

AOC=50µg/L; T=16°C; UV dose= 40mJ/cm²;
The impact of retention time

AOC=50µg/L; Temperature=16°C; UV dose= 40mJ / cm²;

The HRT impact on the density on the coupon of BAR in a certain level.
**AOC and Chlorine residual impact on HPC in DWDS**

![Graph showing the impact of AOC and chlorine residual on HPC](image)

### Regression

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>t Stat</th>
<th>P-value</th>
<th>Down 95.0%</th>
<th>Upper 95.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>alternation</td>
<td>2.910432</td>
<td>21.91405</td>
<td>5.54E-26</td>
<td></td>
</tr>
<tr>
<td>AOC</td>
<td>0.006761</td>
<td>5.959354</td>
<td>3.33E-07</td>
<td></td>
</tr>
</tbody>
</table>

\[
HPC = a \exp(b \cdot AOC + c \cdot RC)
\]

- \(a = 8.1E-18\)
- \(b = -2.51317\)
- \(c = -1.89513\)
SEM after 20 day operation of BAR

No disinfection

UV disinfection only

UV+0.5mg/L chlorine

UV+0.4mg/L chloramine
PCR-DGGE results of BAR following UV with different slide materials

10.29 (R1392 968GC)
The chlorine resistant bacteria

*Sphingomonas*

formed dark-yellow colonies on R2A media
The SEM of the a chorine resistant bacteria
Chlorine inactivation for *Sphingomonas*

The inactivation rate for the chlorine resistant bacteria is under 10% even the chlorine CT above 700 mg.min/L.
UV disinfection is effective for the inactivation of *Sphingomonas*, When the UV dose is 40mJ/cm², the inactivation approximate 3 log.
UV application in rural areas in Beijing:
to verify the impacting of UV disinfection on
distribution system
UV application in rural areas

Aquafine

UV max

UV logic
4# and 5# were the distribution ends (1200 m, 13000 m respectively).
The parameters of UV system and water quality

<table>
<thead>
<tr>
<th>Village</th>
<th>Power/W</th>
<th>Flowrate/m³h⁻¹</th>
<th>Lamp No</th>
<th>Service people</th>
<th>Pipe material</th>
<th>TOC/mgL⁻¹</th>
<th>AOC/μgL⁻¹</th>
<th>UVT</th>
<th>Water temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUZI</td>
<td>280</td>
<td>35</td>
<td>2</td>
<td>2300</td>
<td>PVC</td>
<td>1.2</td>
<td>47</td>
<td>98%</td>
<td>15</td>
</tr>
</tbody>
</table>

For WUZI’s groundwater, The UVT was 98% and the AOC level was under 50 μgL⁻¹, it is suitable for UV disinfection.
The bacteria parameter of samples

<table>
<thead>
<tr>
<th>network points</th>
<th>pipe length (m)</th>
<th>TBC (CFU/mL)</th>
<th>Total coliform (CFU/100mL)</th>
<th>HPC (CFU/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>08.1.19</td>
<td>08.4.4</td>
<td>08.1.19</td>
</tr>
<tr>
<td>influent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>effluent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>450</td>
<td>3</td>
<td>4</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>800</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1100</td>
<td>0</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1200</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1300</td>
<td>2</td>
<td>5</td>
<td>11</td>
</tr>
</tbody>
</table>
HPC are all under 500CFU/ml in the distribution system.
Mutagenicity evaluation

The graph illustrates the mutagenicity evaluation of various disinfectants and UV treatments.

- Cyan
- Cyan + UV
- UV + Chlorine
- UV + Chloramine
- Chlorine + Chloramine

The UV dose is 40 mJ/cm².

**Y-axis:** Genotoxicity (μg 4-NQO/L)

**X-axis:** Disinfectant addition (mg/L, as Cl₂ equivalent)
Evaluation of HAA formation

UV 剂量为 40mJ/cm²

总 HAA 生成量 / ug·L⁻¹

消毒剂投加量 / mg·L⁻¹
Recommendation for UV based disinfection process used in WTP

UV + chloramine Process

Benefits:
- High disinfection efficiency
- Bio-stable distribution
- Minimum mutagenicity
UV application in WTP
UV disinfection in Teda WTP, Tianjin
UV disinfection in Teda WTP, Tianjin
UV disinfection in Lianjiang WTP, Shanghai
UV disinfection for ballast water treatment
Challenges of UV in WTP in the future

Do we really need UV for WTP in China???

We drinking tea and boiled water, microbes is not of concerns
Microbe pollution of DW in Chifeng

- The city has an area of 90,000 km² and a population of 4.60 million (2004)
- A prefecture-level city in southeastern Inner Mongolia
Microbe pollution of DW in Chifeng

- Water for industrial and domestic use are all extracted from a groundwater source
- Water usage in many parts of town are near maximum capacity
- Water usage in some areas are past maximum capacity
Microbe pollution of DW in Chifeng

- Heavy rainstorm on July 23\textsuperscript{rd}, 2009

- Few days later, thousands of residents in the “new city” area reported cases of diarrhea, vomiting, dizziness, fever and other symptoms after drinking tap water

- On July 26th, official statement was made on the cause of the outbreak: recent storm water along with sewage has intruded into water supplies causing contamination
Microbe pollution of DW in Chifeng

- The Culprit: Salmonella
- Rain water flooded into the No. 9 well, resulting in excessive coliform and salmonella detected
Preparation of the Standards for UV

Coordination of preparing the first national standards regarding UV applications in water treatment which was promulgated by the National Standardization Administration Commission and has been effective since Jan. 1st 2006.

Promotion of the creation of the National Technical Committee 299 on Ultraviolet Disinfection of standardization Administration of China. The committee consist of 26 members and Wenjun Liu has been appointed to the Chair.
Acknowledgement

- Wenjun Sun, Ted Mao, Yanjiu Qie, Lifeng
- All who have contributed to facilitate the UV knowledge distributed in China.