



# HALAMINE CHEMISTRY AND ITS APPLICATIONS IN MEDICAL TEXTILES

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# INTRODUCTION

- **Nosocomial infection rate has been growing rapidly in recent years and has become a serious concern for healthcare community**
- **Surface contact transmission is a major factor contributing to the disease spreading**
- **Survival of many microorganisms on textile materials have been proven, which may contribute to the contact transmission**
- **Biocidal textiles can serve as a good means to reduce microorganisms on their faces and consequently reduce nosocomial infection in hospitals**

# CDC Guideline-Rankings

*Guideline For Prevention of Surgical Site Infection, 1999*

- **Category IA:**
  - Strongly recommended for implementation and supported by well-designed experimental, clinical, or epidemiologic studies
- **Category IB:**
  - Strongly recommended for implementation and supported by some experimental, clinical, or epidemiologic studies and strong theoretical rational
- **Category II:**
  - Suggested for implementation and supported by suggestive clinical or epidemiologic studies or theoretical rational
- **No Recommendation (Unresolved Issue):**
  - Practices for which insufficient evidence or no consensus regarding efficacy exists

- **Surgical gowns, drapes and gloves that are barriers at wet**
  - Category IB
- **Uniforms and linen products– Category II**

# Prevention of Infectious Diseases

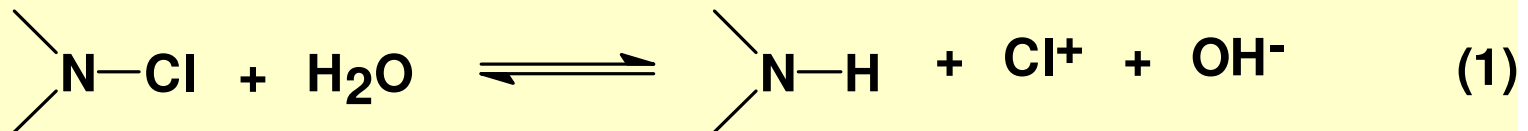
## Using Antimicrobial Materials

- **Biostatic** functions
  - Inhibit growth of microorganisms
  - Prevent materials from biodegradation
  - Odor-control textiles
- **Biocidal** functions (Antibacterial)
  - Kill microorganisms completely
  - Protect wearers of textiles from biological attacks
  - Odor-free textiles
- **Biocidal** and reusable uniforms and surgical gowns for healthcare workers
- **Biocidal** and reusable face masks and gloves
- **Antibacterial** and reusable patient dresses and bed linens
- **Biocidal** and reusable surface covering materials
- **Biocidal** polymers for medical catheters and other devices

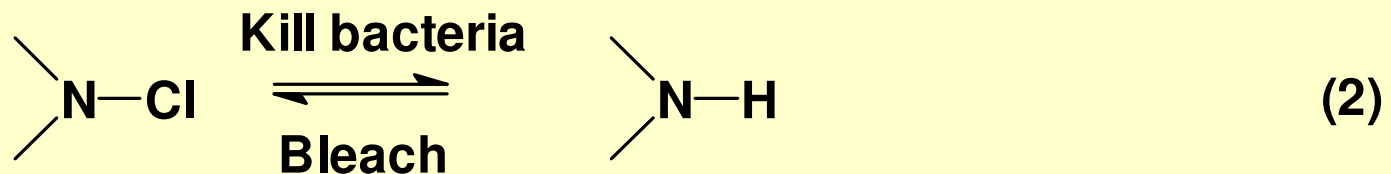
# Functions and Limitations of Biocides

<i>Biocides</i>	<i>Function</i>	<i>Limitation</i>
Halogens (Cl <sub>2</sub> , Br <sub>2</sub> , and I <sub>2</sub> )	Oxidizing	Toxicity and skin irritation
H <sub>2</sub> O <sub>2</sub>	Oxidizing	Toxicity and skin irritation
Formaldehyde	Alkylating	Carcinogen and skin irritation
Alcohols	Dehydrating	High concentration, less effective on spores
Quaternary Ammonium salts	Affecting Permeability	Less effective and skin irritation
Phenols	Affecting permeability	Less effective and skin absorption
Heavy metals (Ag, Cu)	Sulfhydryl binding	Not effective against spores, water pollution
<b>Antibiotics</b>	Reproductive Enzyme inhibitors	Creating drug-resistance

# Halamine Chemistry



Free chlorine can be released from halamine at different amount, but depending on structures. Most swimming pool disinfectants are based on this reaction.

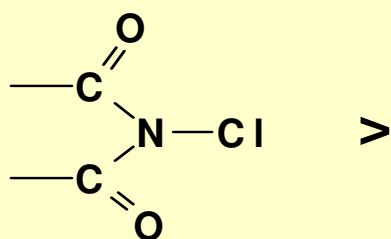


Solid state halamine structures mostly kill germs based on this reaction

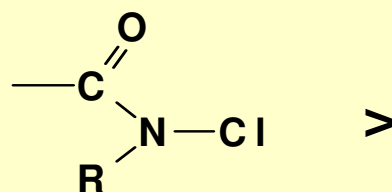
# Halamine Chemistry

## Three Halamine Structures

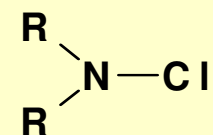
### DISSOCIATION OF $\text{Cl}^+$



imide halamine

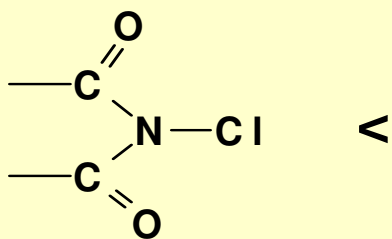


amide halamine

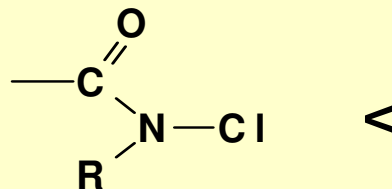


amine halamine

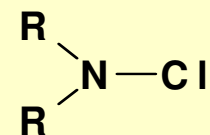
### CHLORINE STABILITY



imide halamine



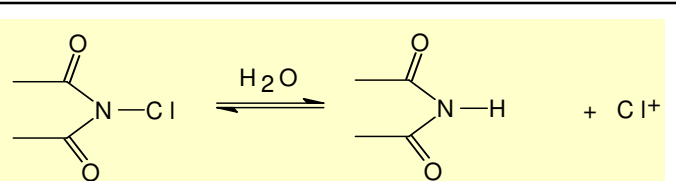
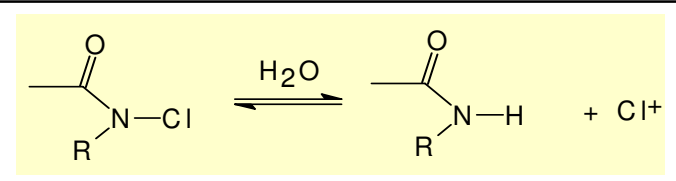
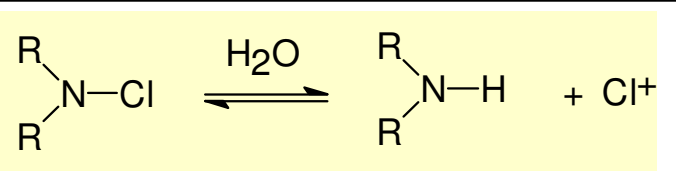
amide halamine



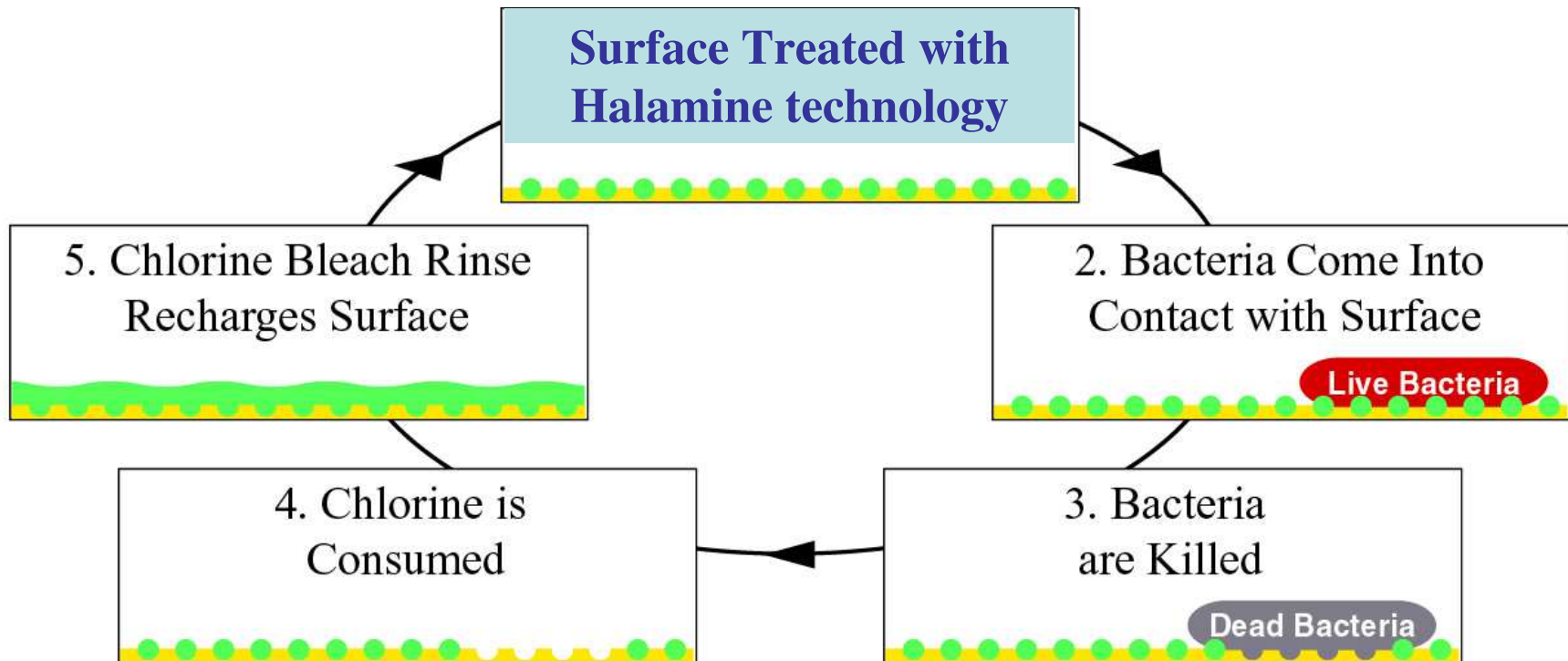
amine halamine

# STABILITY OF HALAMINE BONDS

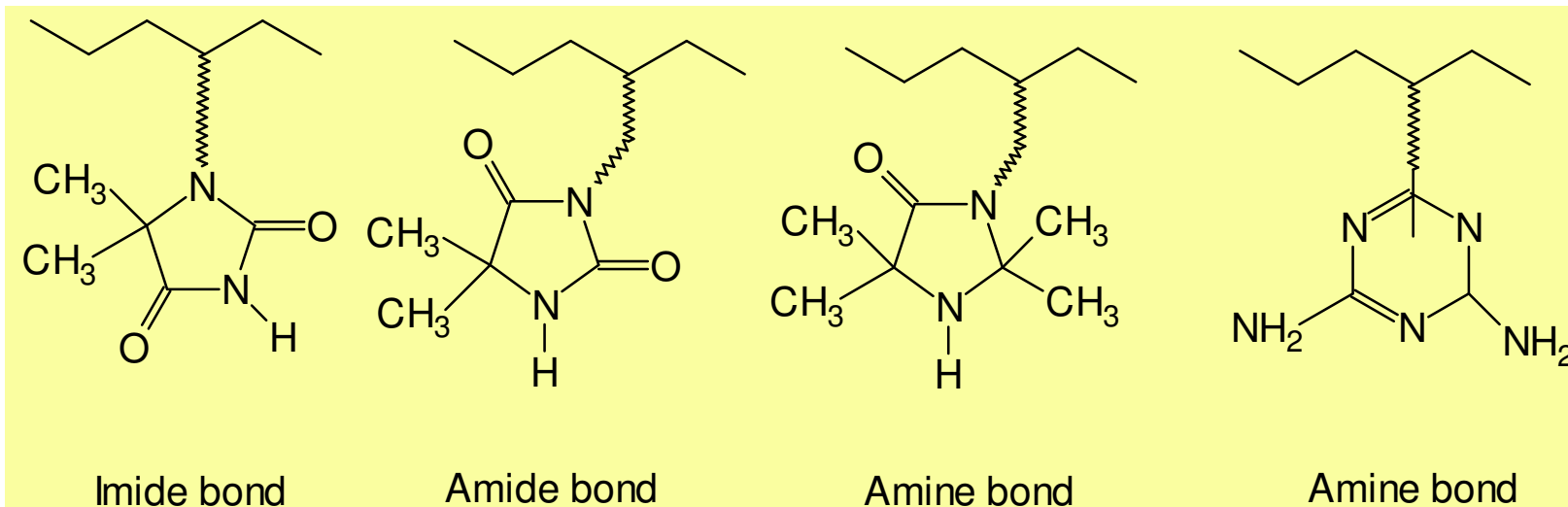
DISSOCIATION CONSTANTS (Kd)

Halamine bond	Dissociation Reaction	Dissociation Constant
Imide		$10^{-2} - 10^{-4}$
Amide		$10^{-8} - 10^{-9}$
Amine		$<10^{-12}$

# Reusable and Biocidal Functions



## Examples of Halamine Polymers



**All halamine structures could kill a broad spectrum of microorganisms**

**Contact time to a complete kill may be different, but in an order of Imide>Amide>Amine**

**All above halamine structures are stable because there is no  $\alpha$ -C-H**

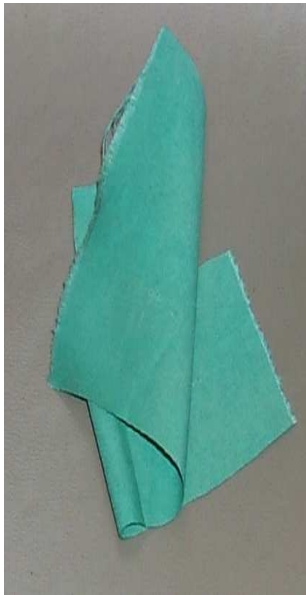
# Microbes Killed by Halamine Textiles

(Contact time could be as short as two min. and reduction rates were  $10^{-6-7}$ CFU)

- *E. coli*
- *Staph aureus*
- *Salmonella*
- *Pseudomonas*
- *Shigella*
- *Brevibacterium*
- Methicillin-resistant *Staphylococcus*
- Vancomycin-resistant *Enterococcus*
- *Candida albicans* (yeast)
- Retroviruses (viruses of blood cells)
- *Trichophyton* (athletes' foot fungus)
- *Aspergillus* sp.

# Efficacy of Treated Medical Scrubs vs. Murine Leukemia Virus (MLV)

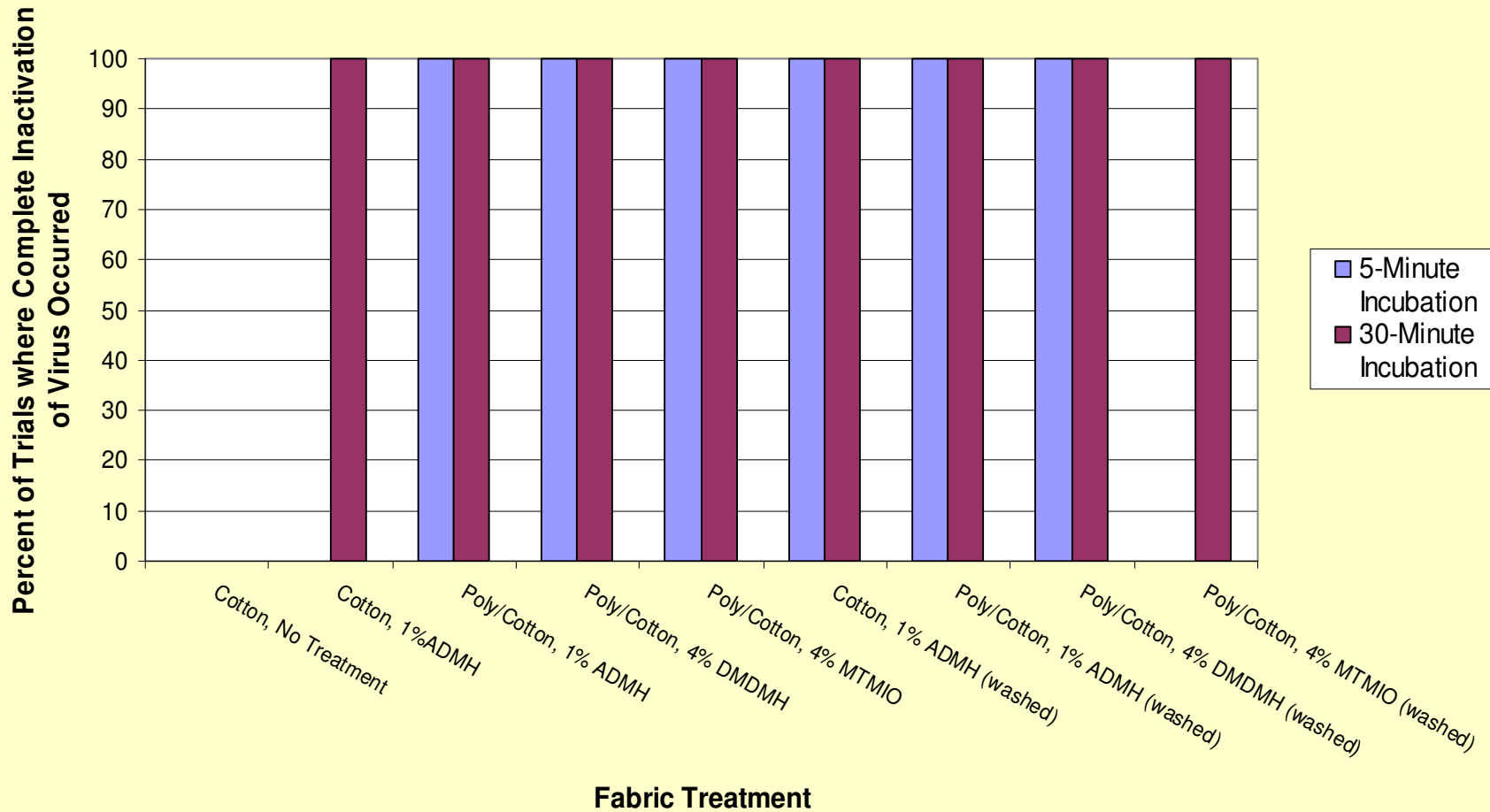
(AATCC 100 Protocol)



Fabric Type	Bioburden	Contact Time	Log Reduction *
Scrubs Cotton/PET	50% Bovine Serum	30 min.	> 3.5 *
Scrubs Cotton/PET	100% Bovine Serum	30 min.	> 3.5
Scrubs Cotton/PET	100% Bovine Serum	20 min.	> 3.3
Scrubs Cotton/PET	100% Bovine Serum	10 min.	> 3.9
Scrubs Cotton/PET	100% Bovine Serum	2 min.	> 3.8
Polyester/viscose	100% Human Serum	2 min.	> 3.8
Polyester/viscose	100% Human Serum	1 min.	1.8

\* Most conservative estimate, based on virus recovery from unhalogenated control swatch; Three log reduction equals 99.9% kill of microbial cells

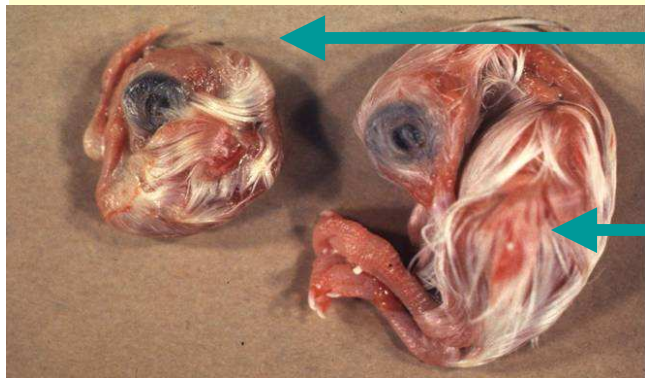
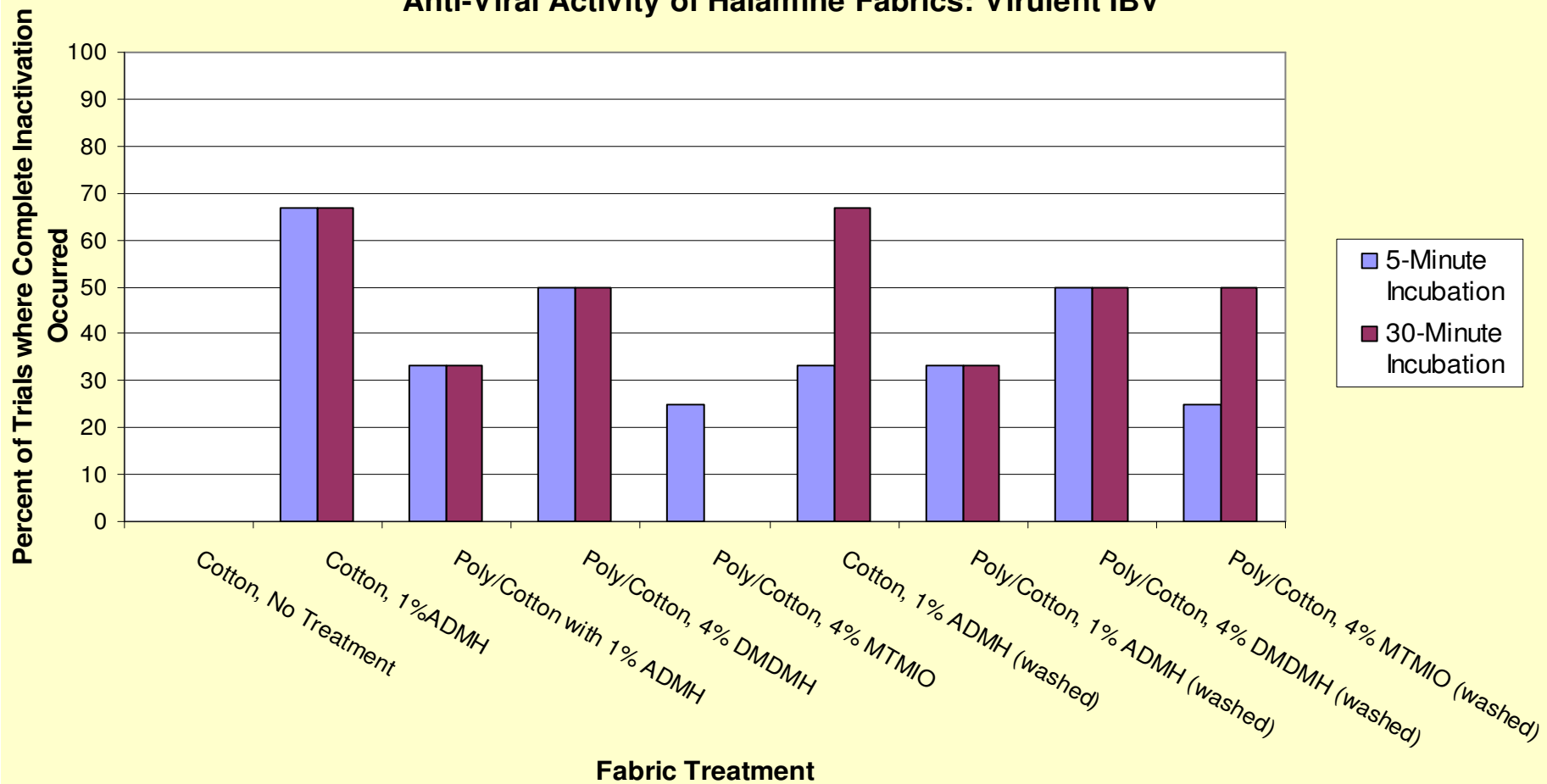
## Anti-Viral Activity of Halamine Fabrics: Vaccine IBV



**Plain woven fabrics (scrubs) were treated by ADMH (amide halamine, 1%) or DMDMH (both amide and imide halamines 4%) or MTMIO (amine halamine 4%);**

**Washed: after 20 times machine washes**

## Anti-Viral Activity of Halamine Fabrics: Virulent IBV

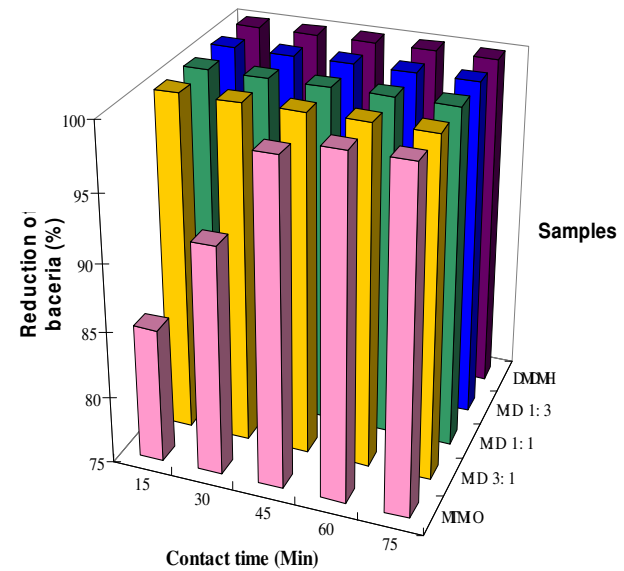
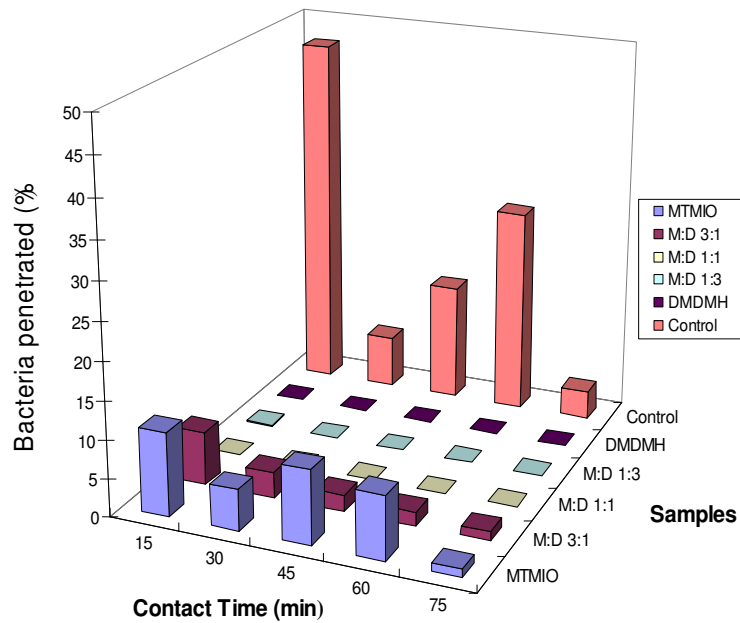


\* Embryo on left is positive for IBV (stunting, curling of toes, clubbing of down, urate deposition, thick amniotic membrane)  
 \* Embryo on the right is normal.

## Prevention of Wet Microbial Penetration

- Bacterial penetration through textiles (fabrics and face masks) is a concern of infection
- Currently used testing method (AATCC) only reveals contact antibacterial efficacy but may not tell whether bacteria have penetrated through the material
- Wet microbial penetration test (an European method, prEN 13795-4) is designed to demonstrate such function
- We compared the contact antibacterial efficacy and bacterial wet penetration results and found that textile must possess **quick** and **complete** kill ability to prevent the wet penetration of diseases

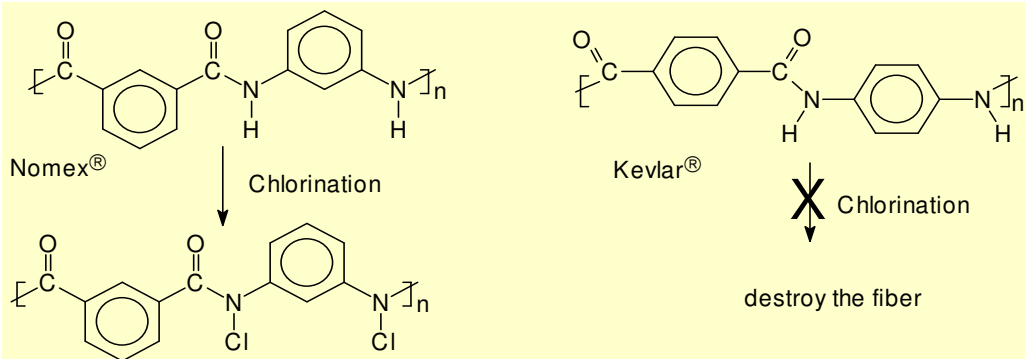
# Comparison of Contact Kill and Wet Penetration of Microbes



Wet penetration of E. coli after 10 times washing and recharging

Contact inactivation of E. coli after 10 times washing and recharging

# Biocidal Nomex Fibers (NTC C02-CD06 and S02-CD01)



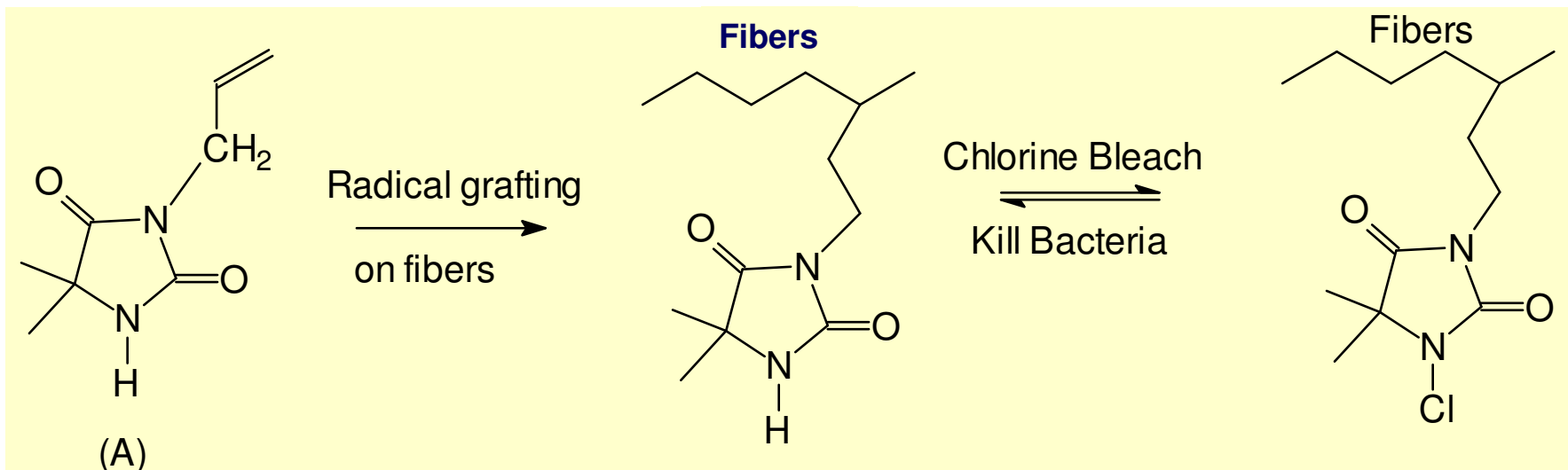
Run	Age (days)	Wash times	[Cl] on fabrics (ppm)	Contact time (min)	Reduction of <i>E. coli</i> (%)	Reduction of <i>S. aureus</i> (%)
1	2	1	425	2	99	99
2	2	1	425	10	99.9999	99.9999
3	2	1	425	30	99.9999	99.9999
4	15	1	425	10	99.9999	99.9999
5	30	1	425	10	99.9999	99.9999
6	60	1	430	10	99.9999	99.9999
7	90	1	404	10	99.9999	99.9999



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# Graft Polymerization Halamine

(NSF DMI-0323409)

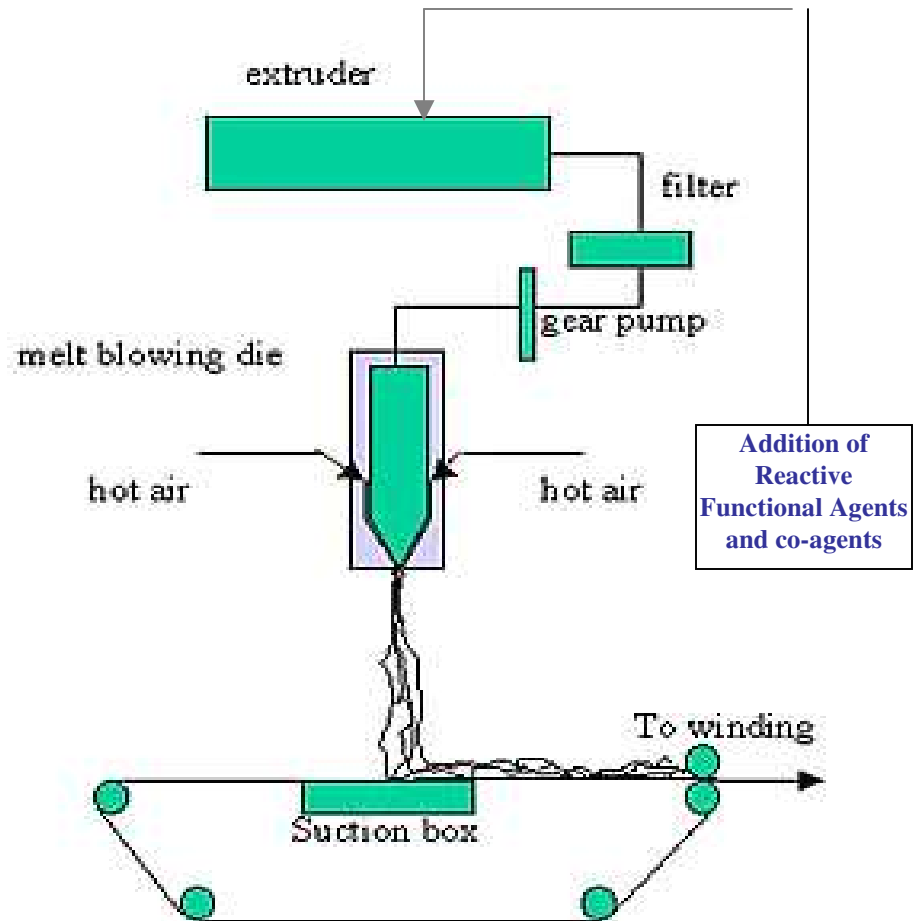


**Halamine precursors can be incorporated to polypropylene fibers during extrusion process**

**Activation of the halamine structures can be achieved by spraying chlorine bleach solution**

# Biocidal Polypropylene Fibers

- Design of a manufacturing technology to carry out graft polymerization during fiber spinning
- Preparation of biocidal fibers and nonwoven fabrics using the above process
- Direct preparation of reusable and rechargeable biocidal N95 respirators and face masks



# Reusable Biocidal Products

- Bed linens
- Uniforms
- Patient dresses
- Drapes and gowns
- Masks
- Wipers and mops



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# Single-Use Biocidal Products

- Drapes
- Surgical gowns
- Wipers
- N95 masks
- Covers



# Acknowledgements

## Participants

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