PAA (Peracetic Acid): A Possible Alternative to Chlorine in Water and Wastewater Disinfection

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Background

Since early 1900s chlorine is being used as water disinfectant. It was favorite to the industries like water and wastewater for disinfection until Rook[1] (1974) discovered several harmful disinfection by products in chlorinated water. Since then the water community started looking for alternative disinfectant such as ozone, UV, PAA, and Hydrogen Peroxide (HP) etc.

Currently chlorine is proven to be the main source for causing several harmful disinfection by products (DBPs). Studies are being done to find and eliminate the DBPs precursors and look for the alternative disinfectant. PAA, mostly known as a water & wastewater disinfectant in European countries, because of its similar disinfection abilities to chlorine, without producing any harmful DBPs [2].

Production

There are several methods to produce peracetic acid.

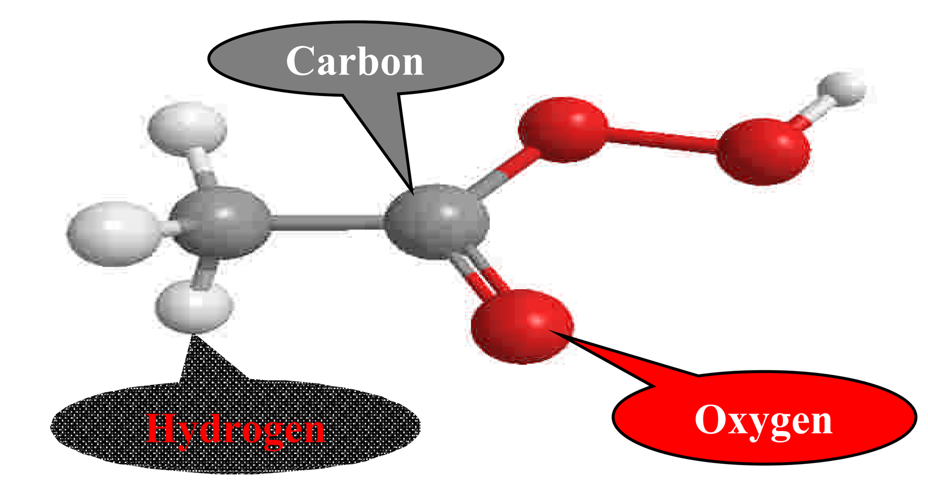
1. PAA is produced by reacting acetic acid and hydrogen peroxide. The reaction is allowed to continue for up to ten days in order to achieve high yields of product according to the following equation:

$$CH_3COOH + H_2O_2 \rightarrow CH_3COOOH + H_2O$$

Acetic acid Hydrogen peroxide Peracetic acid water

2. An additional method of preparation is the oxidation of acetaldehyde.
3. Alternatively, it is produced as an end product of the reaction of acetic anhydride, hydrogen peroxide, and sulfuric acid.
4. Recently a solid powdered form of PAA (BIOXY S) has been approved by Health Canada and Canadian Food Inspection agency.

Physical and Chemical Properties



General	
Molecular formula	$C_2H_4O_3$
Molar mass	76.05 g/mol
Appearance	Colorless liquid
Odor	Strong like vinegar
Properties	
Density and phase	1.13 g/ml, liquid
Solubility in water	10 g/100 ml (19 °C)
Boiling point	105°C

Mechanism of action

PAA kills microorganisms by oxidation and subsequent disruption of their cell membrane, via the hydroxyl radical (OH·). As diffusion is slower than the half-life of the radical, it reacts with any oxidizable compound in its vicinity. It damages virtually all types of macromolecules associated with a micro-organism: carbohydrates, nucleic acids (mutations), lipids (lipid peroxydation) and amino acids. This ultimately leads to cell lysis and true microbial death. Fig 1.

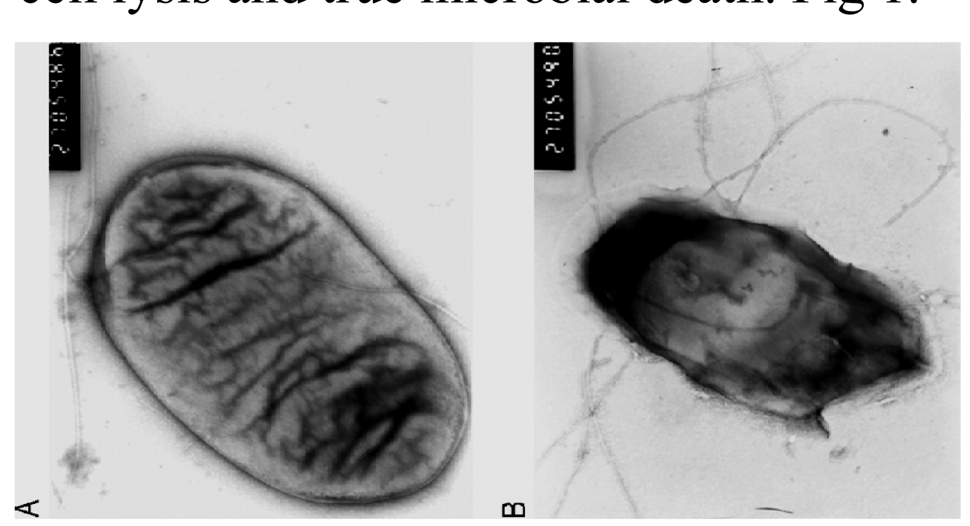


Fig. 1, Transmission electron microscopy of Salmonella typhimurium LT2 without treatment with PAA and after exposure for 1 h to 7 mg/l. Source: A. Jolivet-Gougeon et al; International Journal of Food Microbiology 112 (2006) 147–152

The mechanism of oxidation is the transfer of electrons, therefore the strong oxidizer (Table 1) will produce faster killings or inactivation of the microorganism.

Table 1. Oxidation Capacity of Oxidizers

Disinfectant	eV*
Ozone	2.07
Peracetic Acid	1.81
Chlorine Dioxide	1.57
Sodium Hypochlorite	1.36

•electron volt

Source : Enviro Tech Chemicals, Inc

Application

EPA had registered PAA as an antimicrobial in 1985 for indoor use on hard surfaces. It is being used in following industries as disinfectant:

- Meat, Poultry, Seafood, processing and packaging plants.
- Food processing industries.
- Hospitals and Healthcare facilities as sterilant.
- Paper and pulp Industries.
- Water and wastewater [3]industries
- Plumbing disinfectant.
- Water reuse applications such as cooling tower water disinfectant where it prevents bio film formation and effectively controls Legionella bacteria.

Advantages:

- No mutagenic DPBs. The disinfection end products like carboxylic acids and water are harmless to humans.
- Synergic effect[4&5] of PAA and UV has greater effects (can save lot of cost caused by using PAA alone).
- No alteration in disinfection tank required.
- pH, hardness, and presence of organic matters has no or little effect on biocidal activity of PAA[6].

Disadvantages:

- Good performance with biologically treated wastewater, but probably more pilot studies needed before using in water treatment[7].
- High degradability.
- High transportation Cost.
- Higher cost of production and storages.

Compatible to Chlorine

Studies have reported that disinfection capacity of PAA for same doses is similar to chlorine or slightly better. Synergic effect (PAA + UV) has a lot better results. It can help by reducing the dose of PAA, which will reduce the disinfection cost.

Table 2. (Log$_{10}$ reduction (average ± standard deviation) of enteric microorganism with different disinfection treatment in peptone water)[4]

	E. Faecalis		*E. Coli*		*S. Enteritidis*		*MS2 Coliphase*	
Disinfection treatment	*Dose*	*Log$_{10}$ Reduction*	*Dose*	*Log $_{10}$ reduction*	*Dose*	*Log$_{10}$ reduction*	*Dose*	*Log$_{10}$ reduction*
PAA (mg/L)	1.5	1.74 ± 0.67	2.0	0.57 ± 0.19	2.0	0.38 ± 0.19	7.0	0.86 ± 0.16
	3.0	3.12 ± 0.23	3.0	2.81 ± 0.37	3.0	1.93 ± 0.53	15.0	1.28 ± 0.33
PAA/UV	1.0/8.0	2.32 ± 0.50	2.0/10.0	2.29 ± 0.32	2.0/6.0	1.80 ± 0.21	7.0/22.0	1.72 ± 0.06
(mg/L)/(mWs/cm^2)	1.5/8.0	4.56 ± 0.40	3.0/10.0	5.56 ± 0.59	3.0/6.0	3.56 ± 0.45	15.0/22.0	1.96 ± 0.20
	1.0/10.0	3.00 ± 0.76	2.0/14.0	4.66 ± 0.29	2.0/10.0	4.24 ± 0.55	7.0/38.0	2.37 ± 0.18
	1.5/10.0	4.40 ± 0.79	3.0/14.0	5.97 ± 0.34	3.0/10.0	6.16 ± 0.56	15.0/38.0	2.58 ± 0.23
Chlorine (mg/L)	12.0	2.69 ± 0.52	18.0	0.28 ± 0.11	18.0	0.44 ± 0.08	18.0	1.03 ± 0.05
UV (mWs/cm^2)	8.0	0.61 ± 0.20	10.0	0.55 ± 0.11	6.0	0.87 ± 0.12	22.0	0.79 ± 0.12
	10.0	1.20 ± 0.18	14.0	1.44 ± 0.12	10.0	2.61 ± 0.35	38.0	1.40 ± 0.15

Table 3. (Efficiency of disinfection with PAA and UV)

PAA^a	*UV*	*PAA^b*	*Average log inactivation*						
(ppm)	*(mJ/cm^2)*	*(ppm)*	*Total Coliform*	*Faecal coliform*	*Faecal Strept*	*E.Coli*	*Pseud. aeruginosa*	*Heter. Plate count 22^{0}C*	*Heter. Plate count 36^{0}C*
2.0	165.0	0.0	T.I.	T.I.	T.I.	4.28	2.02	1.87	1.92
2.0	192.0	0.0	T.I.	T.I.	T.I.	T.I.	2.65	2.11	2.31
4.0	192.0	0.0	T.I.	T.I.	T.I.	T.I.	T.I.	3.30	3.36
0.0	165.0	2.0	4.57	4.03	T.I.	4.28	2.32	2.13	2.10
0.0	192.0	2.0	3.43	3.43	T.I.	T.I.	1.56	1.46	1.64
0.0	192.0	4.0	5.60	T.I.	T.I.	T.I.	T.I.	2.63	2.62

T.I.:Total inactivation of the microorganisms. ^{a} = PAA introduced before the UV reactor. ^{b} = PAA introduced after the UV reactor. Source: Caretti, C. and Lubello, C. (2003)

Conclusion:

There are no doubts about PAAs bactericidal, virucidal, fungicidal abilities. Usages in food processing and medical facilities itself is a kind of approval of harmless end products. The cost factor (production, storage and transportation) can be reduce by local manufacturing and a much stable percentage of quaternary solution of PAA (PAA, Acetic acid, H_2O_2 and Water).

References:

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