DEVELOPMENT OF AN ENVIRONMENTAL BENIGN MICROBIAL INHIBITOR TO CONTROL INTERNAL PIPELINE CORROSION

Presented by:

J. Robert Paterek, Ph.D

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PREVIEW

- Definitions and abbreviations
- Scope of the problem
- Materials at risk
- Corrosion types
- Common control/prevention methods
- Innovative processes
- GTI's activities
- What next?

DEFINITIONS AND ABBREVIATIONS

- **MIC - Microbially Influenced Corrosion or Microbial Induced Corrosion**
- **MICC - Microbially Influenced(Induced) Concrete Corrosion**
- **BAC - Biologically Active Compounds**
- **COS - Currently Off-the-Shelf**
- **Bio-corrosion - an electrochemical process where microorganisms initiate, facilitate, or accelerate the corrosion reaction**
- **Biofilm - matrix of microbial cells, extracellular polymeric substances (EPS) and high water concentration**

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TIME ANALYSIS

Research Activity Quarter:	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd
Isolate and cultivate MIC-causing microorganisms from operational transmission pipelines.												
Design, construction, and testing of laboratory-scale pipeline simulation system.												
Determine optimal environmental conditions for biofilm formation & MIC activities using pipeline simulator.												
Evaluate pepper oil components to inhibit or mitigation of biofilm formation / MIC under optimal conditions.												
Identify and test biofilm formation / MIC mitigation and inhibition at various concentrations (BAC determinations).												
Identify commonly used pipeline chemicals (coatings,other biocides, corrosion inhibitors, *etc.*).												
Analyze interactions of biofilm / MIC mitigating components / concentrations with pipeline chemicals												
Evaluate potential delivery systems for biofilm/MIC mitigating components as foams, coating, injection, *etc.*												
Determine potential cost-effective production systems / sources for biofilm / MIC mitigating products.												

COST AND SCOPE OF CORROSION PROBLEM

Estimate Date	Country	Industry	Cost	Percent GNP
1978	USA	All	$70 Billion	4.2
1977	Japan	All	$9.2 Billion	1.8
1969	UK	800 industries and gov't	$3.2 Billion	3.5
1969	USSR	All	$6.7 Billion	2.0
1969	Germany	All	$6.0 Billion	3.0
1995	USA	All	$300 Billion	Not determined

COST ELEMENTS

Capital Costs

- Equipment and building replacement
- Excess capacity
- Redundant equipment

Design Costs

- Construction materials
- Corrosion allowance
- Special processing

Control Costs

- Maintenance and repair
- Corrosion control

Associated Costs

- Product loss
- Technical support
- Insurance
- Parts and equipment inventory

MATERIALS AT RISK

Metals

iron

stainless steel

high Mo austenitic stainless steel

titanium

aluminum

Concrete and masonry

Manmade materials

plastics

fiber-reinforced polymeric composites

COS TECHNOLOGIES

- Biocides
- Coatings, Sleeves, and liners
- Pigging and Cleaning
- “Corrosion-resistant” materials for pipes, etc.
- Electrochemical, such as cathodic protection

BIOCIDES AND ENVIRONMENTAL ANTIMICROBIALS

COST: $1.3 BILLION PER YEAR

- **Availability**
- **Cost**
- **Storage and Handling**
- **Regulations**

BIOCIDES AND ANTIMICROBIAL PROVIDERS

- Amoco
- Calgon
- Chevron
- Clorox
- Rohm and Haas
- Aramco
- Ondeo/Nalco
- Olin
- S.C. Johnson Wax
- Union Carbon

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INNOVATIVE TECHNOLOGIES ADDRESSED IN THIS PROJECT

- Rapid screening of biocide candidates
- Computational chemistry
- Natural products
  imitating natural microbial fouling control
- Microbial ecology and physiological control
- Traditional chemical engineering used in non-traditional ways

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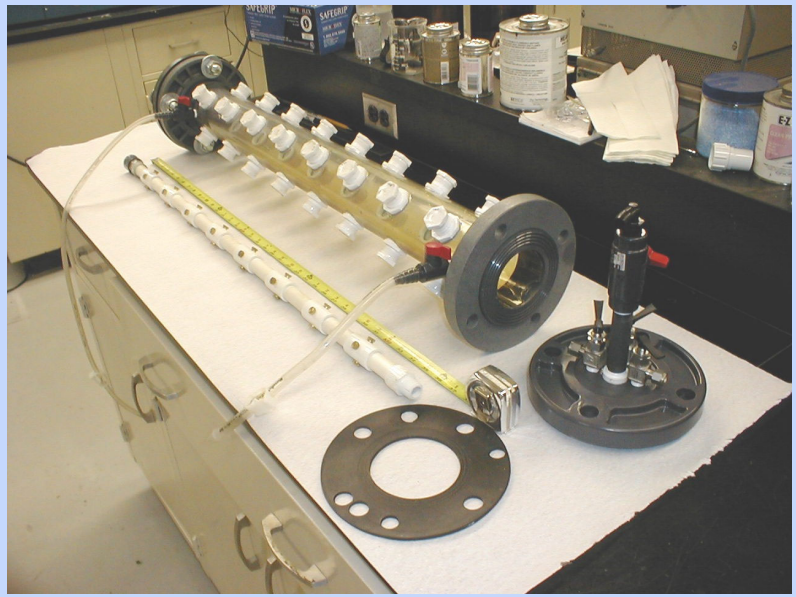
GTI's FOCUS IN INNOVATIVE TECHNOLOGIES

- **Rapid screening of biocide candidates**

Screening of biocides and biofilm control agents in "habitat-simulating laboratory systems

"HABITAT-SIMULATING LABORATORY SYSTEMS"

Pipeline Test Loop



- 44 metal coupons
- Misters for liquid addition
- Atmosphere: natural gas
- Anaerobic conditions

WHAT IS PEPPER EXTRACT?

- Source is plant seeds and pods of genus *Capsicum* of the family *Solanaceae*
- Members of *Capsicum*

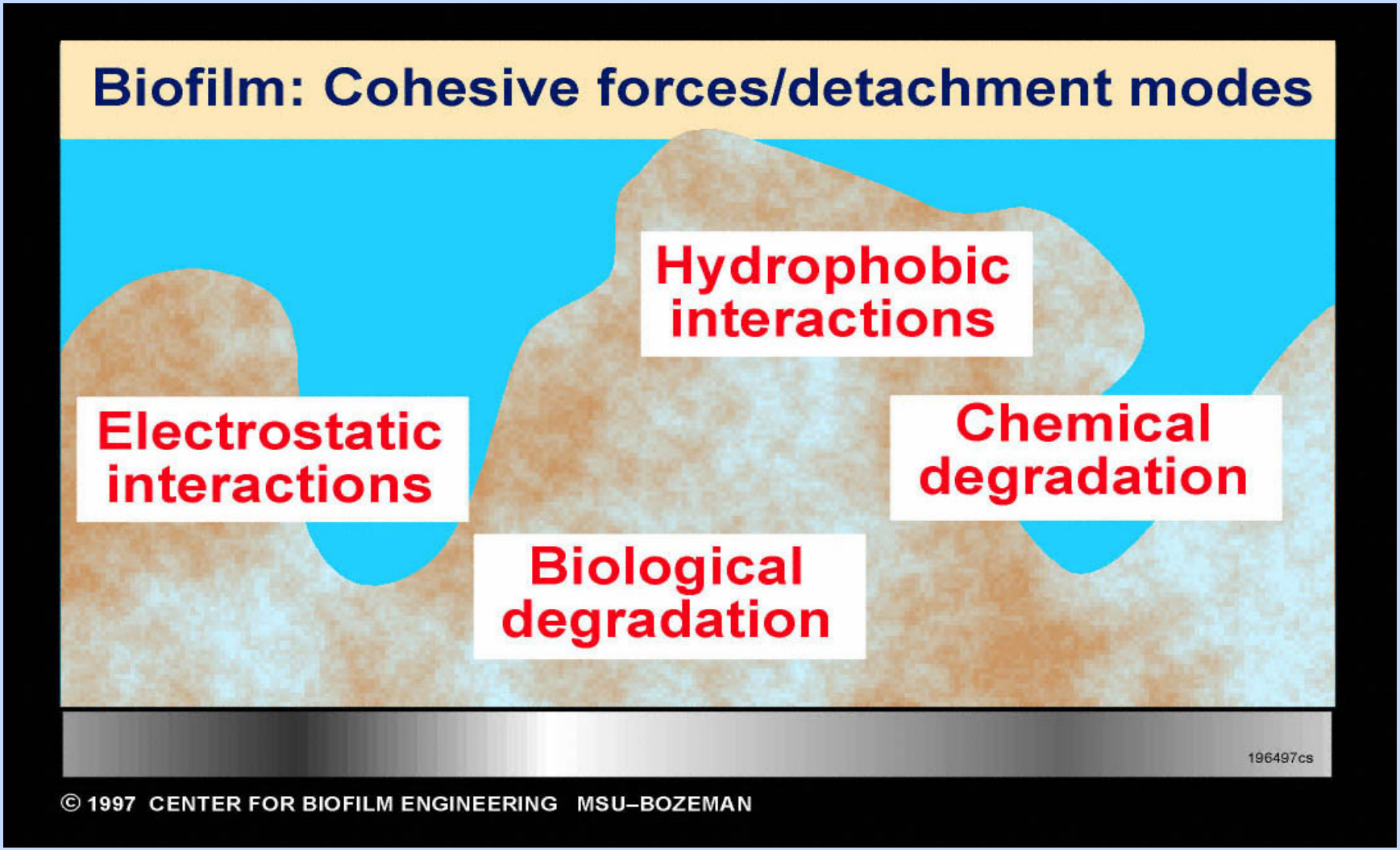
  Capsicum annuum (Serrano)

  Capsicum chinense (Habanero)

WHY PEPPER EXTRACT?

- Environmentally benign, i.e. food product
- Available plant product
- Stability
- Concentration of active ingredient(s) can be controlled

COMPLEXITY OF BIOFILM



Antimicrobial Activity of *Capsicum sp.* Compounds Against *Desulfovibrio sp.*

Agents	*D. vulgaris*		*D. desulfuricans*	
	MIC	MBC	MIC	MBC
H1E	312.5	625.0	78.0	312.5
H1M	156.0	312.5	78.0	312.5
S1E	156.0	312.5	78.0	156.0
S1M	156.0	156.0	78.0	156.0
Capsaicin	156.0	312.5	312.5	1,250.0
Dihydrocapsaicin	240.0	480.0	240.0	960.0
Caffeic Acid	302.5	302.5	302.5	302.5
Cholorogenic Acid	312.5	312.5	312.5	625.0
Sitosterol	4.11	16.43	65.75	65.75
Kanamycin	>200.0	ND	>200.0	ND
Ampicillin	6.25	6.25	6.25	25.0
Methanol	0.625%	1.25%	1.25%	2.5%

ND – Not Determined (exact MIC value not obtained)
Concentrations- ug/mL unless otherwise stated

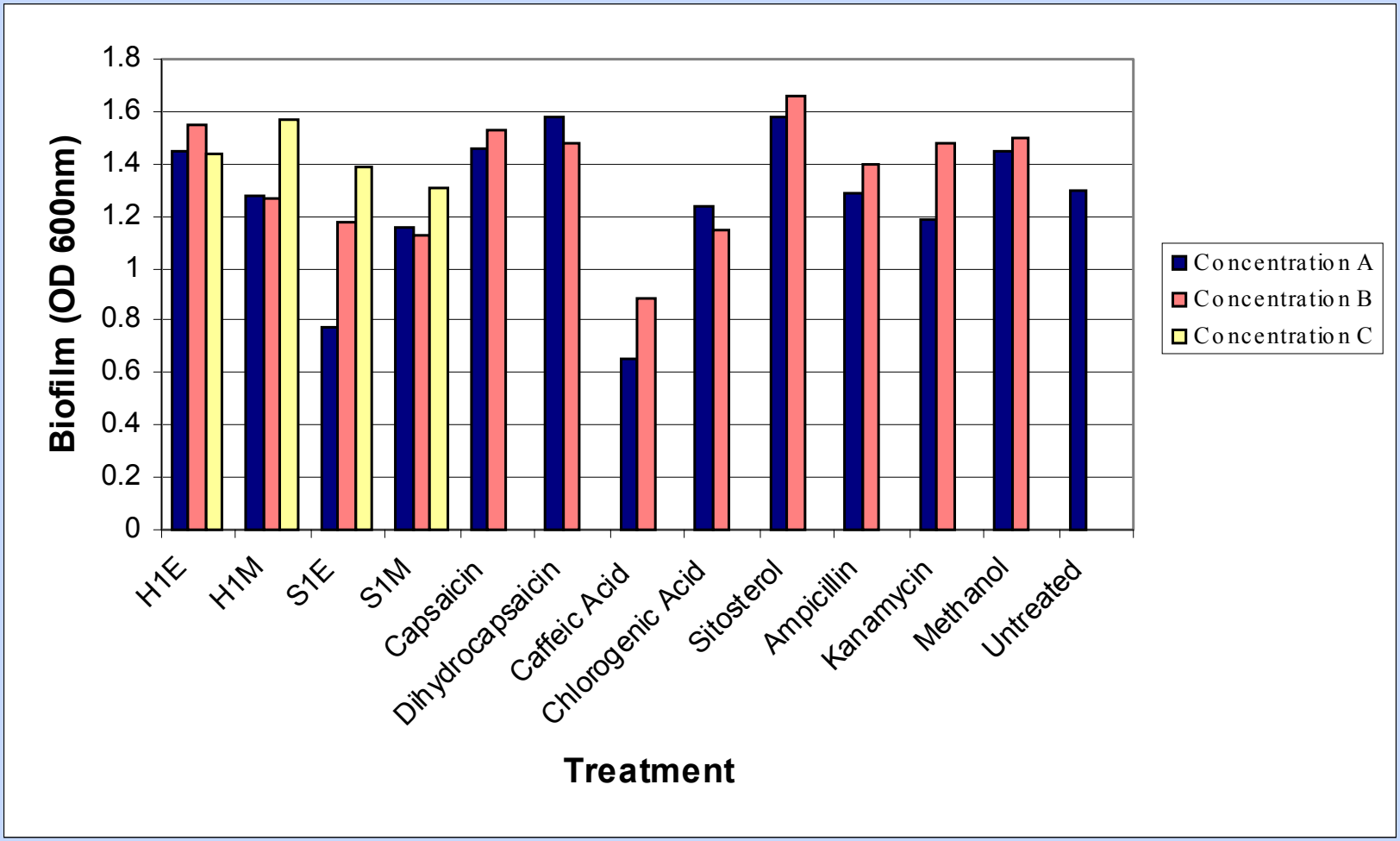
INHIBITION OF BIOFILM FORMATION

- Add test compounds to bacterial cells in growth medium (96-well plates)
- Incubate anaerobically for 120h @ 30-37^{o}C
- Stain with 1% crystal violet after washing with distilled water
- Destain with 95% EtOH
- Measure the optical density at 600 nm

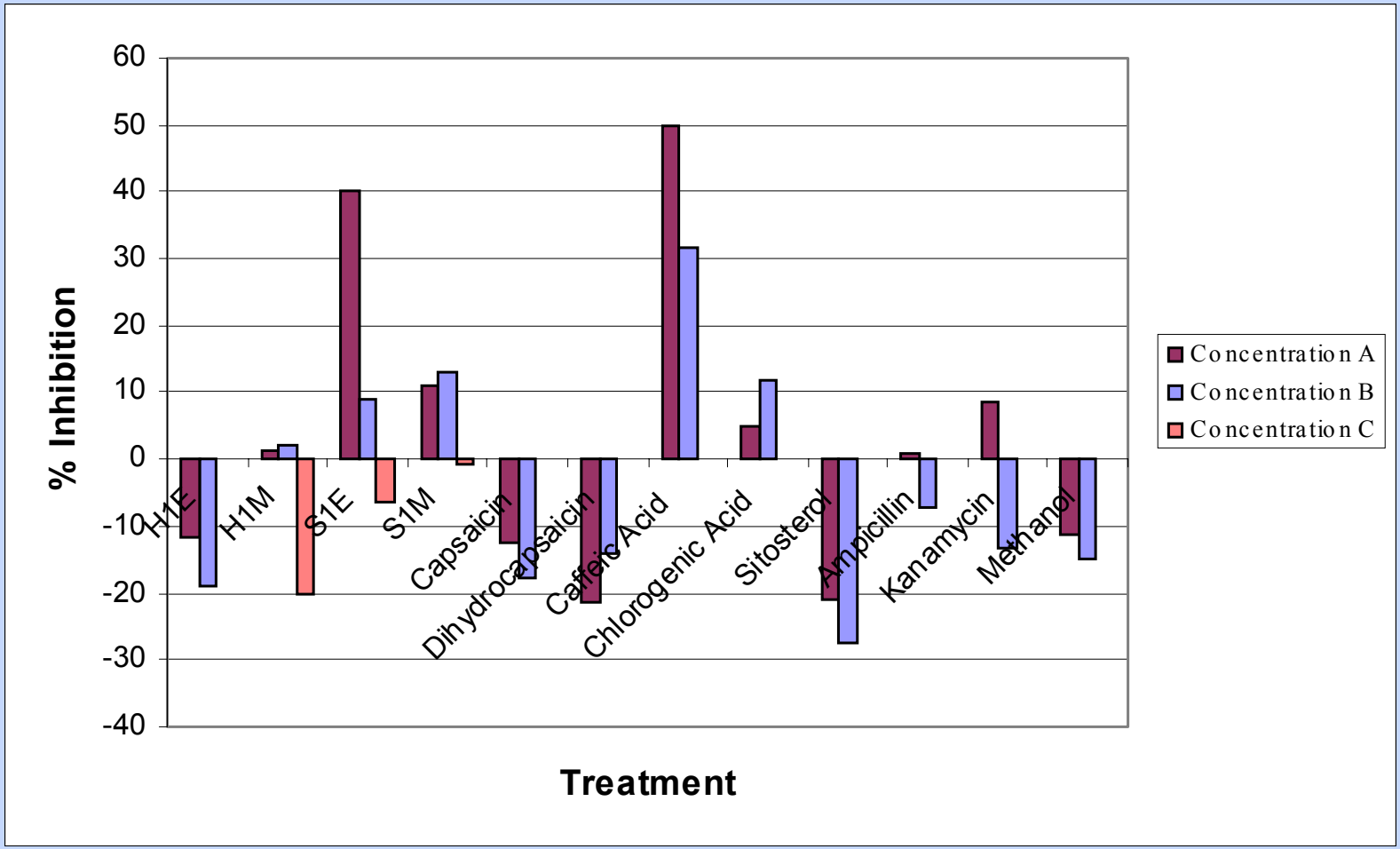
DETACHING FORMED BIOFILM

- Allow bacterial culture to grow in appropriate conditions for 96h
- Feed with fresh media & incubate for 48h
- Discard media; treat with test agents for 1h
- Stain with 1% crystal violet after washing with distilled water
- Destain with 95% EtOH
- Measure optical density at 600 nm

Capsicum sp. Compounds Effects on *Desulfovibrio desulfuricans* Biofilm (Raw Data)

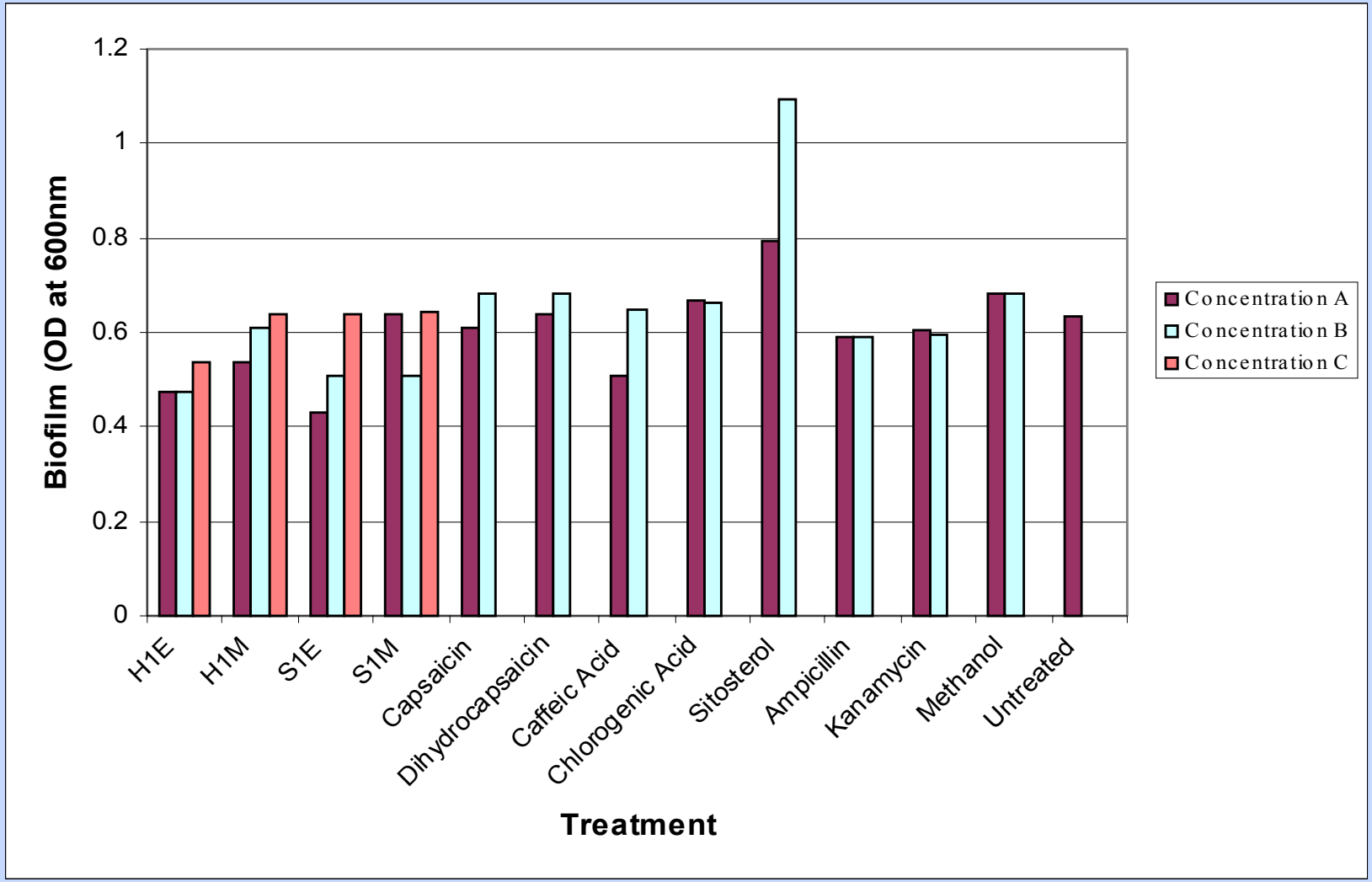


Inhibition of *Desulfovibrio desulfuricans* Biofilm Formation

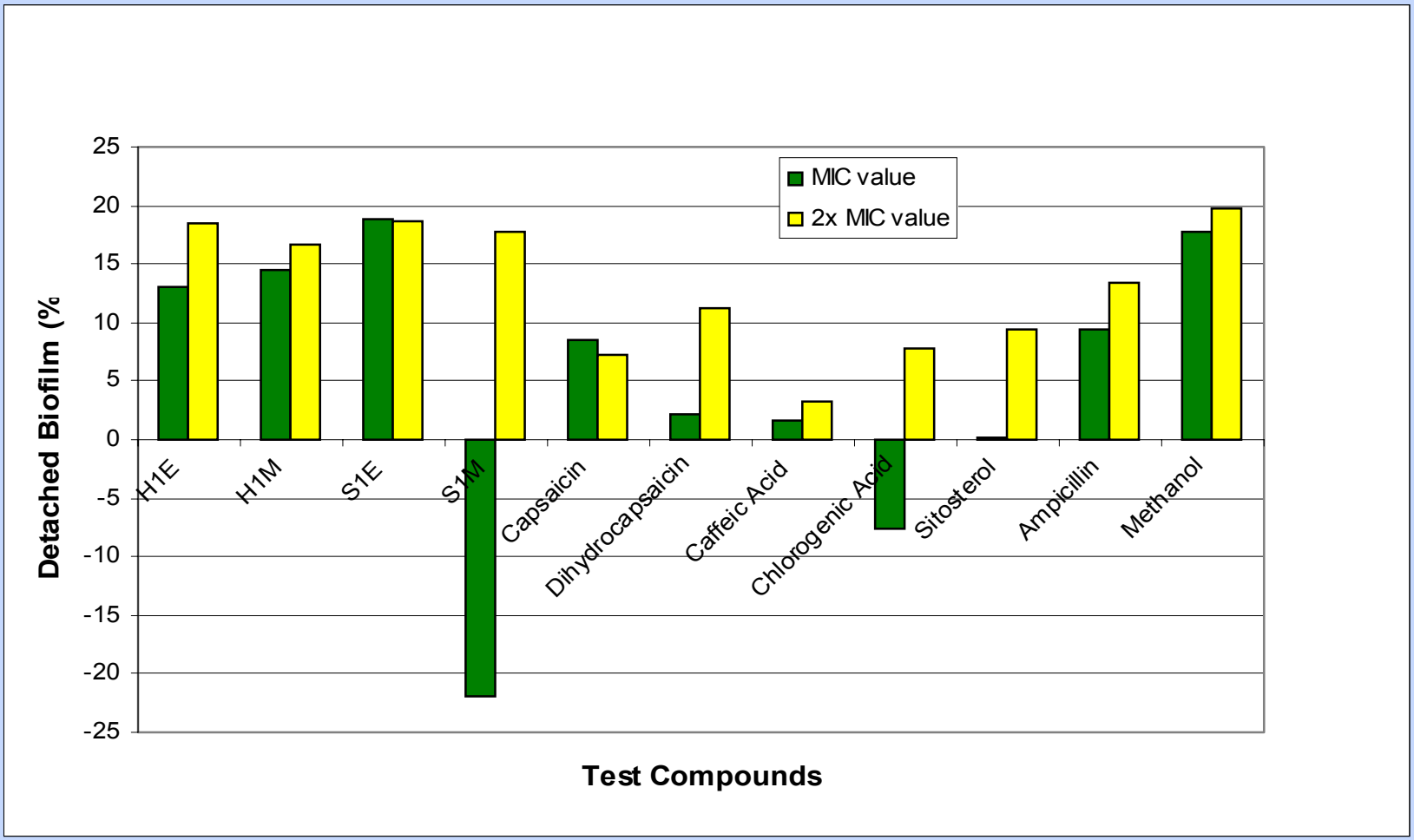


Concentrations: Extracts& Chlorogenic Acid=1250, 625, 312.5; Capsaicin=625, 312.5; Dihydrocapsaicin=960, 480; Caffeic Acid=1210, 605; Sitosterol=131.5, 65.75, Ampicillin & Kanamycin=200, 100ug/mL, MeOH=2.5, 1.25%

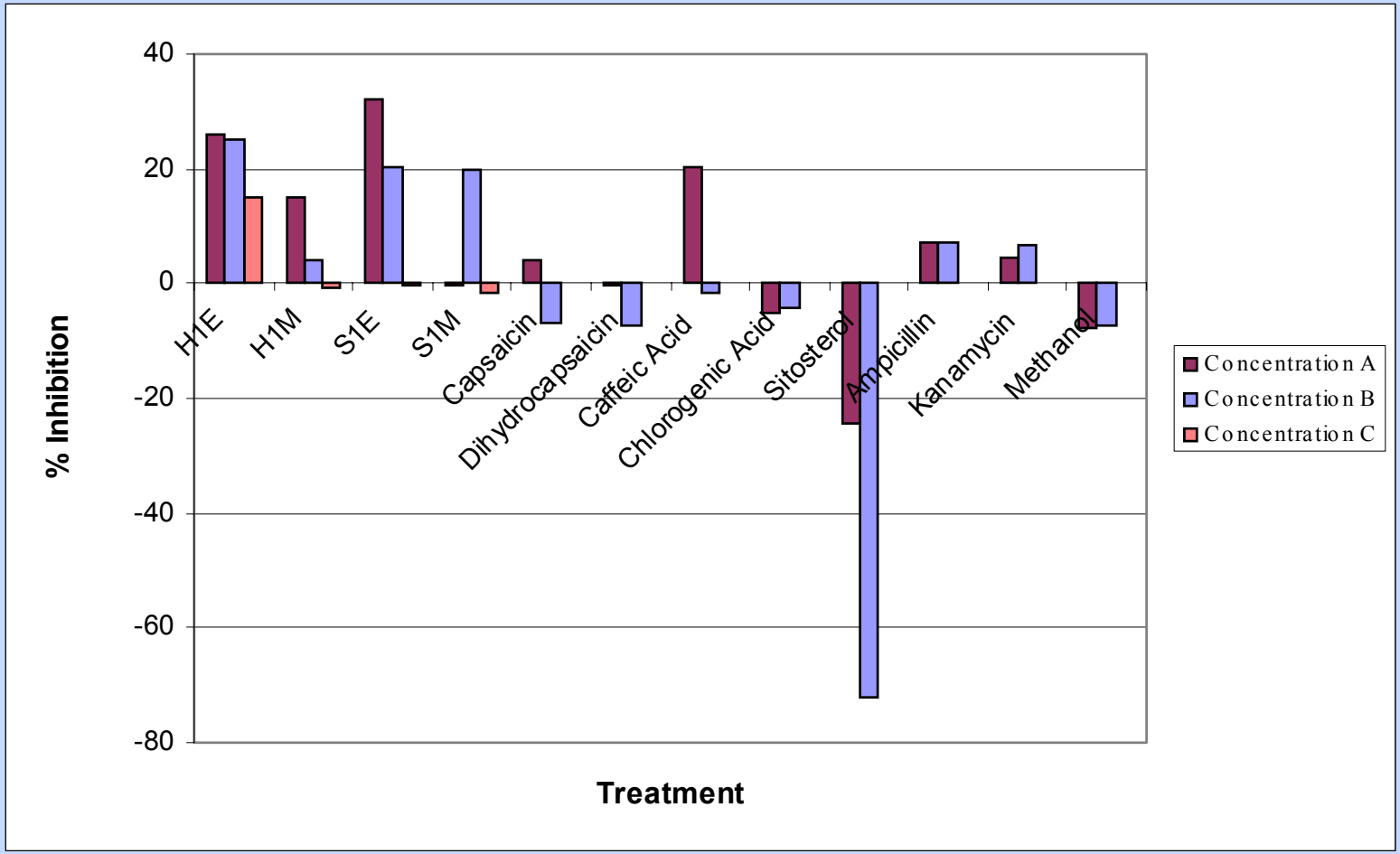
Capsicum sp. Compounds Effects on *Desulfovibrio vulgaris* Biofilm (Raw Data)



Capsicum sp. Detachment of *Desulfovibrio vulgaris* Biofilm



Inhibition of *Desulfovibrio vulgaris* Biofilm Formation



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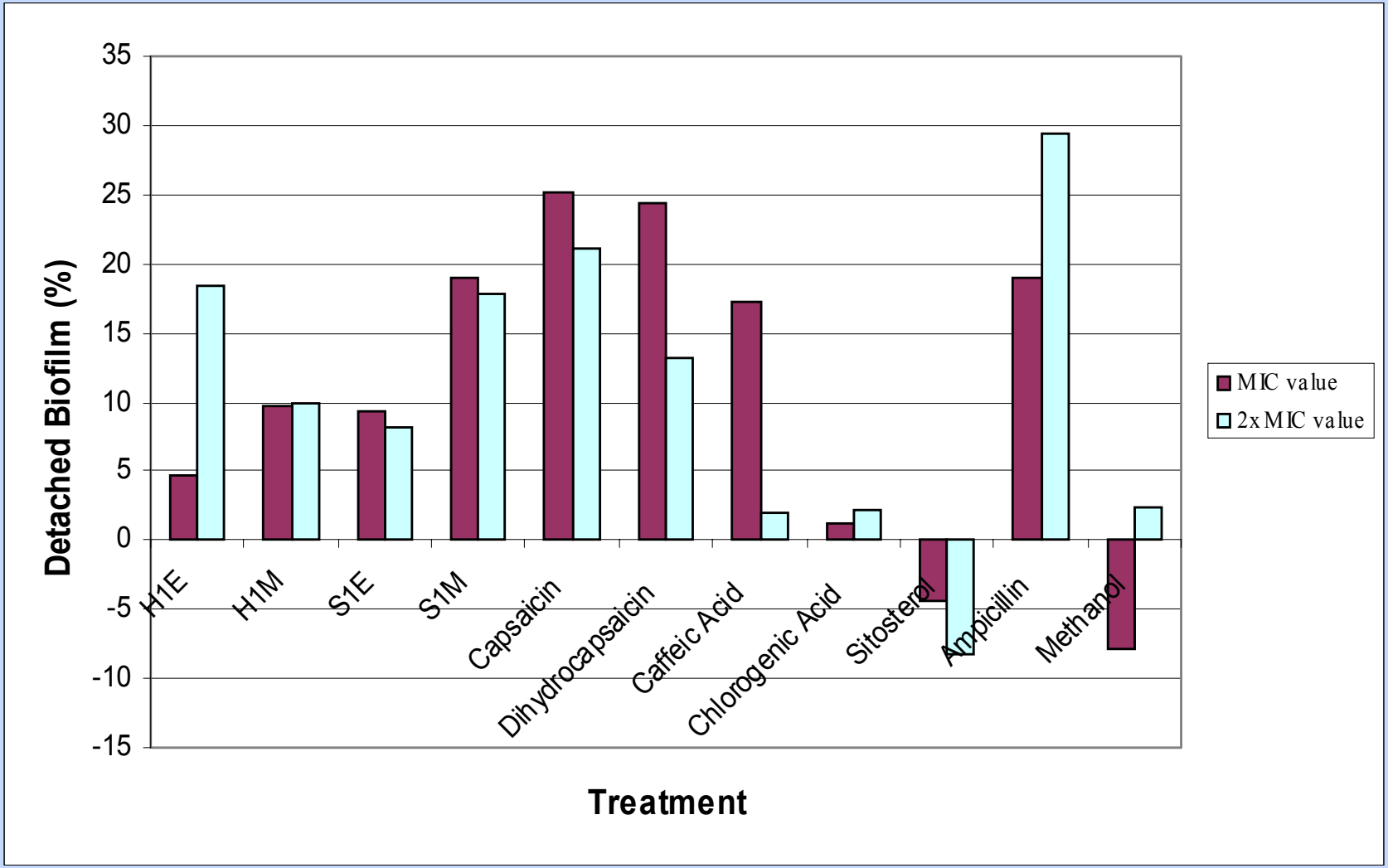
Capsicum sp. Detachment of *Desulfovibrio desulfuricans* Biofilm

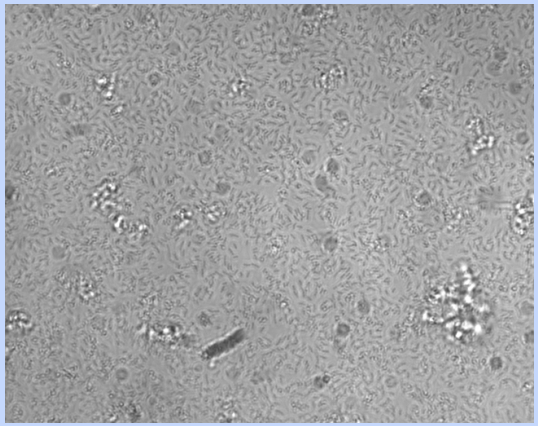


EFFECTIVE INHIBITORS OF *Desulfovibrio* BIOFILMS

Agent	Concentration, µg/mL	
	D. vulgaris	*D. desulfuricans*
H1E	1250, 625, 312.5	
H1M	1250	
S1E	1250, 625	1250, 625
S1M	625	1250, 625
Caffeic Acid	1210	605
Chlorogenic acid		625

Monitoring *D. vulgaris* Biofilm using Continuous Flow Cell System

2h



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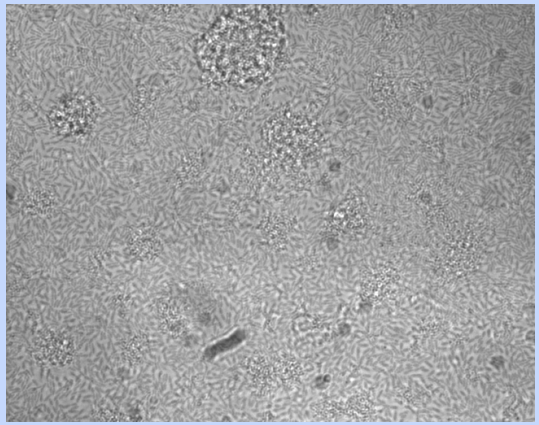

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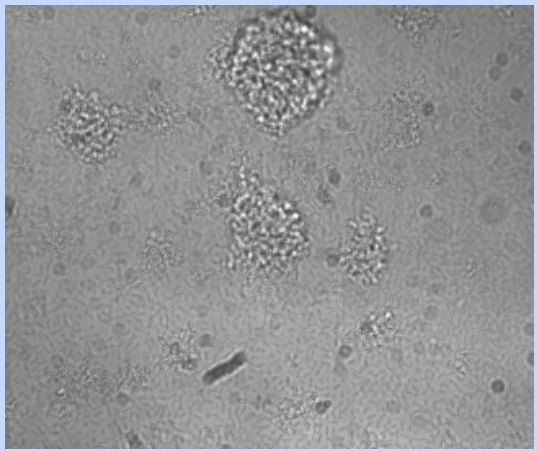
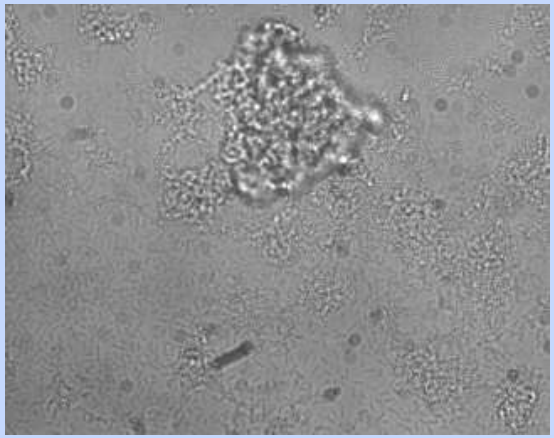
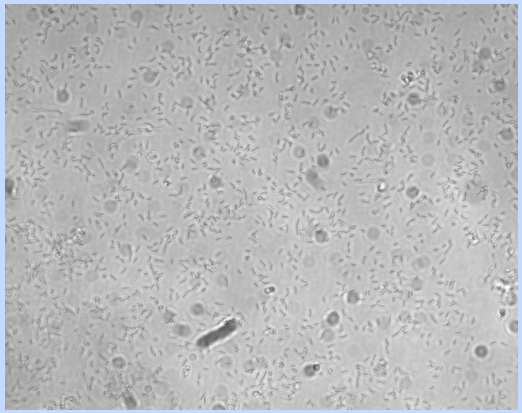


72h



Monitoring *D. desulfuricans* Biofilm using Continuous Flow Cell System

2h



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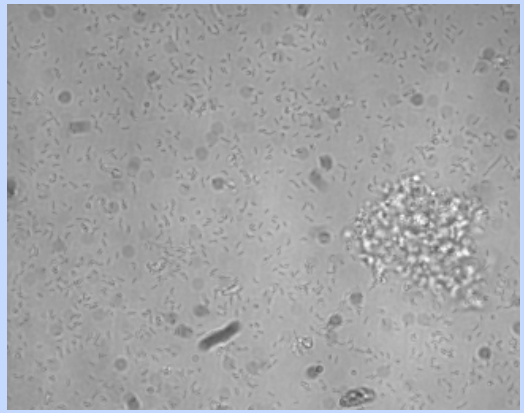

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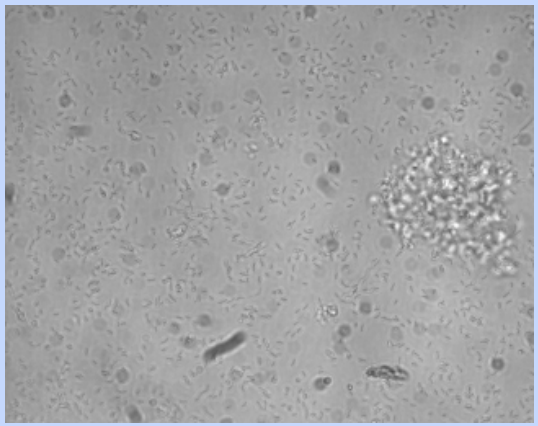

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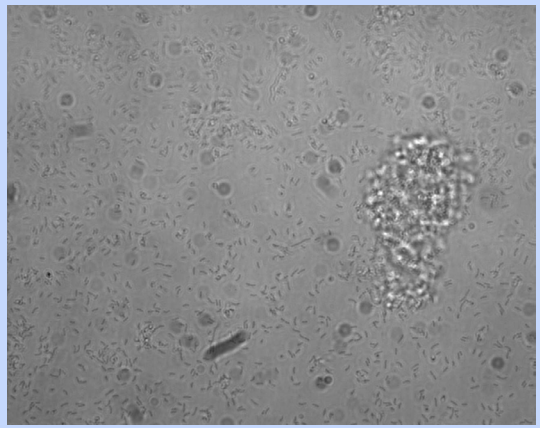
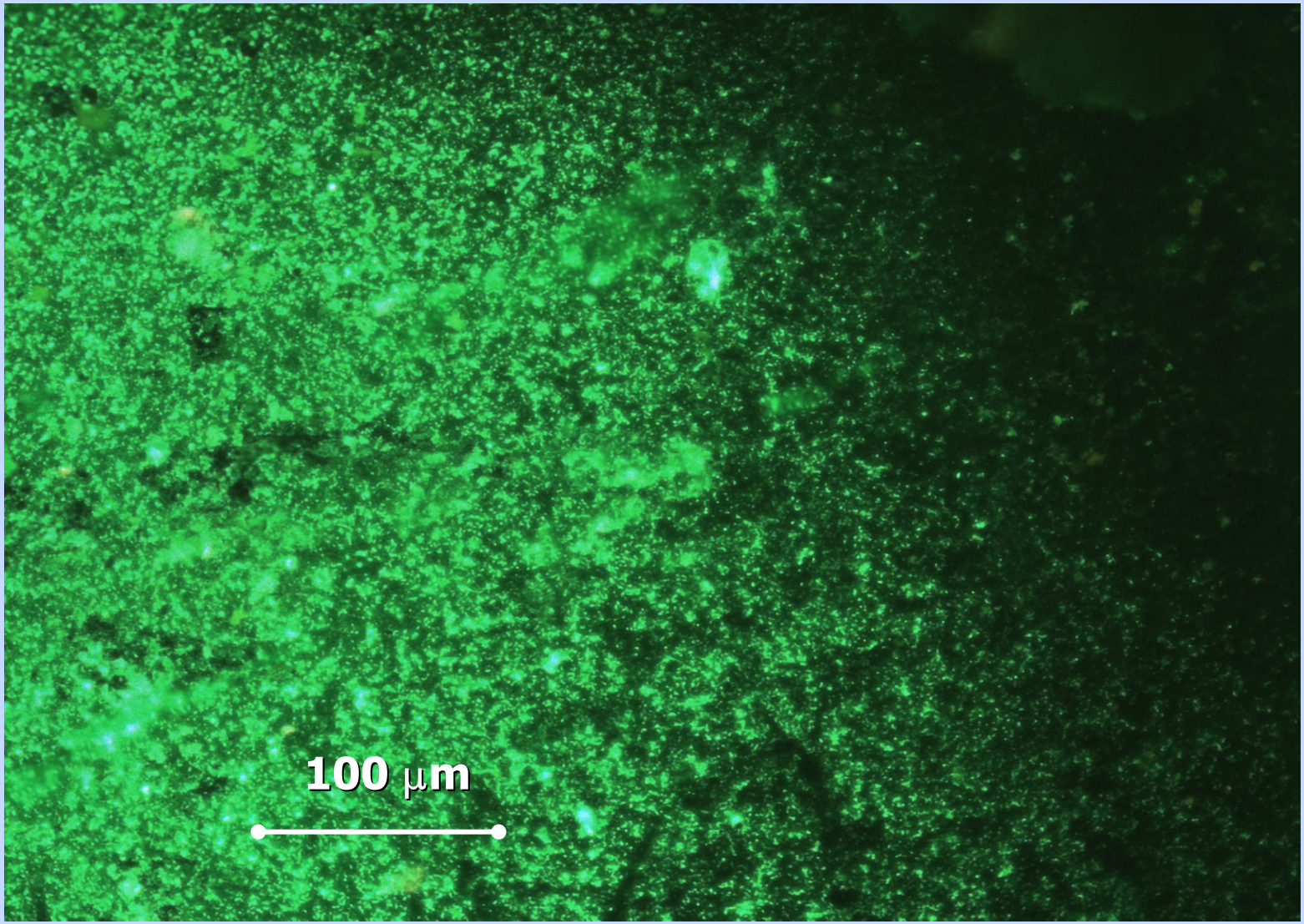
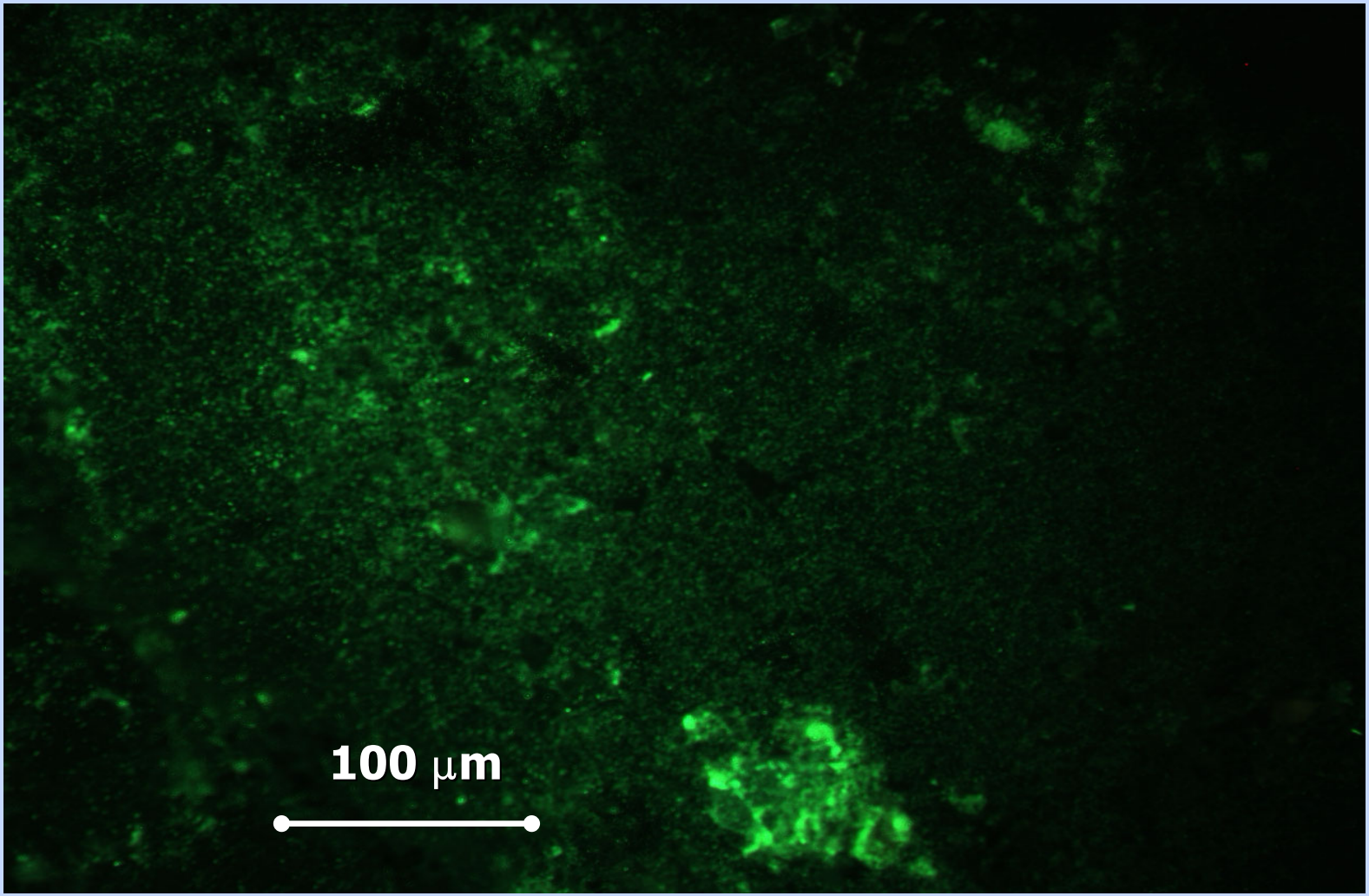


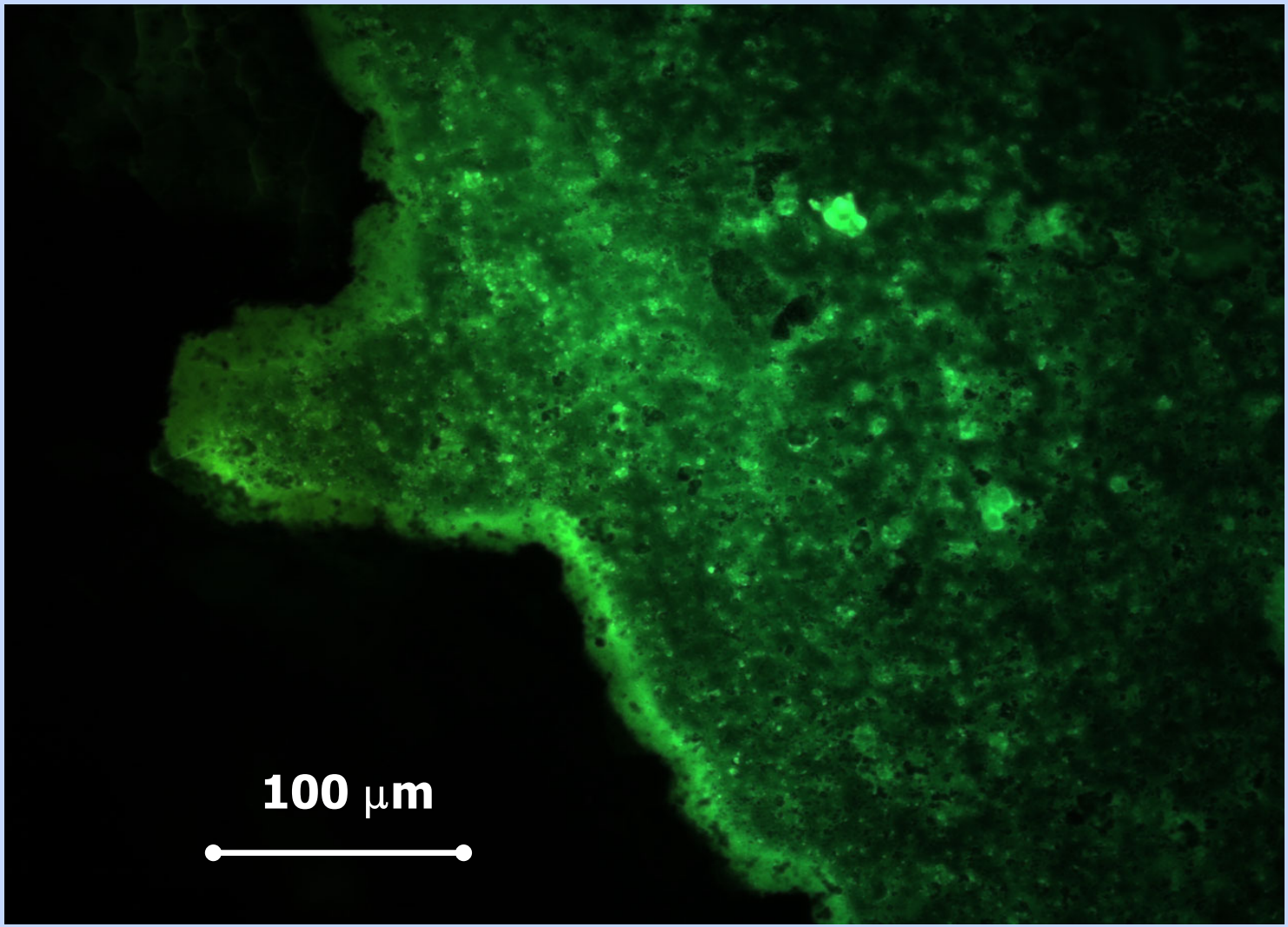
"HABITAT-SIMULATING LABORATORY SYSTEMS": NO EXTRACT



"HABITAT-SIMULATING LABORATORY SYSTEMS": PEPPER EXTRACT #1



"HABITAT-SIMULATING LABORATORY SYSTEMS": PEPPER EXTRACT #2



GTI's FUTURE FOCUS

- **Rapid screening of biocide candidates**
- Computational chemistry
- Natural products
  imitating natural microbial fouling control
- **Microbial ecology and physiological control**
- Chemical engineering