

BIOCIDAL TECHNOLOGY FOR REUSABLE AND DISPOSABLE TEXTILES

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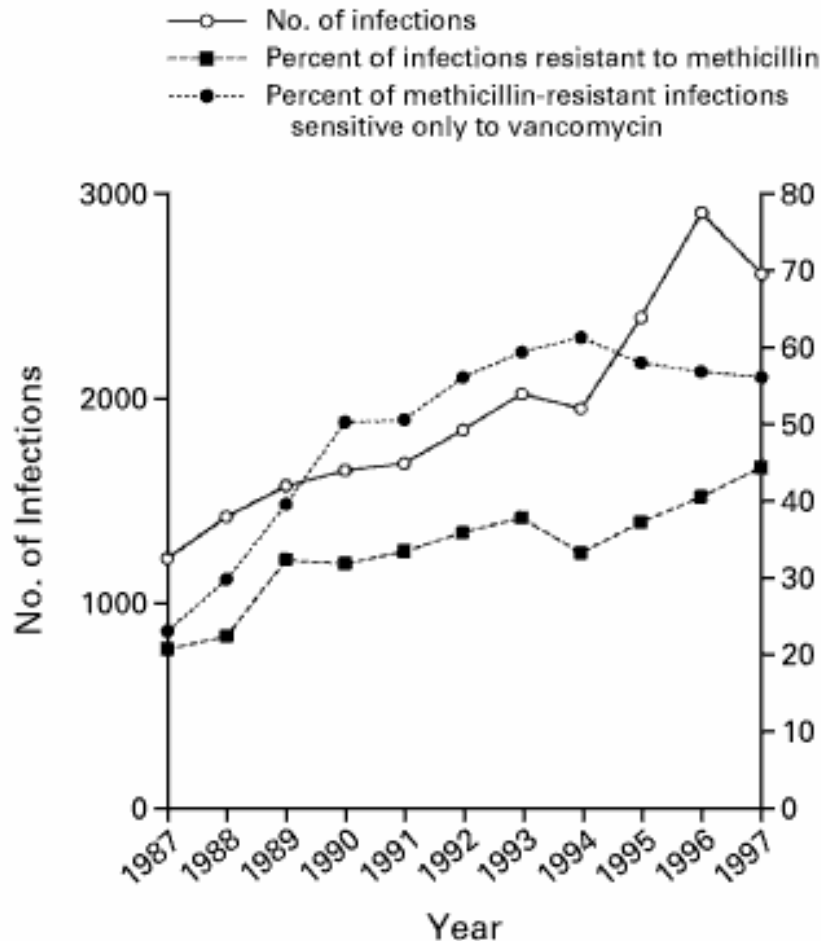
Outline

- Requirements for surgical textiles
- Performance of current medical textiles
- Needs for antibacterial functions
- Developments in biocidal materials

Challenges in Hospitals

- **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**
- **Antimicrobial textiles can serve as a good means to reduce microorganisms on their faces and consequently reduce nosocomial infection in hospitals**

S. aureus and MRSA Infections*



***S. Aureus* infections in Intensive Care Units in the National Nosocomial Surveillance System, 1987-1997**

***Lowy, FD, *The New England Journal of Medicine*, August 520-532, 1998**

Hospital Related Infections of Diseases (Hospitals- Nosocomial Effect)



- **One in 20 hospitalized Americans**
- **1.8 million people — develop an infection**
- **88,000 of them dying**
- **97% of the infections caused by medical materials**

Infections Caused by Textiles

- *Staphylococcus aureus* outbreak is spread by stretcher ¹
- *Staph. aureus*: 65% of nurses attending patients contaminated their uniforms ²
- Nurses uniforms spread *Staphylococcus* ³
- *Staph. aureus*: transfer from fabrics to fabrics and hands ⁴

¹ Al-Barrak et al., Am. J. Inf. Control, 1998

² Boyce et al., Inf. Control Hosp. Epid., 1997

³ Babb et al., J. Hosp Inf., 1983

⁴ Sattar, et al J. Appl. Microb. 2001

Requirements for Surgical Textiles

- Two possible paths of infectious diseases to penetrate through gowns and drapes
 - Strike through
 - Soak through
- To protect surgeons from infectious diseases
 - Primarily by using barrier materials-against strike through
 - If the materials liquid-proof-no strike through and no soak through
 - If the materials porous (liquid repellent) no strike through but possible soak through

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**

Biocidal (Germicidal) Functions*

- **Sterilization**
 - Complete elimination or destruction of all forms of microbial life
- **Disinfection**
 - High Level Disinfection -to destroy all microorganisms, with exception of bacterial spores
 - Intermediate Level Disinfection -to inactivate *Mycobacterium tuberculosis*, vegetative bacteria, most viruses and most fungi, but not necessarily bacterial spores
 - Low Level Disinfection – to kill most bacteria, some viruses, and some fungi
- **Sanitization**
 - Reduce microbial population on an inanimate object

*APIC Guideline for Selection and Use of Disinfectants, 1996

Current Standards for Surgical Attires

ANSI/AAMI Classifications for Fluid Resistant Performance

Level	Test	Result	AQL Requirement
1	AATCC 42:2000	≤ 4.5 g	4%
2	AATCC 42:2000	≤ 1.0 g	4%
	AATCC 127:1998	≥ 20 cm	4%
3	AATCC 42:2000	≤ 1.0 g	4%
	AATCC 127:1998	≥ 50 cm	4%
4	ASTM F 1671:2003*	Pass	4%
	ASTM F 1670:2003**	Pass	4%

AATCC 42: 2000 – Impact Penetration Test

AATCC 127: 1998 - Hydrostatic Head Test

ASTM F 1671:2003 - Resistance to Penetration to a Simulated Virus

ASTM F 1670:2003 -Resistance to Penetrated by Simulated Blood

PERFORMANCE OF NONWOVEN

-Against Strike Through

TEST METHOD		AATCC 127		ASTM
		Average (mbar)	Standard Div	Result
Disposable Gown	Fabric Reinforces #7A	106	1.00	Fail
	Standard #8A	56	6.99	Fail
	Imperious #9A	>200	/	Pass
Orthopedic Drapes	#4	101	1.62	Fail
	#5	97	6.23	Fail
	#6	77	2.31	Fail

PERFORMANCE OF TEXTILES

-Continued

Standard Disposable Drape	#1	57	1.37	Fail
	#1 Reinforced	>200	/	Pass
	#2	45	2.50	Fail
	#2 Reinforced	>200	/	Pass
	#3	57	7.68	Fail
	#3 Reinforced	>200	/	Pass
Reusable Gown	Back	22.6	0.5	Fail
	Should	52.5	0.9	Fail
	Chest	>200/	/	Pass

Antimicrobial Functions

- **Biostatic** functions
 - Inhibit growth of microorganisms
 - Prevent materials from bio-degradation
 - Odor-control textiles
- **Biocidal** functions (Antibacterial)
 - Kill microorganisms completely and rapidly
 - Protect wearers of textiles from biological attacks
 - Odor-free textiles
- **Selection requirements**
 - Personal protection should use **biocidal** textiles
 - Medical textiles should have quick **biocidal** functions
 - Consumer products could use **biostatic** materials

Criteria's of Biocidal Surgical Textiles

- Quick kill to a broad spectrum of pathogens including *bacteria, yeasts, fungi, and viruses*
- Non-selective to and no immunity from germs
- Non-toxic to wearers and non-irritating to skin
- Stable under normal sterilization
- Durable for storage or laundry for reusable materials
- Rechargeable if the function is lost in laundry or use



Commercially Available Biocides

- Quaternary ammonium salts
 - AEGIS Environments
 - Biosafe
- Silver ions or nano-particles
 - Agion-Tech and several other companies
- Phenolic compounds
 - Microban and related users
- Halamine
 - HaloSource Inc. and Medline Industries, Inc.

Functions and Limitations of Biocides

<i>Biocides</i>	<i>Function</i>	<i>Limitation</i>
Halogens (Cl ₂ , Br ₂ , and I ₂)	Oxidizing	Toxicity and skin irritation
H ₂ O ₂	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
Antibiotics	Reproductive Enzyme inhibitors	Creating drug-resistance

Durability Requirements

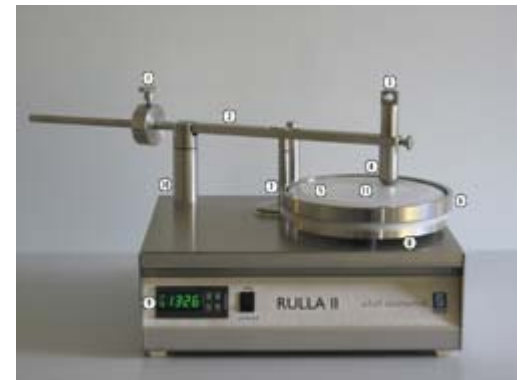
- Washing durability: > 50 commercial laundering
- Storage durability: 3-6 months of shelf life
- Sterilization of steam or ethylene oxide
- Weathering and UV resistance

Challenges:

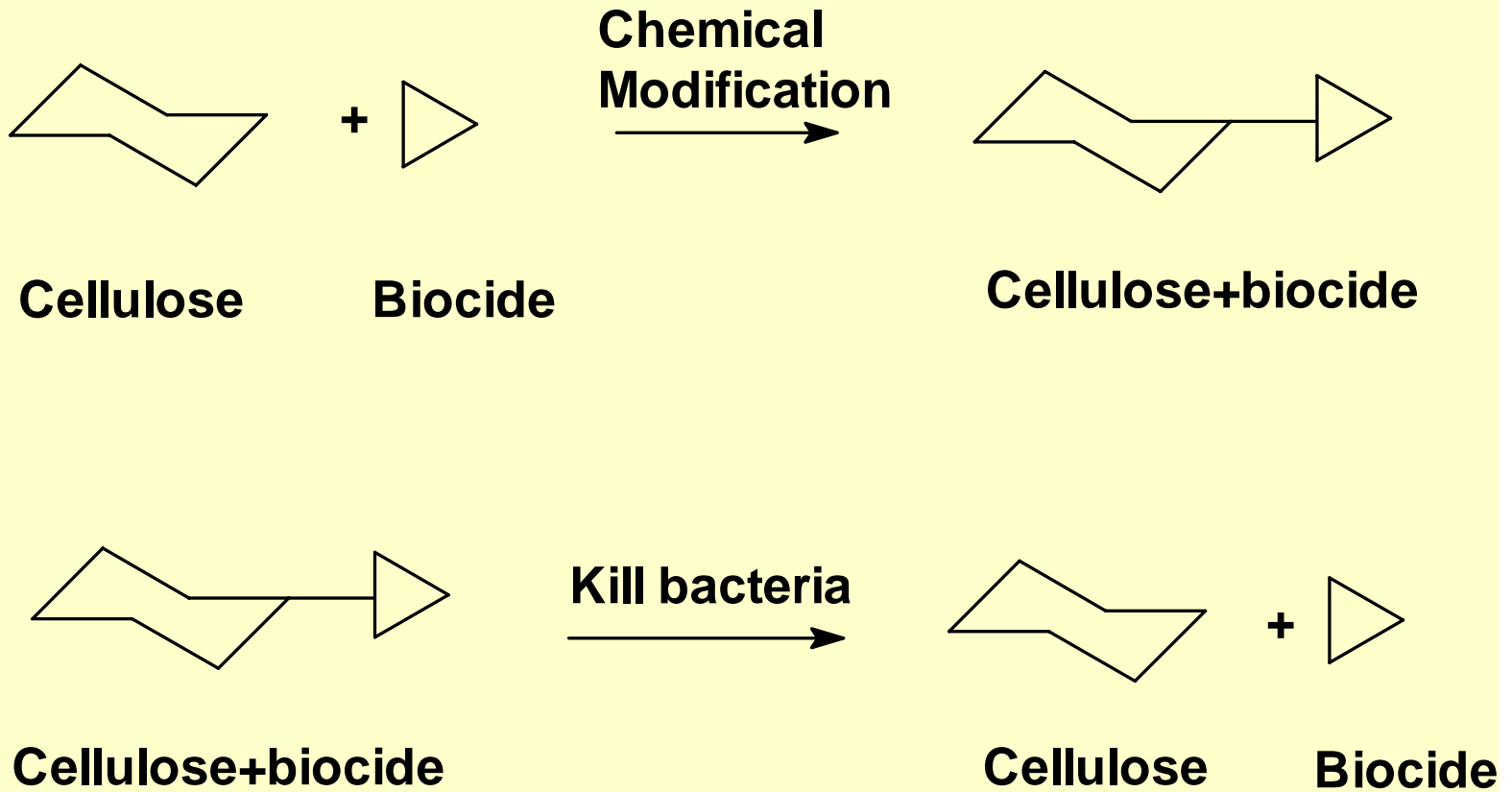
1. Antimicrobial functions always consume biocides
2. Sterilization can destroy many active biocides
3. Biocidal surfaces can be covered by dead bacterial cells or dusts

Test Methods for Antibacterial Medical Attires

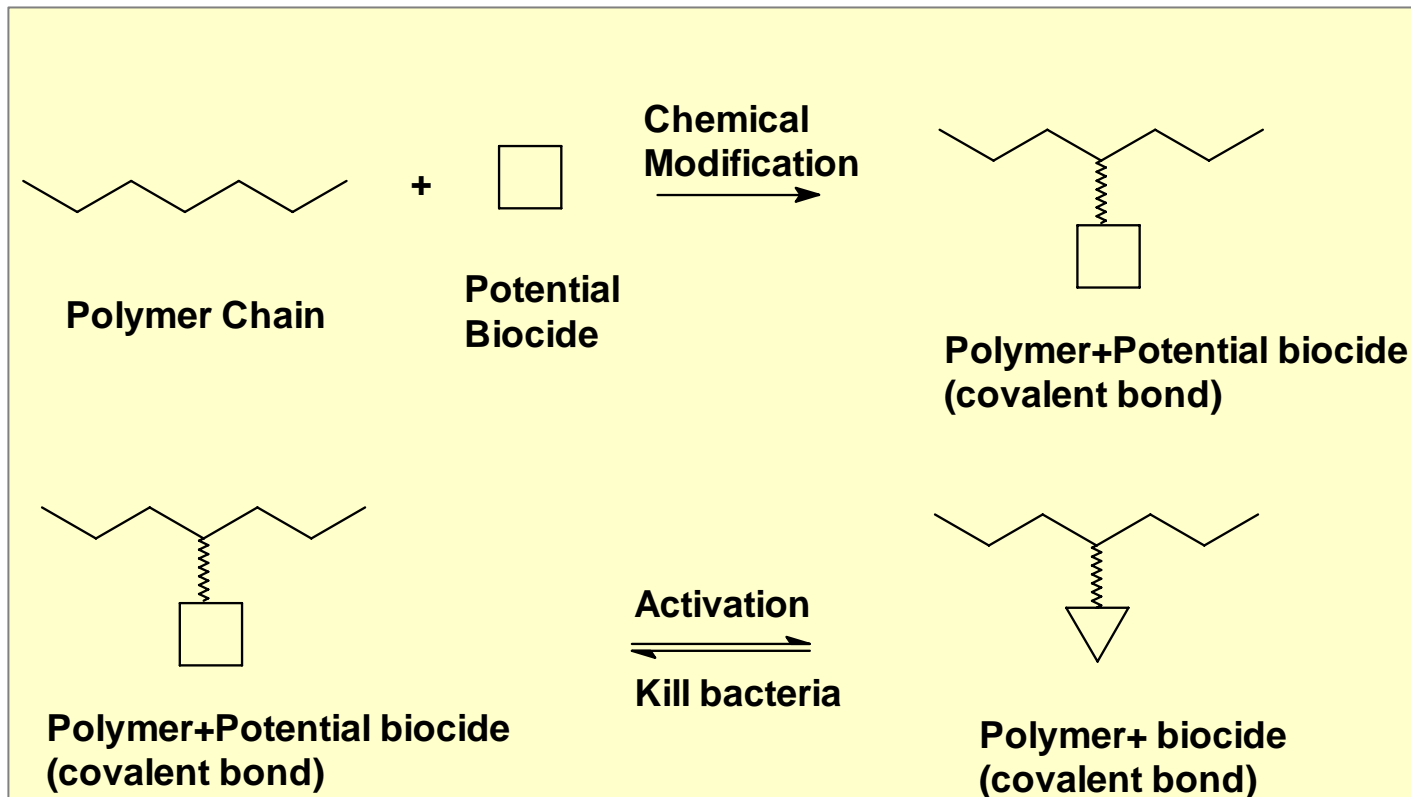
- AATCC test method 100
- AATCC test method 147
- ASTM E2149-01
- ISO 22610
 - Wet bacteria penetration tester



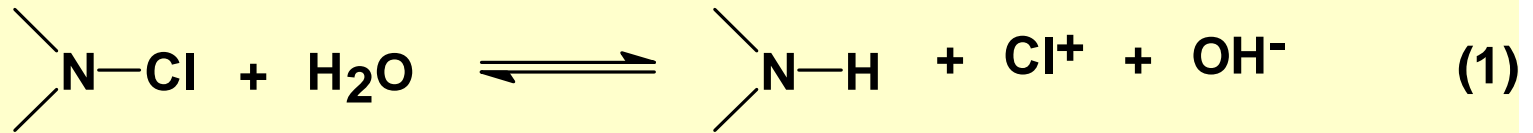
Slow-Releasing Mechanism



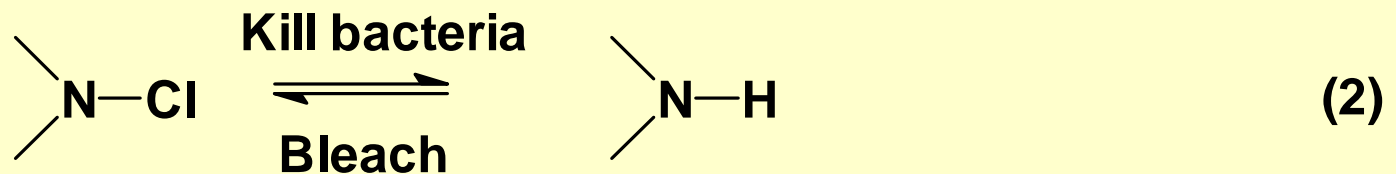
Regenerable Biocidal Effect



Halamine Chemistry



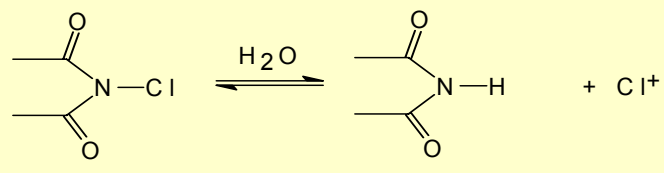
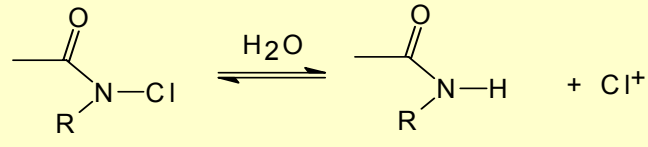
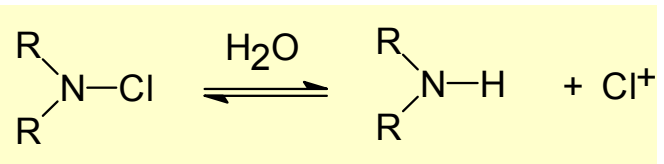
Free chlorine can be released from halamine at different amount, but depending on structures. Most **swimming pool** disinfectants are based on this reaction.



Solid state halamine structures mostly kill germs based on this reaction

STABILITY OF HALAMINE BONDS

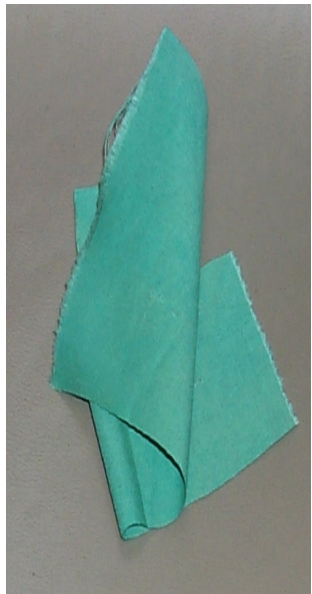
DISSOCIATION CONSTANTS (Kd)

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

Washing Durability and Regenerability

WASHING TEST	FABRICS	BIOCIDAL RESULTS (Imide and amide halamine)			
		2% DMDMH		6% DMDMH	
		<i>E. coli</i>	<i>S. aureus</i>	<i>E. coli</i>	<i>S. aureus</i>
After 10 washes and bleach	Pure Cotton	6 log	6 log	6 log	6 log
	PET/Cotton	6 log	6 log	6 log	6 log
After 20 washes and bleach	Pure Cotton	6 log	6 log	6 log	6 log
	PET/Cotton	6 log	6 log	6 log	6 log
After 30 washes and bleach	Pure Cotton	6 log	6 log	6 log	6 log
	PET/Cotton	6 log	6 log	6 log	6 log
After 40 washes and bleach	Pure Cotton	6 log	6 log	6 log	6 log
	PET/Cotton	6 log	6 log	6 log	6 log
After 50 washes and bleach	Pure Cotton	6 log	6 log	6 log	6 log
	PET/Cotton	6 log	6 log	6 log	6 log

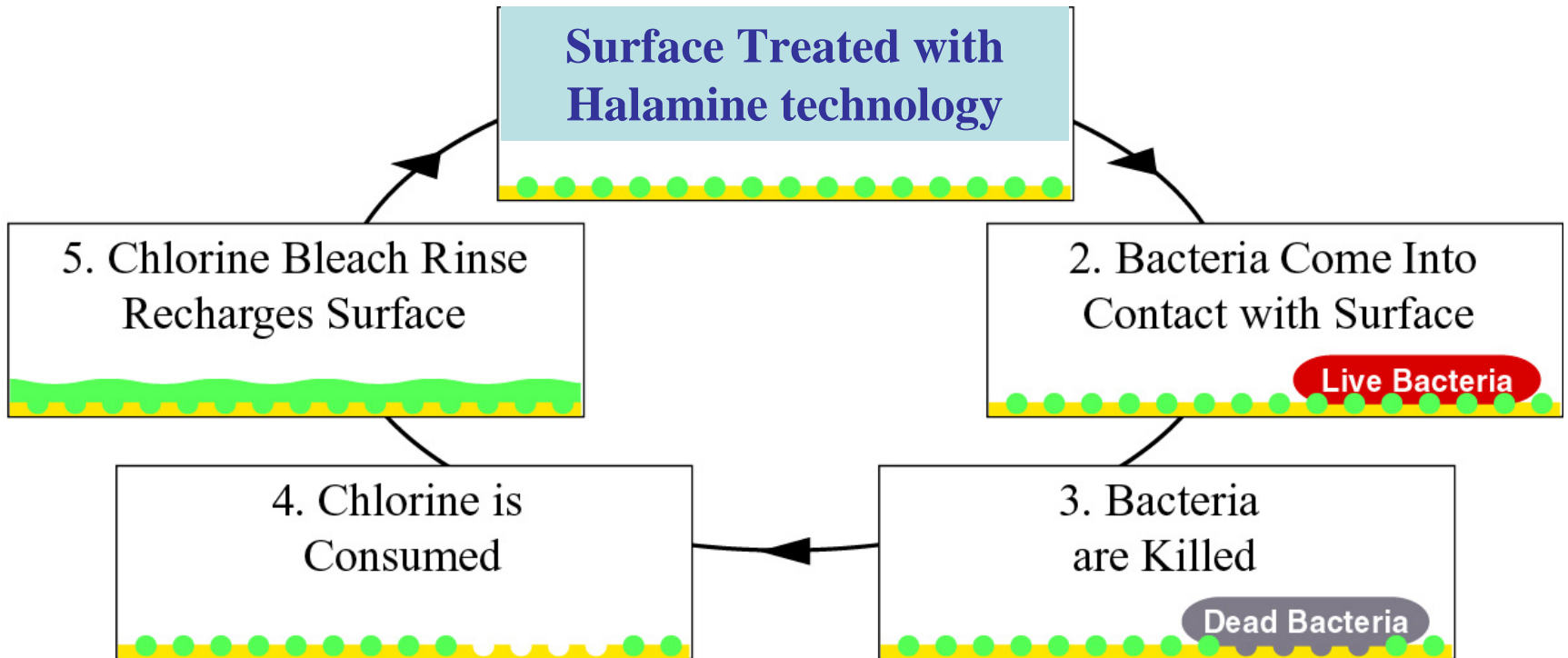
Efficacy of DMDMH (Imide and Amide Halamine) Treated Medical Scrubs vs. Murine Leukemia Virus (MLV)-HaloSource Company (AATCC 100 Protocol)



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

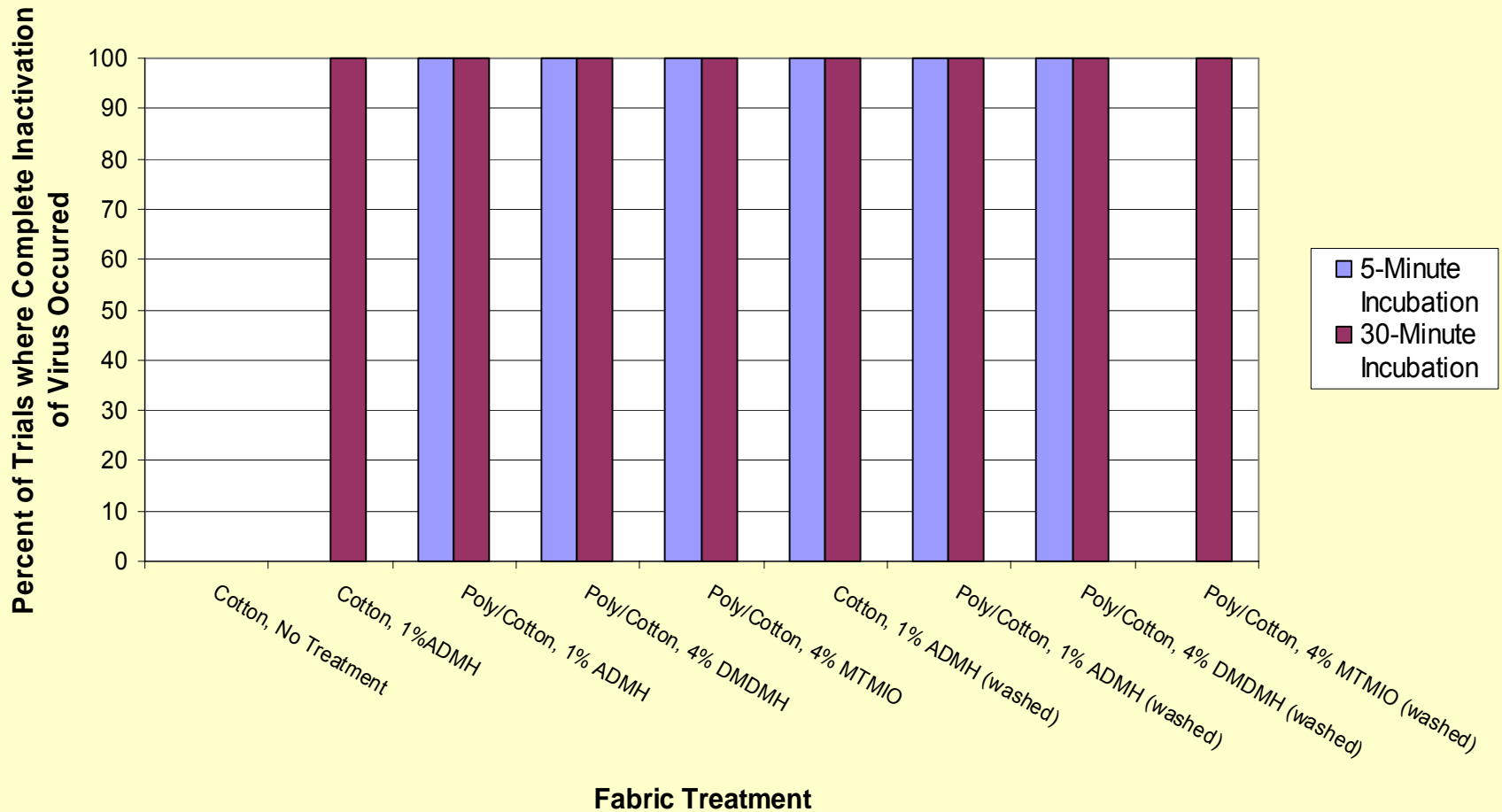
Reusable and Biocidal Functions



Antibacterial Functions of DMDMH Treated Textiles-Sporecidal (HaloSource Company)

- **Target: Spores of *Bacillus subtilis* (anthrax surrogate)**
- **Inoculum: 10⁶ spores on 14 sq. cm. textile**
- **Results: Percent reduction in live spores**
 - **Halamine non-woven textiles**
 - **50/50 polyester/rayon: 100% in 48 hours**
 - **100% rayon: 97% in 24 hours**
 - **30/70 rayon/polypropylene: 99.9% in 24 hours**
 - **Halamine woven textiles**
 - **100% cotton canvas: 99.9% in 48 hours**

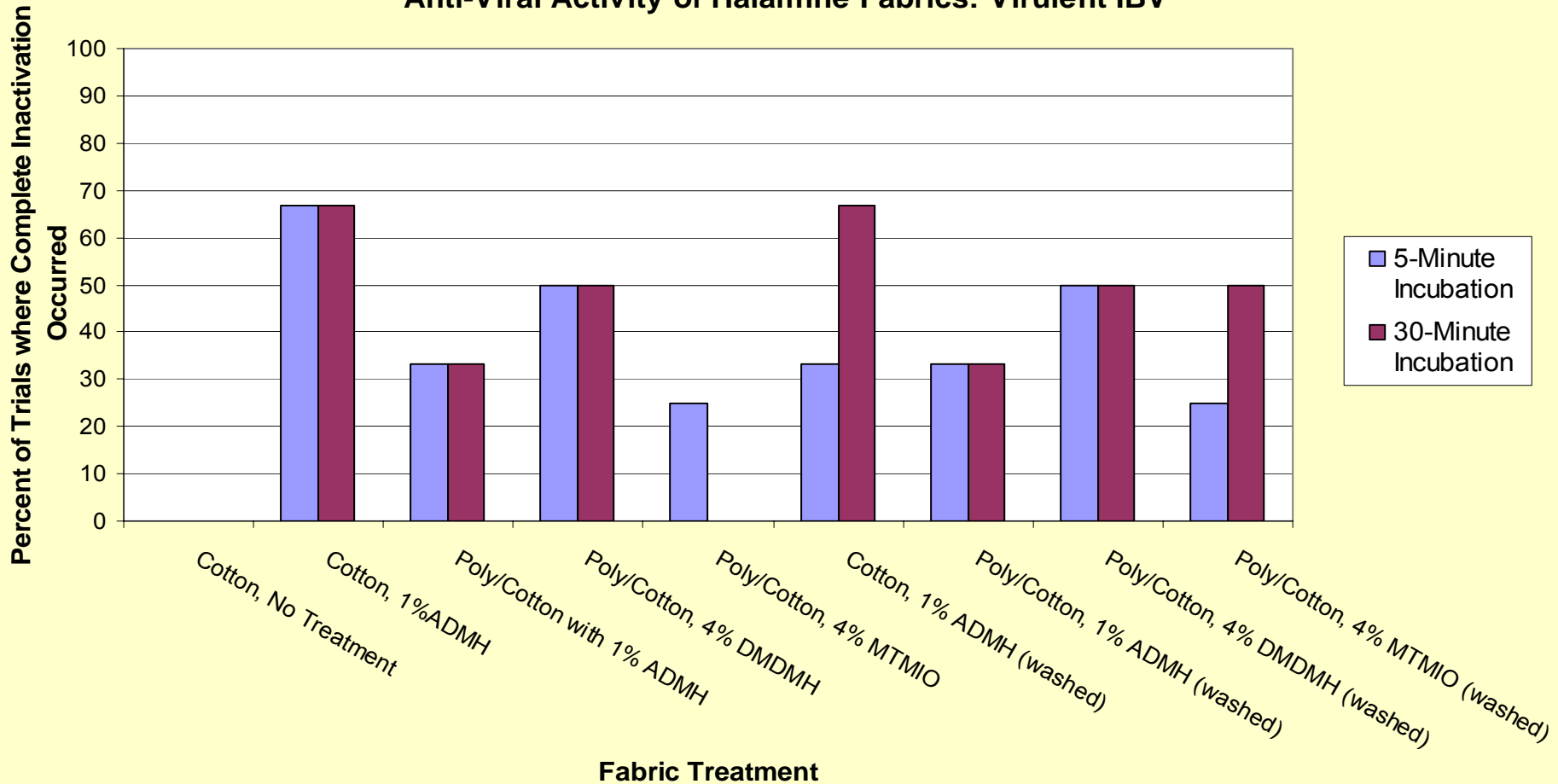
Anti-Viral Activity of Halamine Fabrics: Vaccine IBV



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

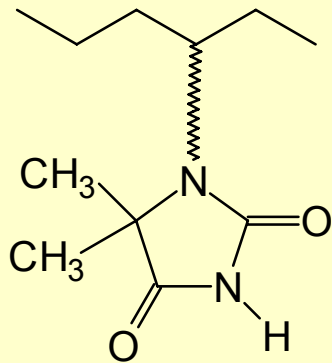
Anti-Viral Activity of Halamine Fabrics: Virulent IBV



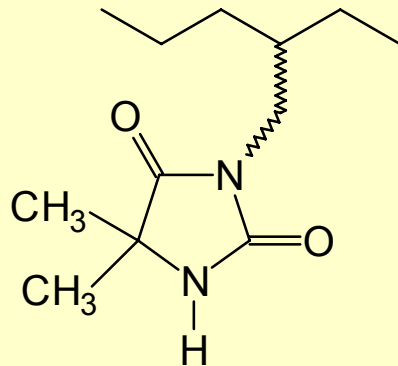
* Embryo on left is positive for IBV (stunting, curling of toes, clubbing of down, urate deposition, thick amniotic membrane)

* Embryo on the right is normal.

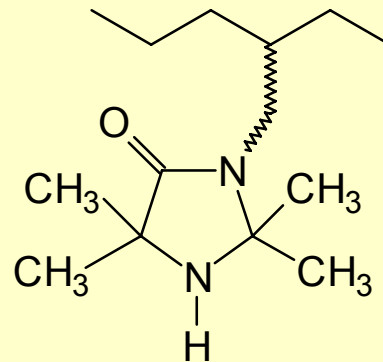
Examples of Halamine Polymers



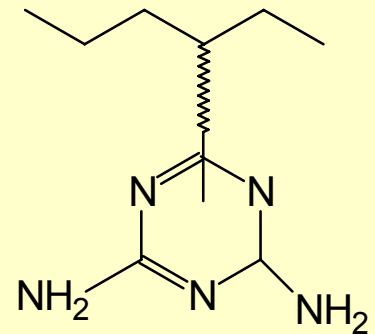
Imide bond



Amide bond



Amine bond



Amine bond

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

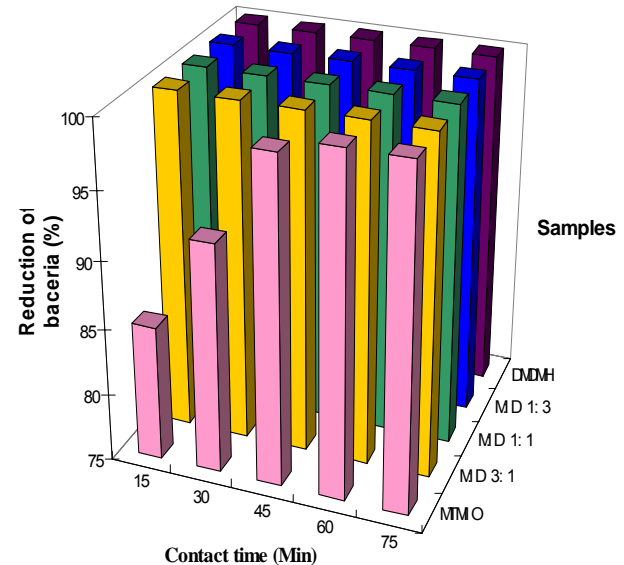
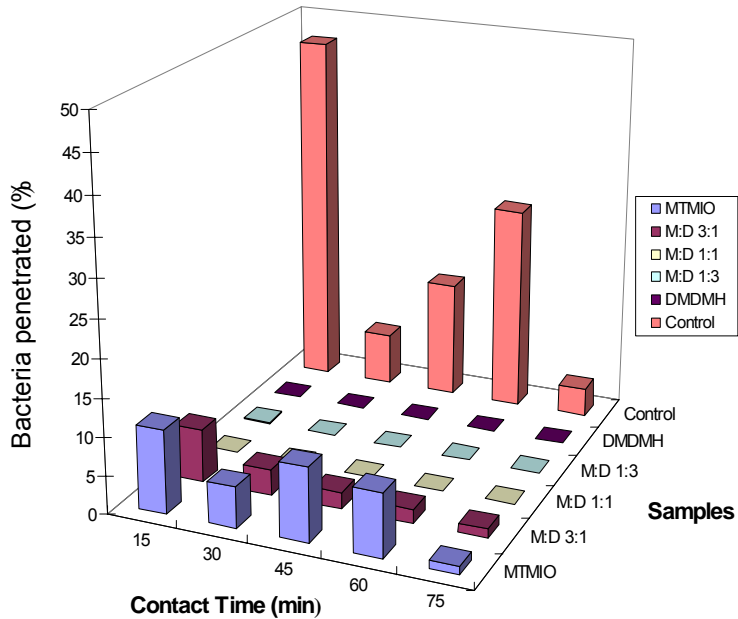
All above halamine structures are stable because there is no α -C-H

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.

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

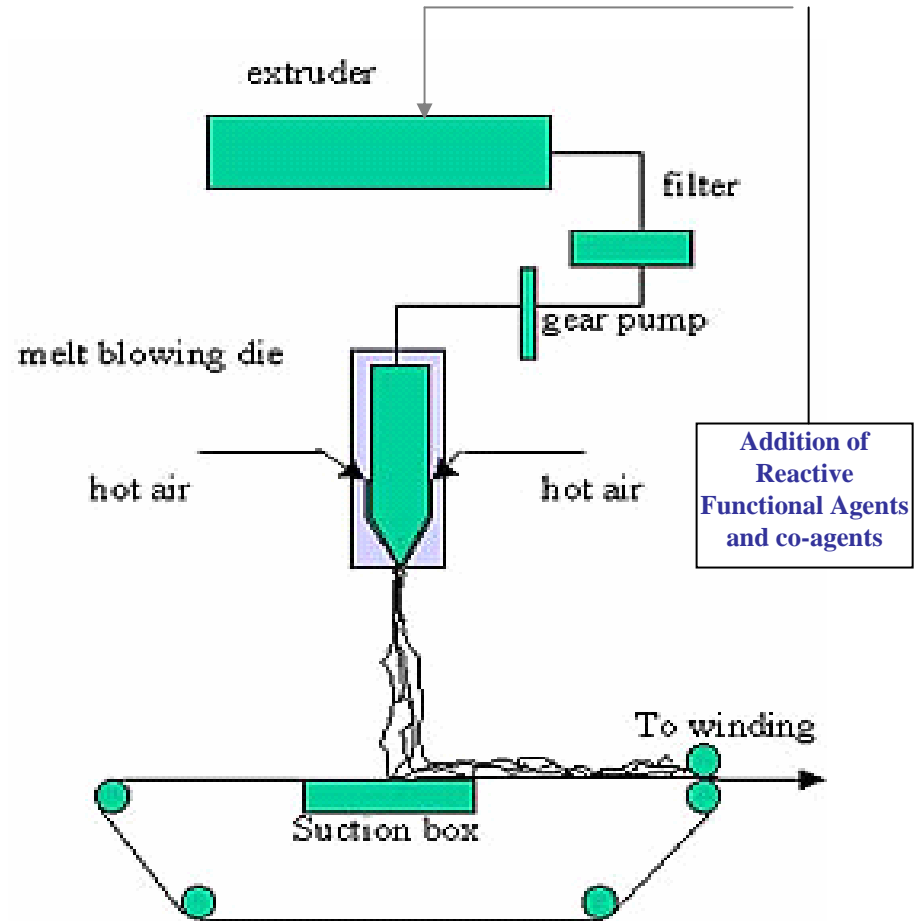
Incorporation of Biocides to Nonwoven Textiles

- Fiber
 - Finishing
 - Fiber extrusion
- Yarn-finishing
- Fabric-finishing or coating
- Garment-finishing or coating

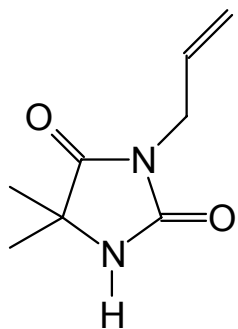
→
Additives in fiber extrusion
Reactive extrusion

Biocidal Polypropylene Fibers

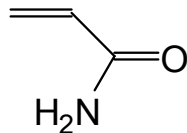
- Design of a manufacturing technology to carry out graft polymerization during fiber spinning
- Preparation of biocidal fibers and nonwoven fabrics using the above process
- Direct preparation of reusable and rechargeable biocidal N95 respirators and face masks



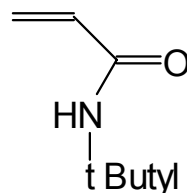
Vinyl Monomers Employed



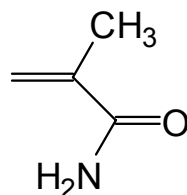
3-allyl-5,5-dimethylhydantoin
(ADMH)



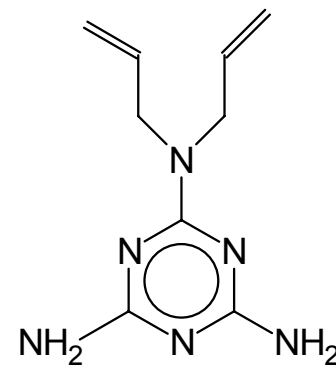
Acrylamide (AM)



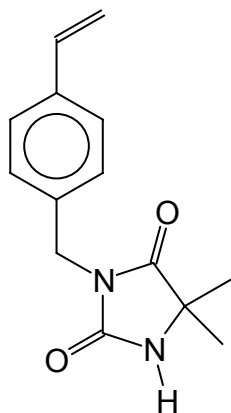
n-t-butyl acrylamide (t-BAM)



Methacrylamide (MAM)



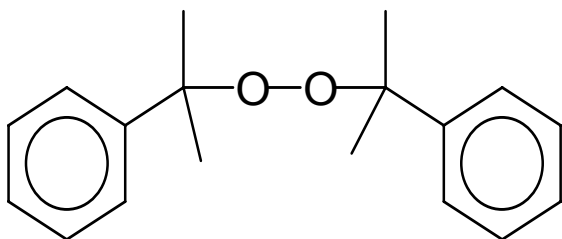
N,N-diallylmelamine



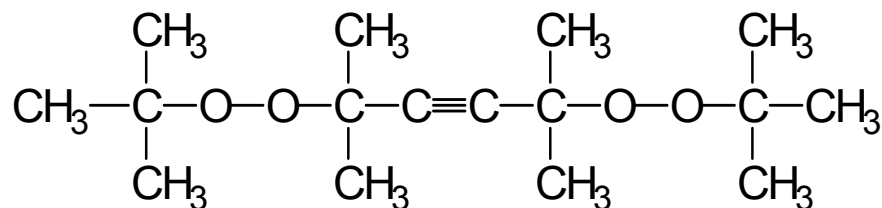
3-vinylbenzyl-5,5-dimethylhydantoin
(VBDMH)

Vinyl monomers containing cyclic and acyclic imide, amide and amine bonds can be employed in this reaction

Radical Initiators



Dicumyl peroxide (DCP)



2,5-di(tert-butylperoxy)-2,5-dimethyl-3 hexyne (DTBHY)

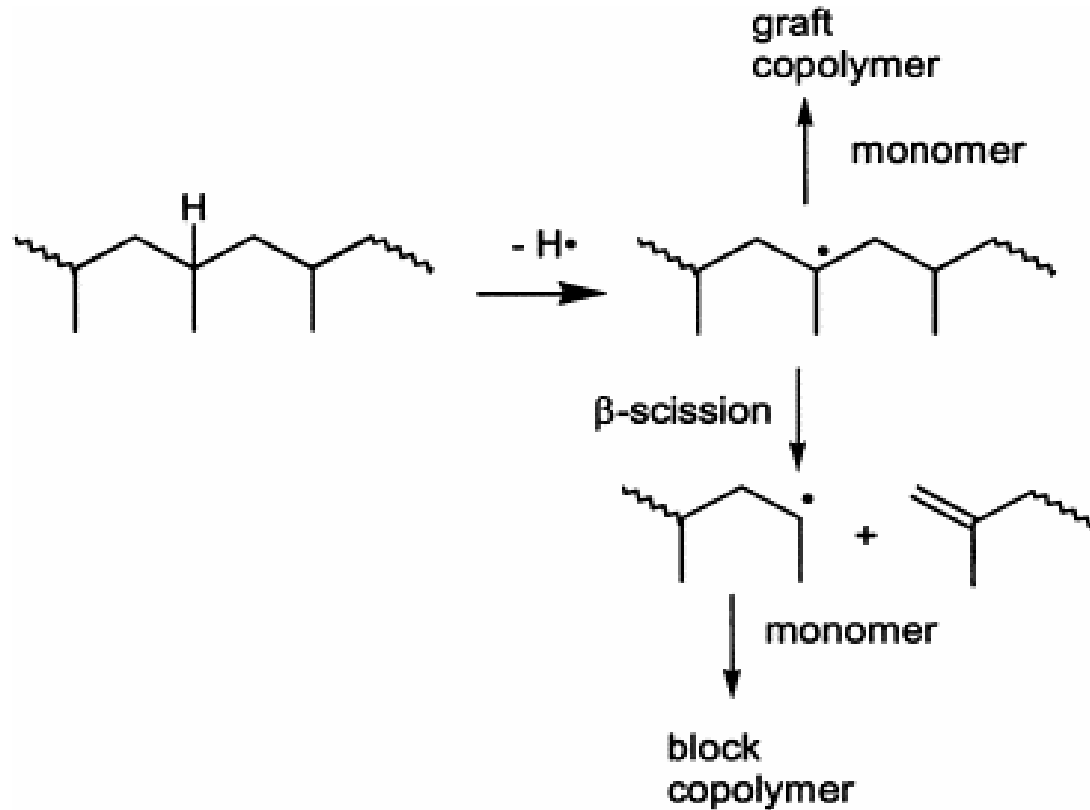
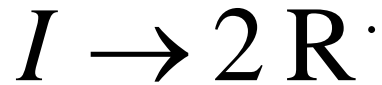
Radical initiators that can go hydrogen abstraction reactions will be employed in the reaction

Half life time (min) at	150(°C)	200(°C)	E _{act} (KJ/mol)	Left at 200(°C) after 5 Min.
DCP	890	0.25	120	1.0 E-6
DTBHY	8200	0.74	140	1.0 E-2

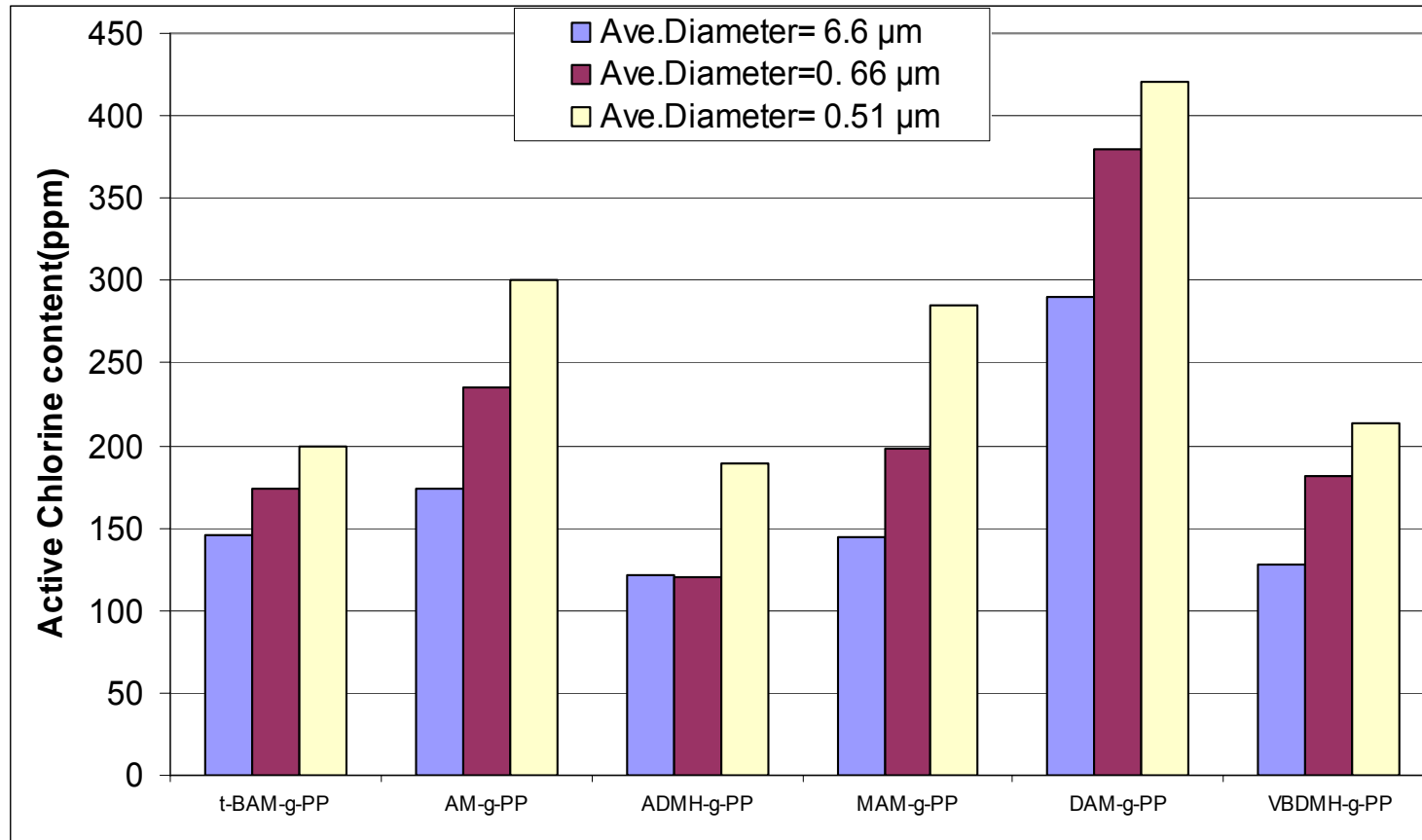
RADICAL GRAFT REACTIONS

Graft Reaction versus β -Scission

Initiation

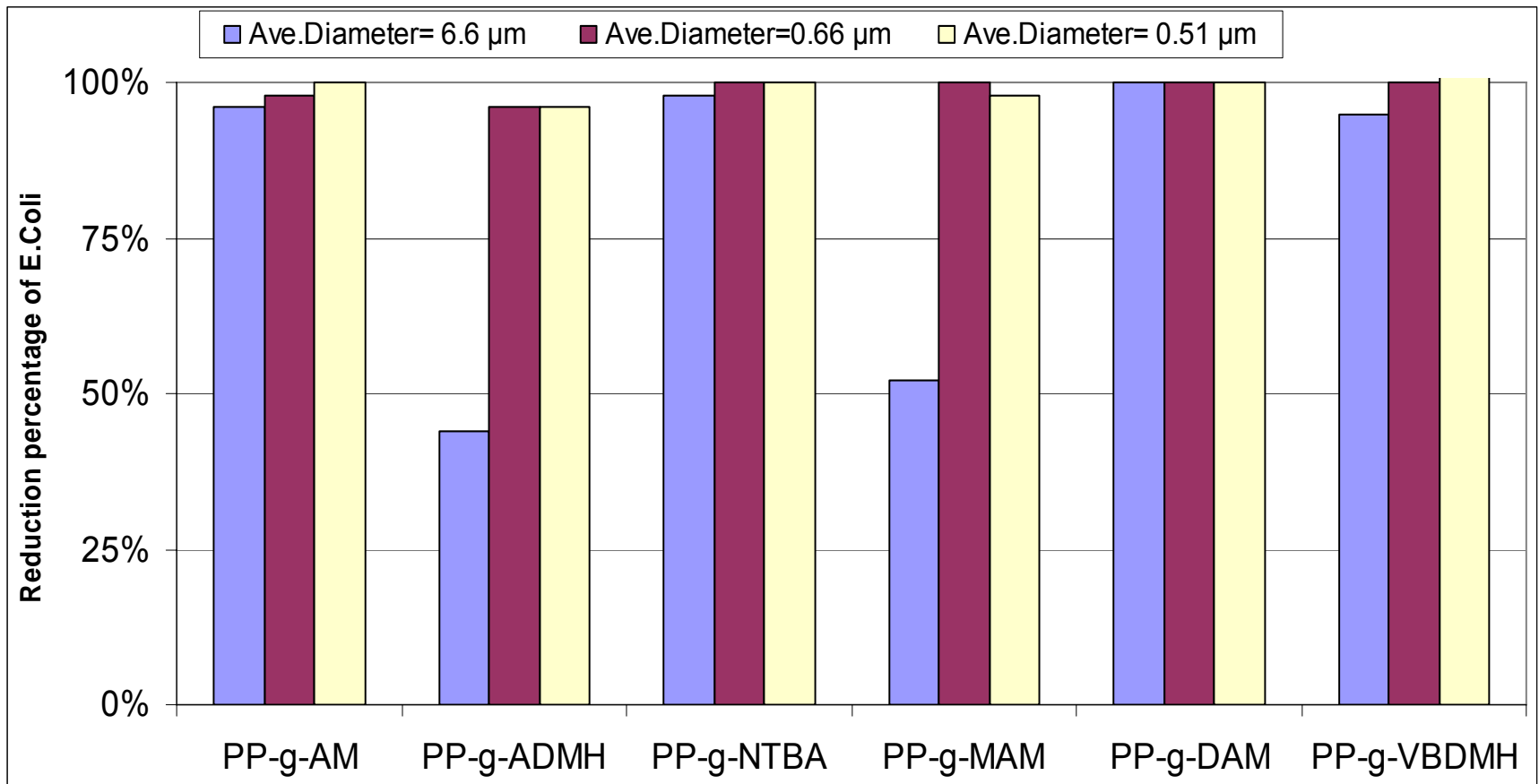


Active chlorine content of grafted fibers in different fiber sizes



The grafted PP was extruded again through a capillary die and chlorinated with diluted bleach (1000 ppm Cl⁺)

Relationships between fiber size and biocidal efficacy



The chlorinated PP fibers were challenged by one mL of E. coli with concentration of 10^{5-6} CFU per mL

Detailed Study with DAM

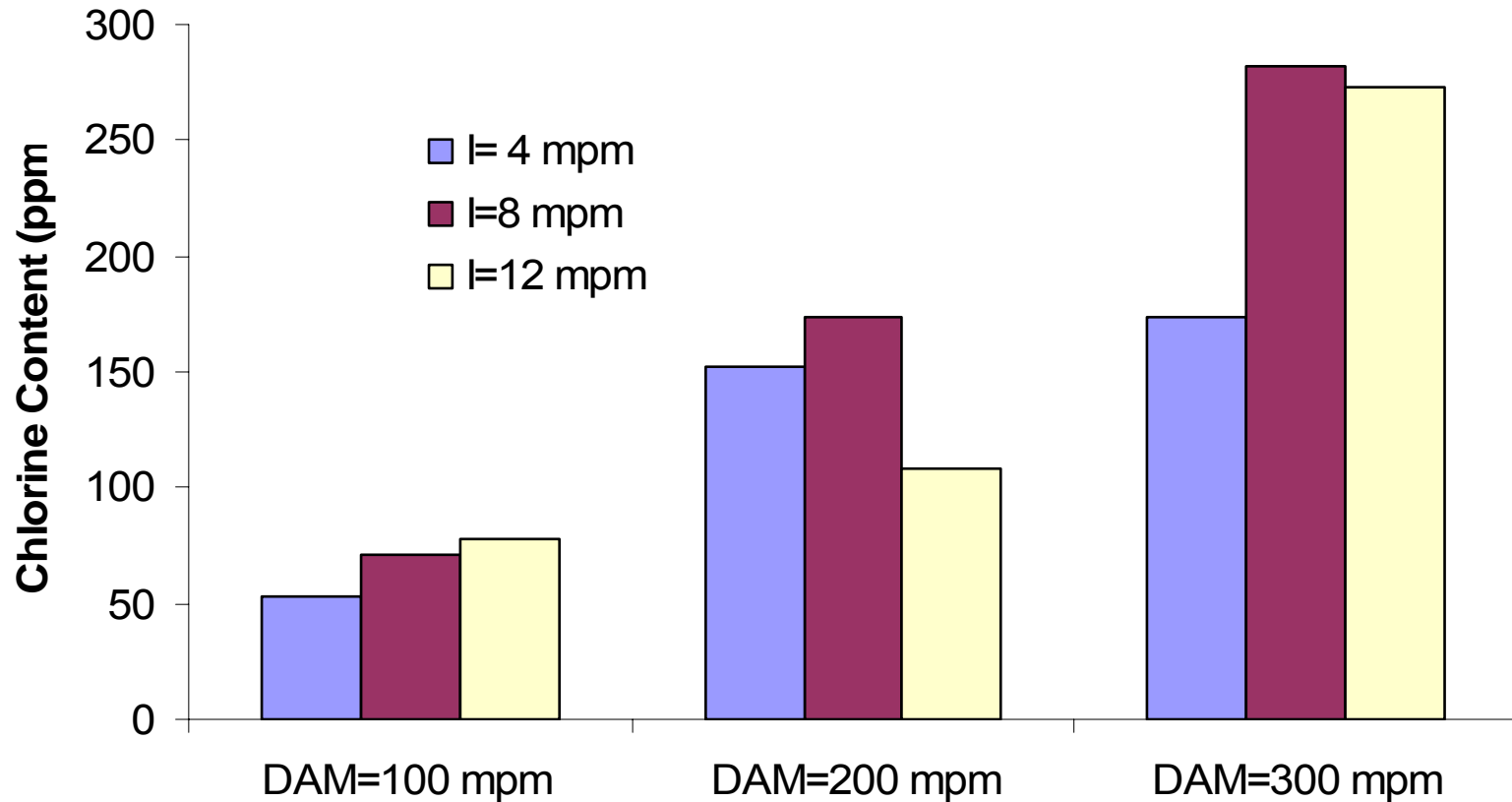
- **Polymer: i-PP powder**
- **Monomer: N,N, Diallyl melamine (DAM)**
- **Initiators**
 - **Dicumyl peroxide (DCP)**
 - **2,5- Di(tert-butylperoxy)-2,5-dimethyl-3 hexyne (DTBHY)**
 - **Instrument: Brabender ATR, Temp: 200 °C**
 - **Speed:50 r.p.m., time of mixing: 5 min**

Detailed Study with DAM

	Monomer mol per million (mpm)	Initiator mol per million (mpm)	M:I ratio
Test# 1, 10	100 (2.06 wt%)	4	25
Test# 2, 11	100 (2.06 wt%)	8	12.5
Test# 3, 12	100 (2.06 wt%)	12	8
Test# 4, 13	200 (4.12 wt%)	4	50
Test# 5, 14	200 (4.12 wt%)	8	25
Test# 6, 15	200 (4.12 wt%)	12	17
Test# 7, 16	300 (6.18 wt%)	4	75
Test# 8, 17	300 (6.18 wt%)	8	37.5
Test# 9, 18	300 (6.18 wt%)	12	25

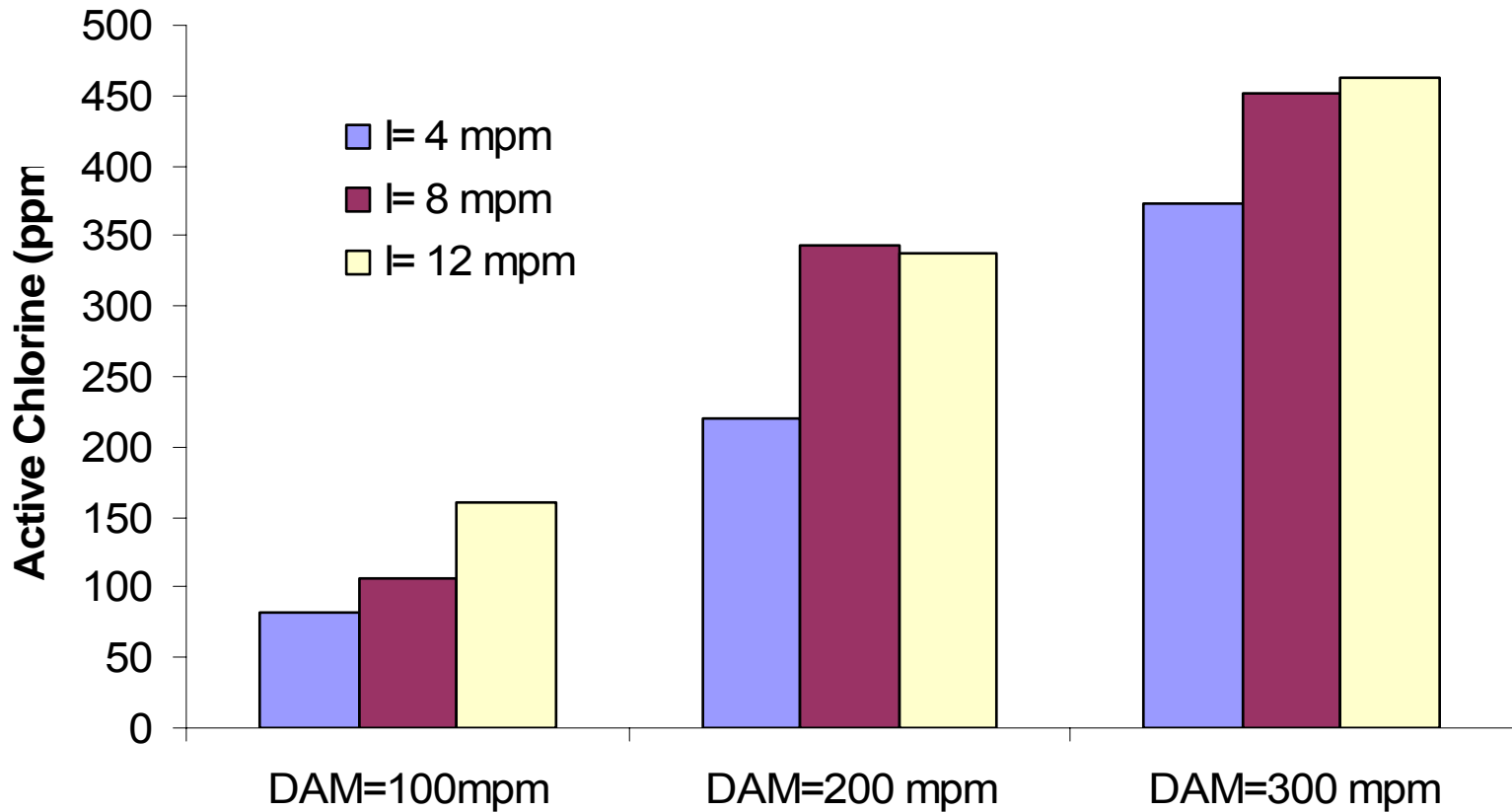
DCP as an initiator in Tests 1-9; DTBHY as initiator
in Tests 10-18

Active Chlorine Contents of DCP Grafted PP



Extruded DAM grafted PP fibers

Active Chlorine Contents of DTBHY Grafted PP



Extruded DAM grafted PP fibers

Antibacterial Results

- All PP fiber samples could provided 6 log reduction against *E. coli* (3×10^6 CFU/mL) in a contact time of 1.5 hr
- The sample DAM9 provided 6 log reduction against *E. coli* (3×10^6 CFU/mL) in a contact time of 10 min.

NEW CHALLENGE AND TECHNOLOGY

CHALLENGE

- Halamine structures cannot survive steaming at temperature $> 100^{\circ}\text{C}$
- Can only be used in uniforms and linen products that do not require sterilization

NEW TECHNOLOGY

- Photo-Induced Antibacterial Materials
- Kill bacteria only upon exposure to 360nm UV
- Provided 6 log reduction against E. coli
- To reach visible light range $>400\text{nm}$

Single-Use Biocidal Products

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



Reusable Biocidal Products

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



Acknowledgements

Participants

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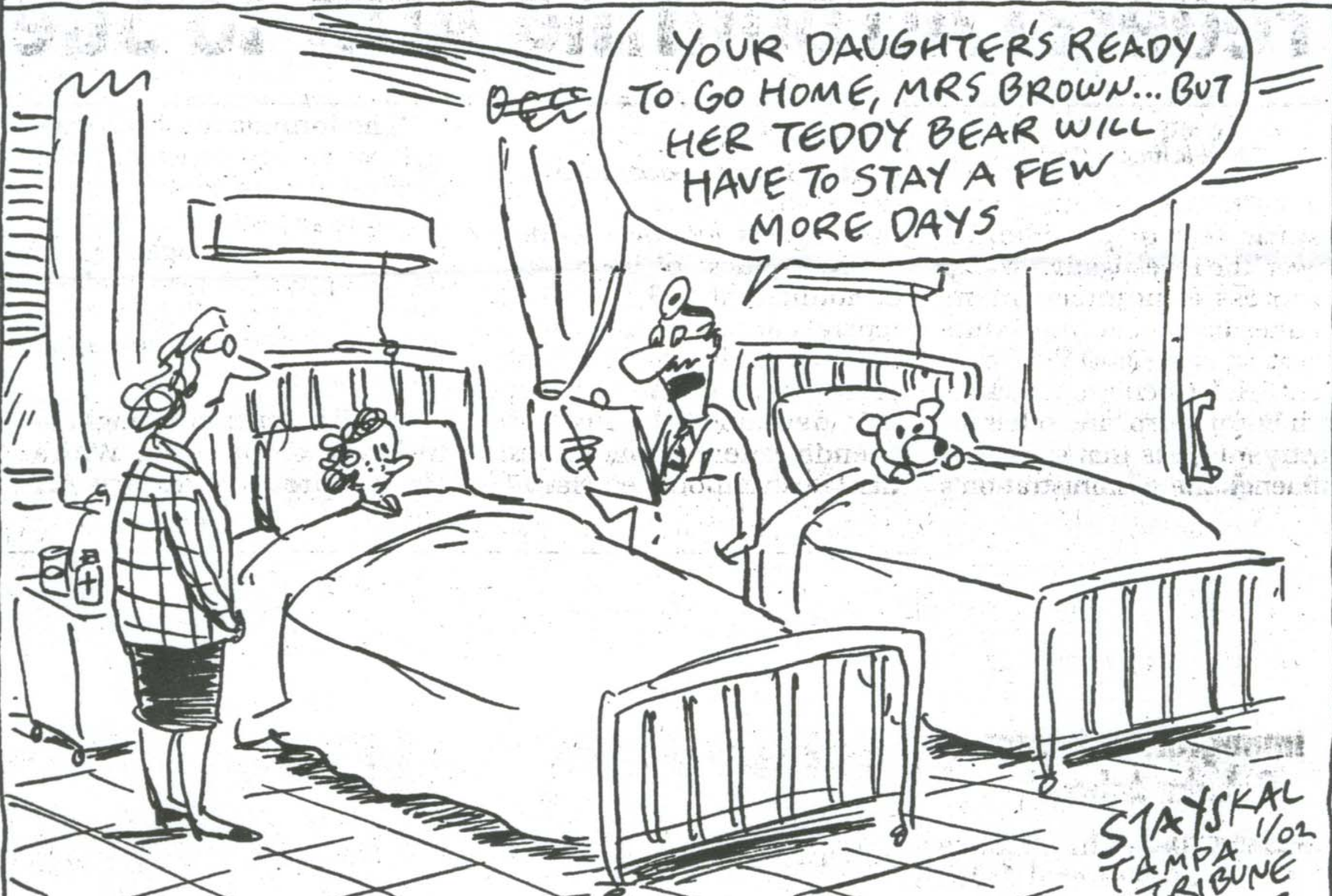
National Textile Center (S02-CD01, C02-CD06 and C06-AC01)

Auburn University

HaloSource Corporation, Redmond, WA, USA

SOFT TOYS SPREAD INFECTION SAY RESEARCHERS

YOUR DAUGHTER'S READY TO GO HOME, MRS BROWN... BUT HER TEDDY BEAR WILL HAVE TO STAY A FEW MORE DAYS



STATSKAL 1/02
TAMPA
TRIBUNE