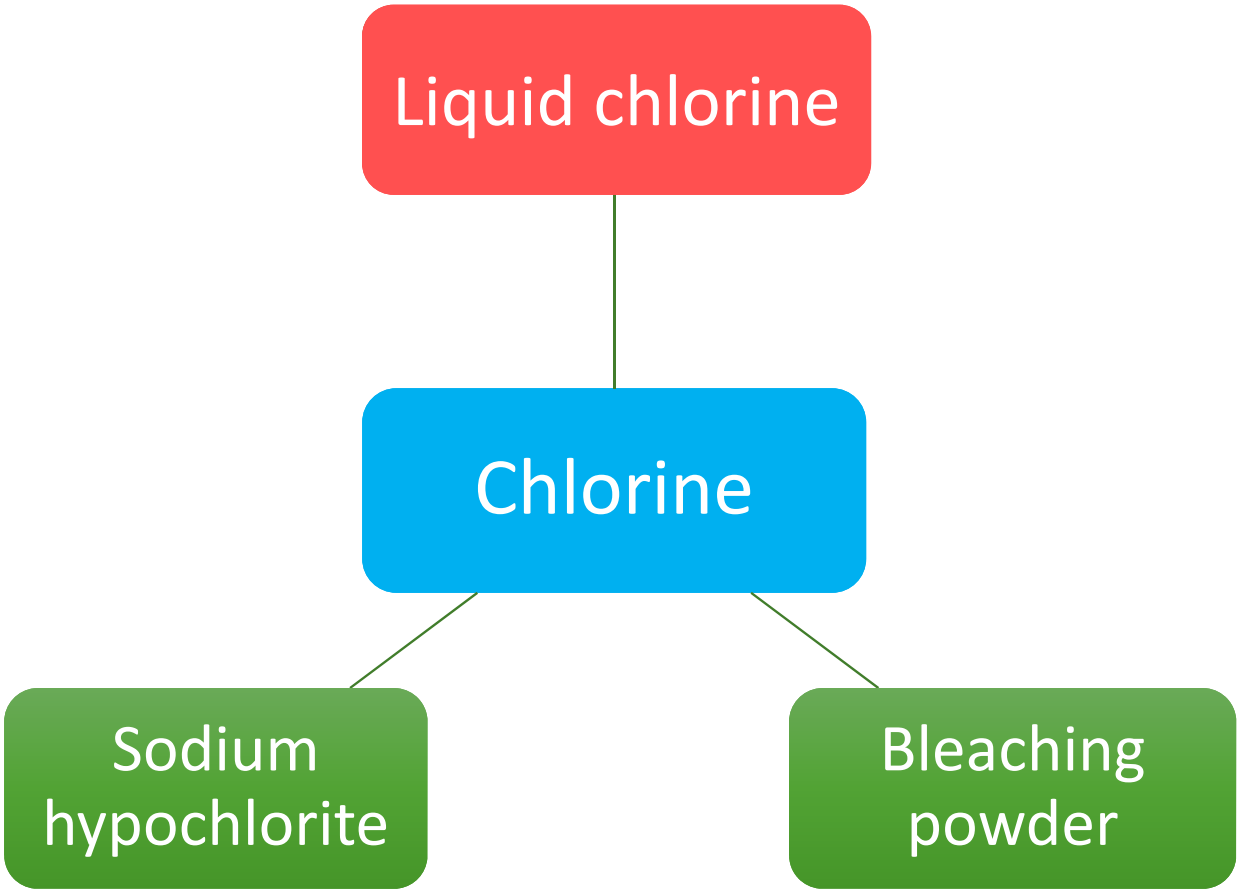
Section 5.3

Disinfection with Chlorine


Liquid chlorine
Chlorine
Sodium hypochlorite
Bleaching powder

1. Reactions in disinfection with chlorine

(1) Free chlorine

Chlorine is soluble in water, the following reaction occurs instantly in water:

$$Cl_2 + H_2O = HClO + H^+ + Cl^-$$

Hypochlorous acid will further dissociate:

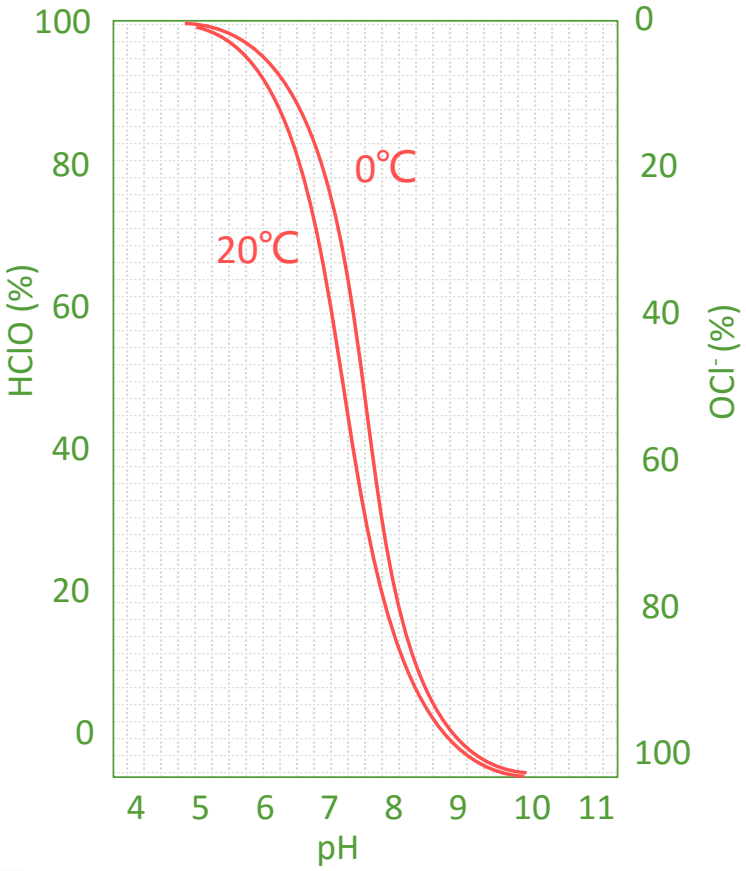
$$HClO \rightleftarrows H^+ + OCl^-$$

Dissociation equilibrium constant:

$$K_i = \frac{[H^+][OCl^-]}{[HClO]}$$

⇨ Temperature depended

1. Reactions in disinfection with chlorine



HClO, OCl^- fractions are related to temperature and pH.

At 20 °C:

pH>9, mostly OCl^-

pH<6, mostly HClO

pH=7.5, HClO and OCl^- each takes 50%

1. Reactions in disinfection with chlorine

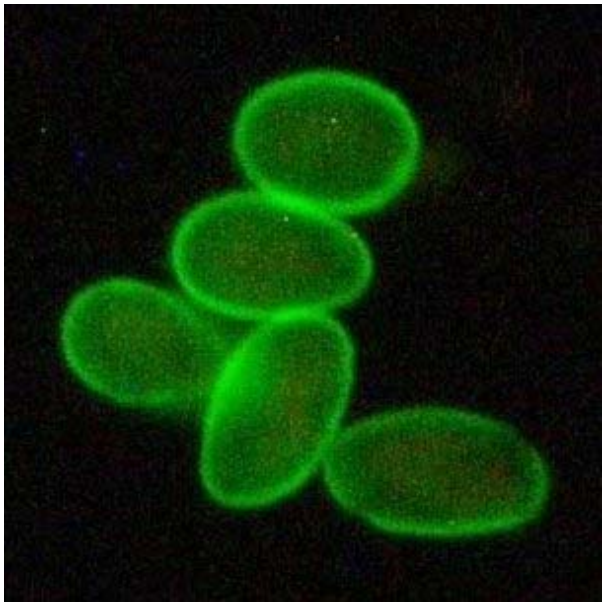
- Disinfection with chlorine is the process of oxidation;
- Both HClO and OCl^- have oxidation and disinfection capabilities.
- HClO, which is a neutral molecule, can easily spread to the bacterium's surface and penetrate into it. Thus it has a strong disinfection capability.
- Under low pH values, HClO takes large proportion, which is good for disinfection;
- When HClO is consumed, OCl^- will transfer into HClO, due to the chemical equilibrium between HClO and OCl^-, and the disinfection continues.
- Both OCl^- and HClO are counted in the calculation of disinfectant amount and existing forms. They are called free available chlorine, or free Chlorine for short.

The chlorine can’t effectively inactivate Protozoan cysts/ oocytes.

(1993, US, over 400,000 person infected)

Giardia lamblia

(8-12 µm X 7-10 µm)



Cryptosporidium oocysts

(4-6 µm)

1. Reactions in disinfection with chlorine

(2) Combined chlorine

If ammonia is present in natural water, chlorine reacts with ammonia and produces chloramines.

$$NH_3 + HClO = NH_2Cl + H_2O$$

$$NH_2Cl + HClO = NHCl_2 + H_2O$$

$$NHCl_2 + HClO = NCl_3 + H_2O$$

The proportions of chloramine species depend on the ratio of chlorine and ammonia, as well as pH:

$Cl/NH_3 \leq 5:1$, pH 7-9: Basically mono-chloramine.

$Cl/NH_3 \leq 5:1$, pH 6: mono-chloramine ≈80%.

pH < 4.5: Tri-chloramine exists.

1. Reactions in disinfection with chlorine

(2) Combined chlorine

- Chloramines are oxidative, and have disinfection ability.
- Less oxidation capability than free chlorine.
- Disinfection mechanisms:

  Direct reaction with microorganism;

  Disinfection by free chlorine through chemical equilibrium with HClO
- Chloramines are called combined available chlorine.

2. Dosage of chlorine

Chlorine dosage = Chlorine demand + Residual chlorine

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Chlorine demand

Within the designed contact time, the chlorine consumption for killing the microorganisms and oxidation of organic matter and reductive substances.

Residual chlorine

After the designed contact time, the remaining chlorine in water.

2. Dosage of chlorine

Free chlorine disinfection:

Contact time → ≥30 min;

Residual chlorine → free chlorine ≥0.3 mg/L in effluent,

≥ 0.05 mg/L in the water at the end of pipelines.

Chloramine disinfection:

Contact time → ≥2 h;

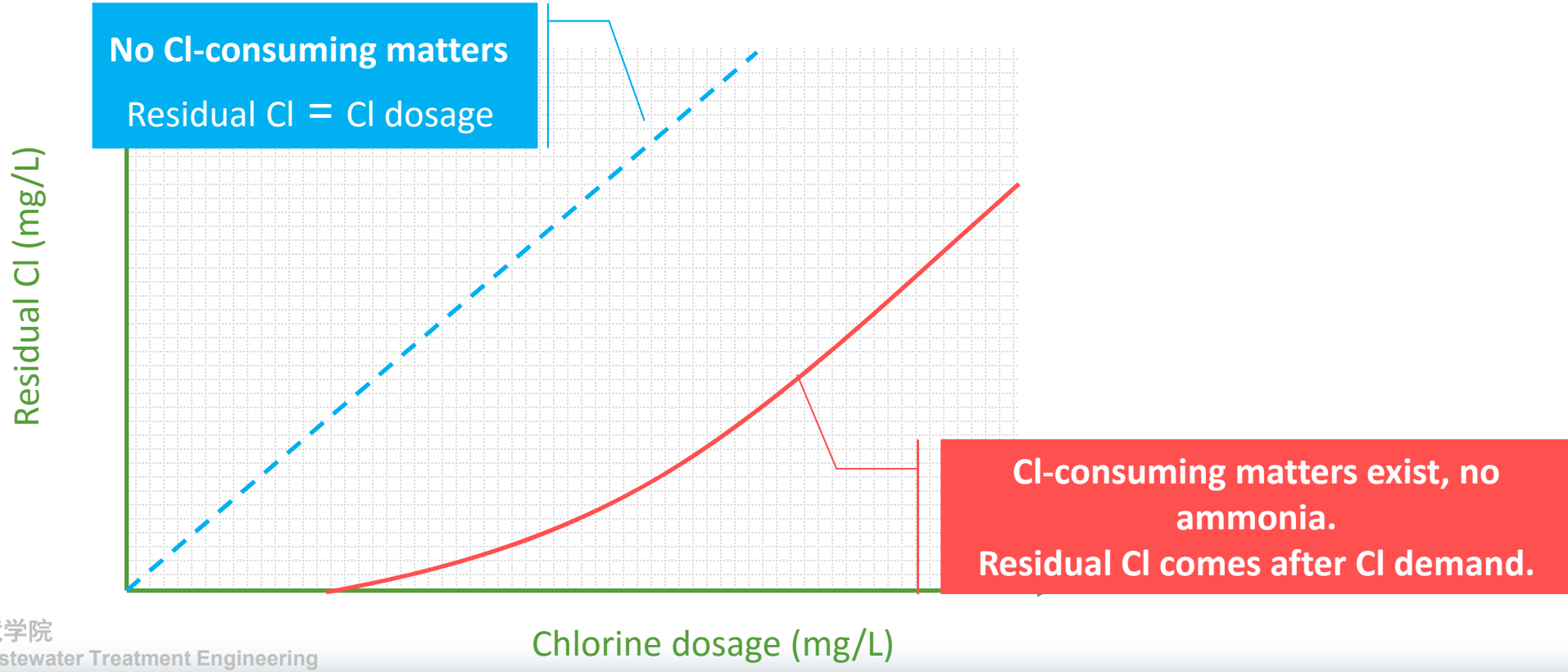
Residual chlorine → total chlorine ≥0.5 mg/L in effluent,

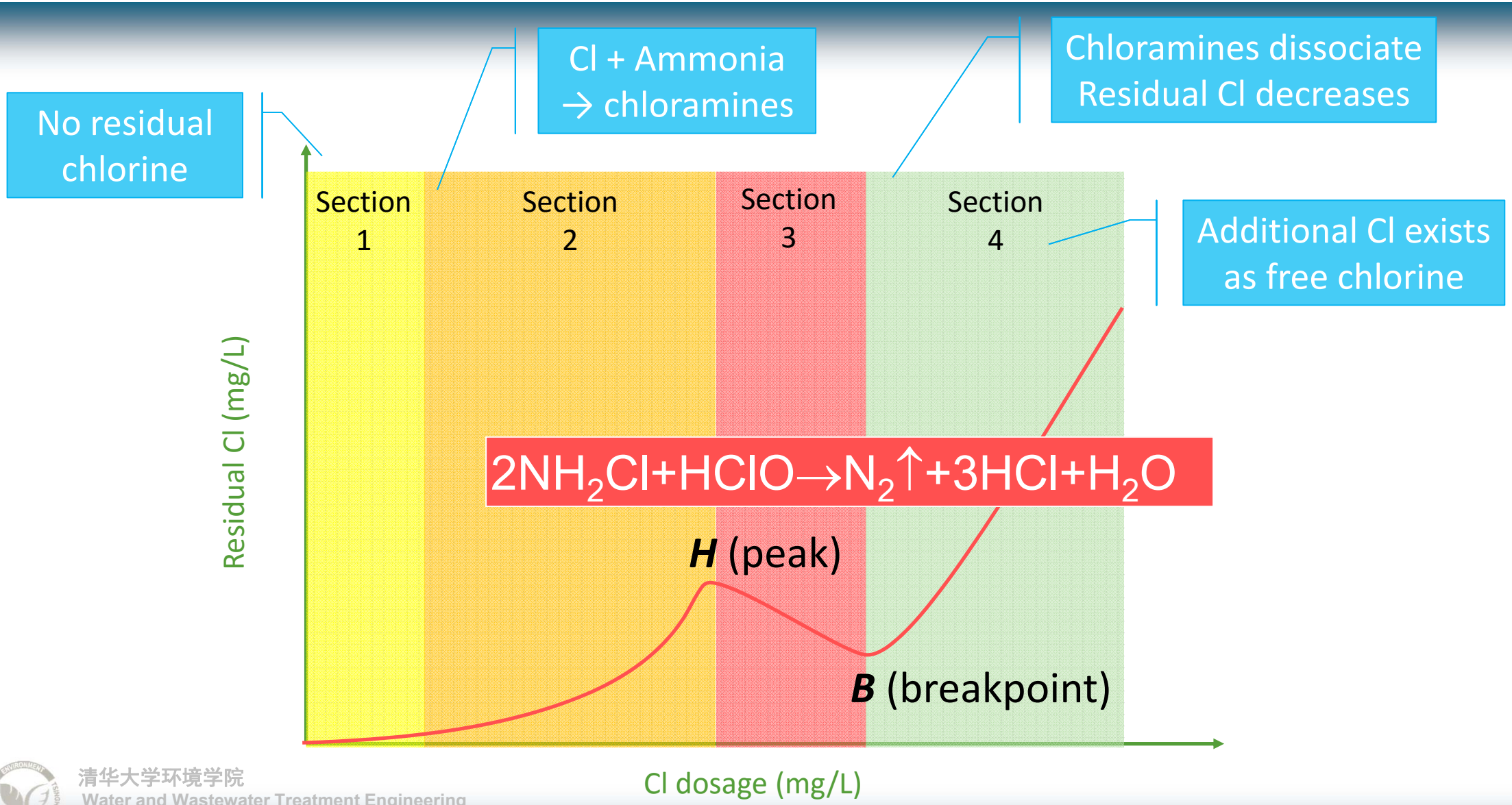
≥0.05 mg/L in the water at the end of pipelines.

2. Dosage of chlorine

The chlorine dosage could be obtained through experiment or experience.

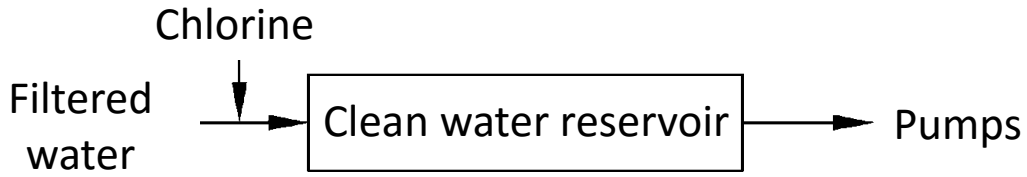
Chlorine dosage curve—Relationship curve between chlorine dosage and residual chlorine.





3. Chlorine disinfection in practice

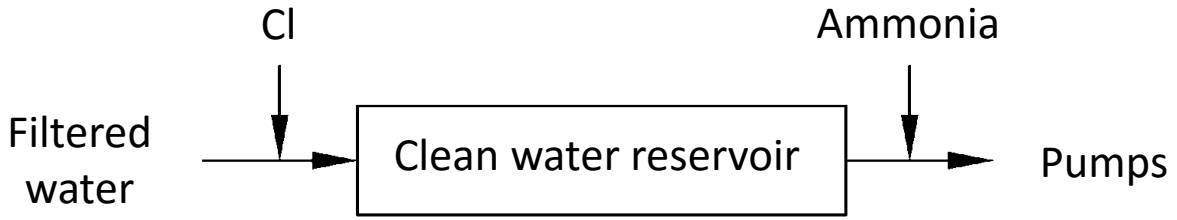
(1) Disinfection with free chlorine



- Breakpoint chlorination is usually applied for water with low ammonia concentration (<0.2 mg/L);
- Good disinfection, can remove some odor and organic matter;
- Water has heavy chlorine smell; when treating polluted water, toxic byproducts would be formed, like trihalomethanes, haloacetic acids, which are mutagenic, carcinogenic and teratogenic.

3. Chlorine disinfection in practice

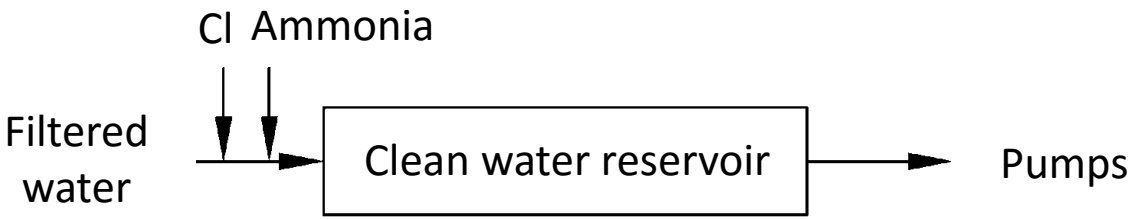
(2) Cl-before and ammonia-after chlorine disinfection



- Effluent by breakpoint chlorination has strong chlorine smell, and free chlorine has limited existing time in the pipelines due to its fast decomposition.
- Cl is firstly dosed according to break point chlorination. Then ammonia is dosed at the secondary pump station before water is pumped out.
- Free Cl turns into residual combined Cl, with less odor and longer residential time.
- $Cl:NH_3$ = 3:1~6:1

3. Chlorine disinfection in practice

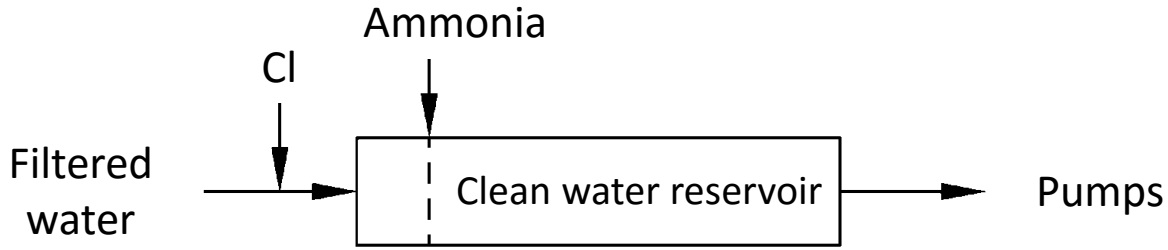
(3) Chloramine disinfection



- Less disinfection efficacy than free chlorine;
- Stable, long existing time, little scent of chlorine and chlorophenol;
- Less health-threatening byproducts like trihalomethanes, haloacetic acids, etc.;
- Low disinfection rate, long contact time (≥2 h);
- For filtered water with high ammonia concentration:
  combined chlorine disinfection (section 2 on the curve);
- For filtered water with low ammonia concentration:
  dose both chlorine and ammonia.

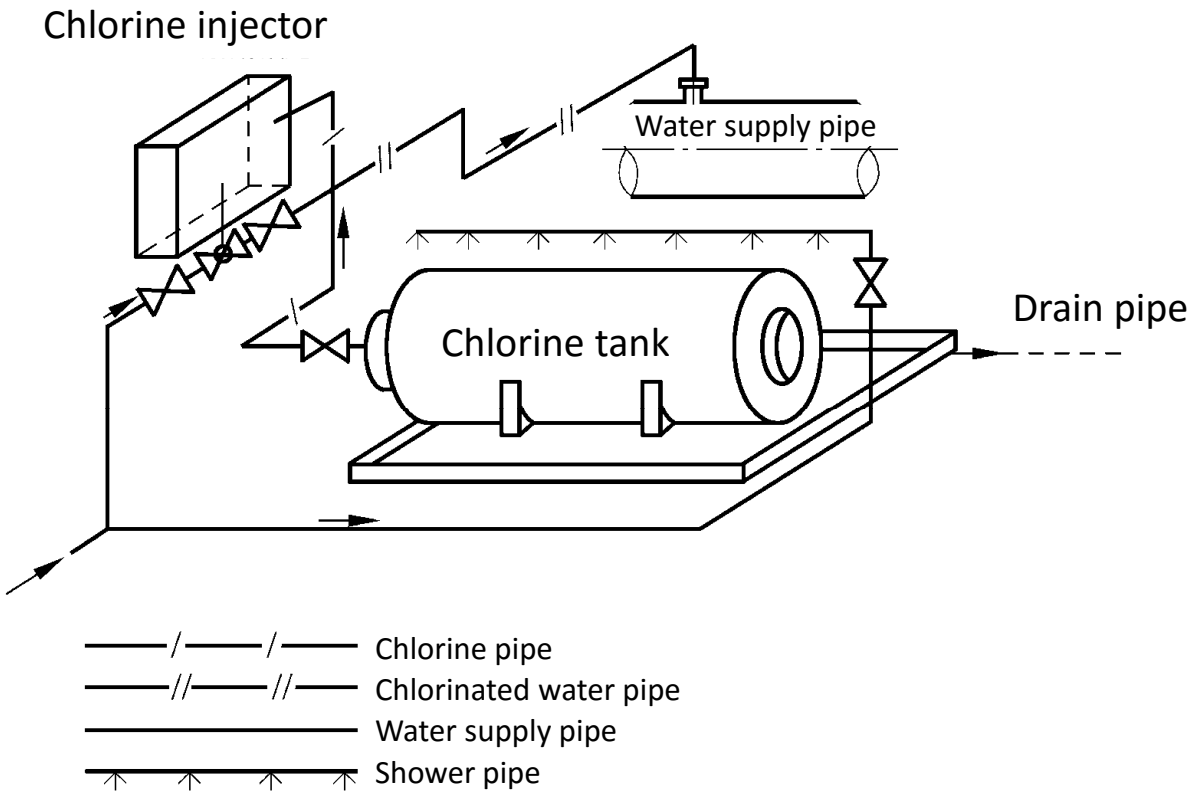
3. Chlorine disinfection in practice

(4) Short free chlorine-before & chloramines-after disinfection



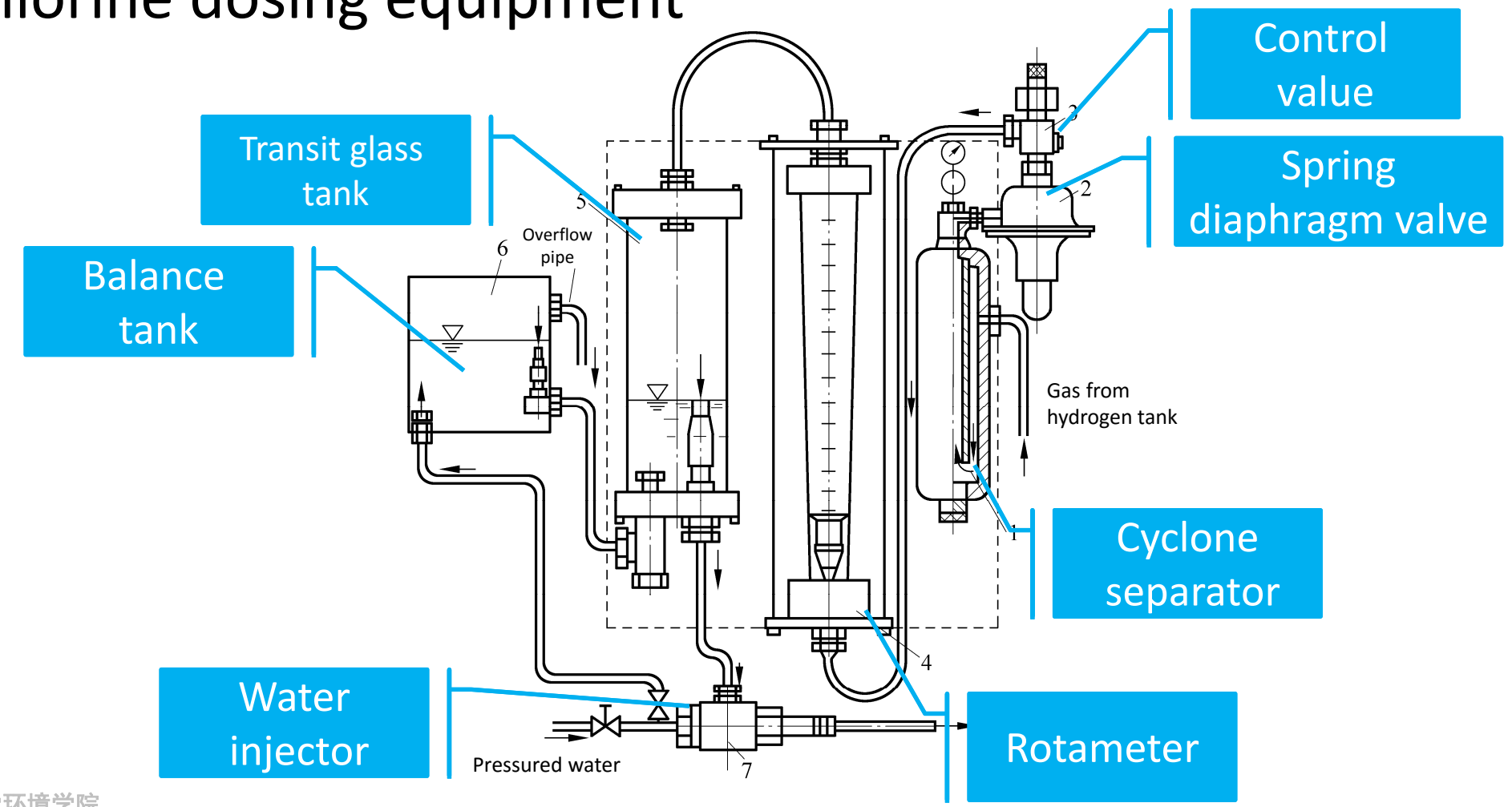
- Dose chlorine at the inlet of clean water reservoir, contact for 10-15 min, to achieve short time free chlorine disinfection;
- Then dose ammonia, with the retention time of water in clean water reservoir ≥ 2h, to achieve the chloramines disinfection;
- Cl:NH_3 usually is 4:1
- Owning characters of both free chlorine and chloramines, control both microorganism and disinfection byproducts.

4. Chlorine dosing equipment



Equipment of disinfection by liquid chlorine

4. Chlorine dosing equipment

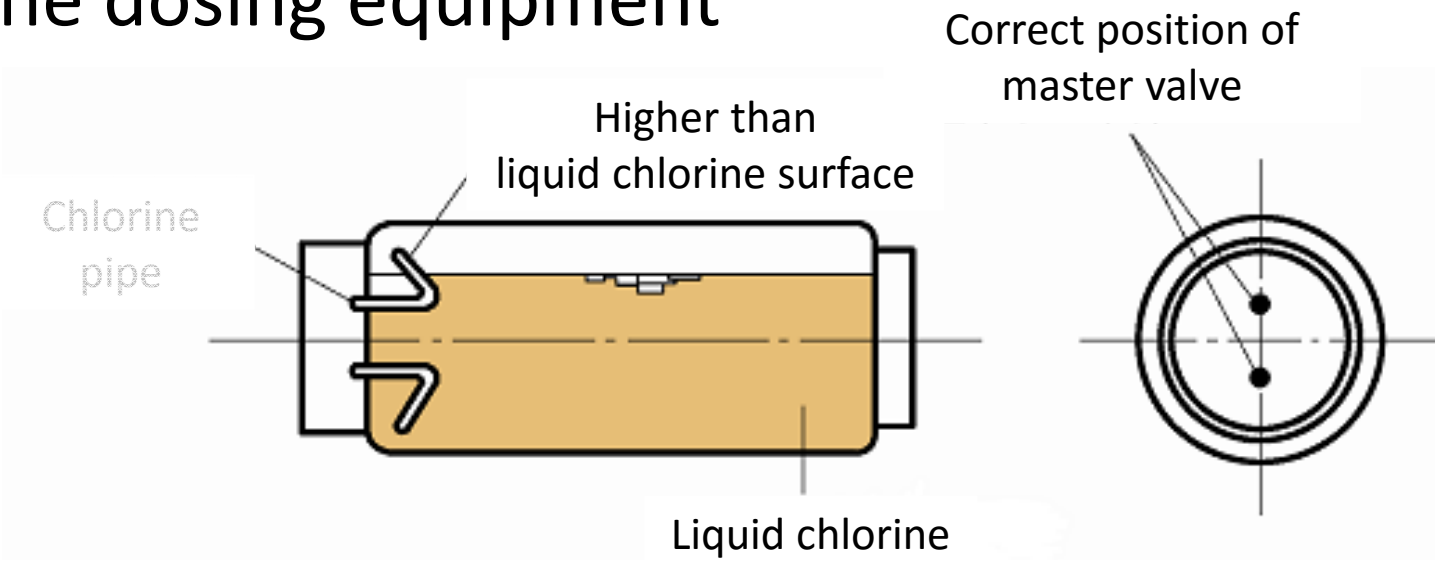


Rota-chlorine dosing equipment

4. Chlorine dosing equipment

Liquid chlorine tank: Dry chlorine gas and liquid chlorine have no damage to the steel tanks, but once they get wet, chlorine will severely corrode the metal.

4. Chlorine dosing equipment



- Chlorine gas turns to liquid chlorine under 6~8 atm. The tank should be 80% full and lay down steadily;
- The evaporation of liquid chlorine is endothermic, so extra heat should be supplied;
- Usually 15-25 ^{o}C water is showered on the chlorine tank as a heat supply.