E. coli Surface Property Characterization and Transport Evaluation

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Potential groundwater contamination with pathogens

Wastewater reclamation for irrigation

- In California, 60% of recycled wastewater used for irrigation

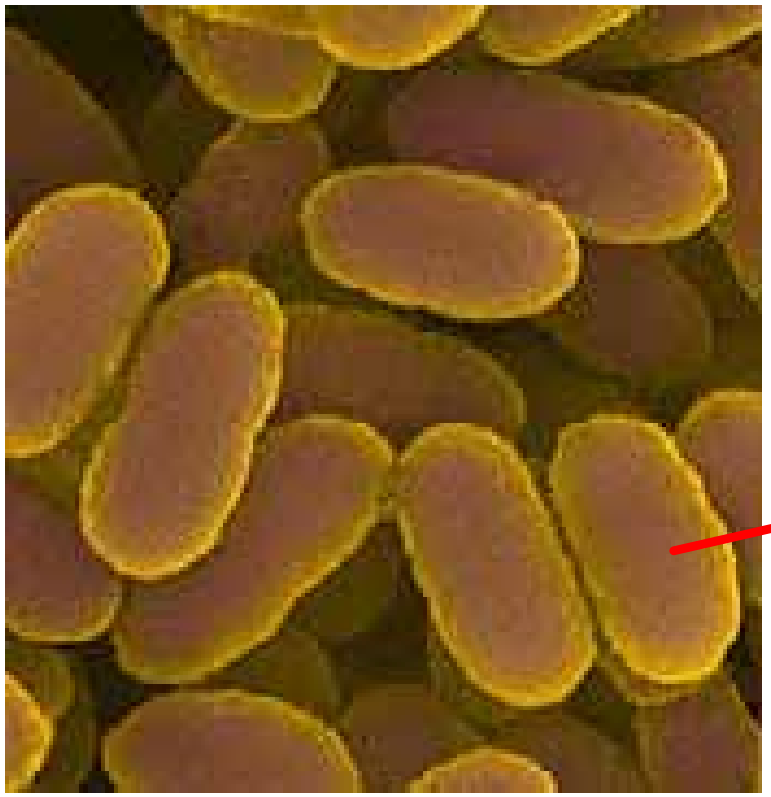
Animal waste applications

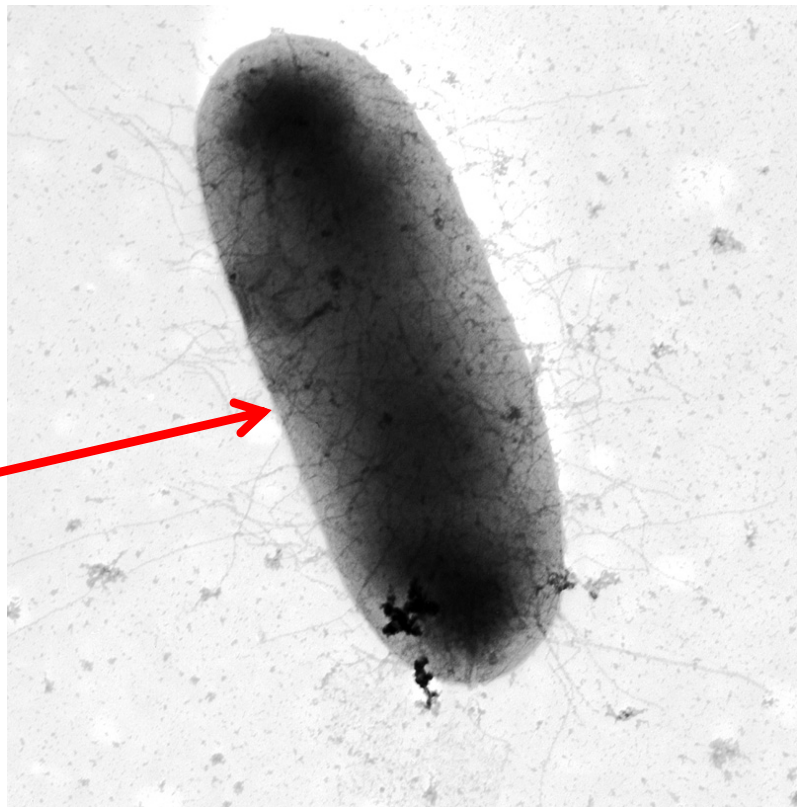
- In US, approximately 1.3 billion tons of animal manure generated annually
- Land applications

Objectives

- *E. coli* surface property characterization under different physiological stage and macro nutrient ratio conditions
- *E. coli* transport in unsaturated porous media
- Correlation of *E. coli* interactions with the surrounding environment with the transport

Bacterial Strain





***E. Coli* HB101**

A plasmidless non-fimbriated bacterium, obtained from ATCC (33694) .

Bacterial Surface Property Quantification

γ^{LW} γ^{+} γ^{-} ζ

γ^{LW}– Liftshitz-van der Waals component surface tension (mJ/m^2)

γ^{+} – Electron-acceptor parameter of Lewis acid/base component surface tension (mJ/m^2)

γ^{-} – Electron-donor parameter of Lewis acid/base component surface tension (mJ/m^2)

ζ – Zeta potential (mV)

van Oss-Chaudhury-Good Equation

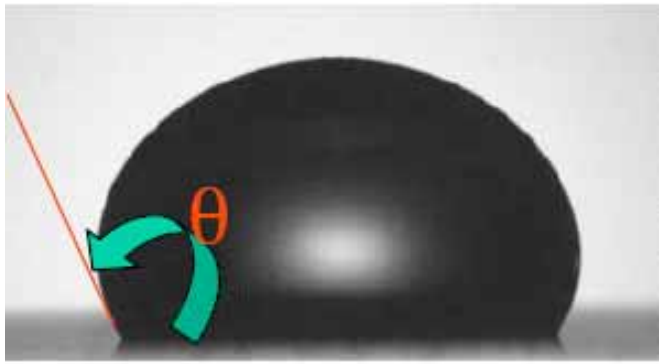
Solve for γ_S^{LW}, γ_S^{+} and γ_S^{-}

$$(1+\cos\theta)\gamma_L = 2\left(\sqrt{\gamma_S^{LW}\gamma_L^{LW}} + \sqrt{\gamma_S^{+}\gamma_L^{-}} + \sqrt{\gamma_S^{-}\gamma_L^{+}}\right)$$

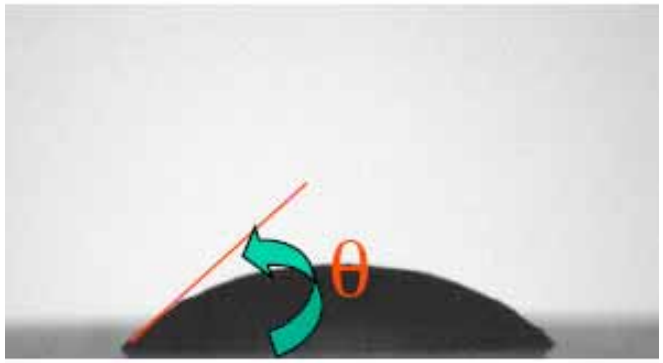
$$\begin{cases} (1+\cos\theta_1)\gamma_1 = 2\left(\sqrt{\gamma_S^{LW}\gamma_1^{LW}} + \sqrt{\gamma_S^{+}\gamma_1^{-}} + \sqrt{\gamma_S^{-}\gamma_1^{+}}\right) \\ (1+\cos\theta_2)\gamma_2 = 2\left(\sqrt{\gamma_S^{LW}\gamma_2^{LW}} + \sqrt{\gamma_S^{+}\gamma_2^{-}} + \sqrt{\gamma_S^{-}\gamma_2^{+}}\right) \\ (1+\cos\theta_3)\gamma_3 = 2\left(\sqrt{\gamma_S^{LW}\gamma_3^{LW}} + \sqrt{\gamma_S^{+}\gamma_3^{-}} + \sqrt{\gamma_S^{-}\gamma_3^{+}}\right) \end{cases}$$

Contact Angle Measurement

A : Moisture-controlled Chamber
B : Sample platform
C : Syringe holder
D : Camera with imaging lens
E : Light source



Contact Angle > 90°



Contact Angle < 90°

Wicking Method

Kruss K100 Tensiometer

Washburn Equation

$$h^2 = (R_e \cdot t \cdot \gamma_L \cdot \cos\theta) \cdot (2 \cdot \mu)^{-1}$$

h : height of capillary rise (m)

R_e : average interstitial pore size (m)

t : measuring time (sec)

γ_L : Measuring liquid surface tension (mJ/m^2)

μ : measuring liquid viscosity ($N \cdot s/m^2$)

Carbon and Nitrogen Conditions

Media	C Source	N Source	C:N	Limitation
1	Glucose 0.2 g	NH_4Cl 0.06 g	5 : 1	
2	Glucose 0.2 g	NH_4Cl 0.01 g	30 : 1	N
3	Glucose 0.2 g	NH_4Cl 0.16 g	1 : 1.5	C

Contact Angle and ζ-Potential Values

C:N	θ^D	θ^F	θ^W	ζ-potential
		Logarithmic Growth Stage		
5 : 1	40.0 ± 0.6	21.1 ± 0.4	13.1 ± 0.5	-16.1 ± 0.4
30 : 1	44.3 ± 0.4	30.0 ± 0.3	18.8 ± 0.6	-17.2 ± 0.3
1 : 1.5	34.0 ± 0.7	12.2 ± 0.5	13.3 ± 0.3	-14.4 ± 0.2
		Stationary Growth Stage		
5 : 1	41.0 ± 0.3	23.6 ± 0.3	12.3 ± 0.7	-16.3 ± 0.4
30 : 1	44.5 ± 0.1	31.0 ± 0.7	17.1 ± 0.3	-17.8 ± 0.1
1 : 1.5	32.6 ± 0.6	8.81 ± 0.8	1.06 ± 0.8	-15.1 ± 0.3
		Decay Growth Stage		
5 : 1	40.0 ± 0.4	24.4 ± 0.9	15.3 ± 0.3	-16.2 ± 0.4
30 : 1	42.4 ± 0.3	31.6 ± 1.2	20.5 ± 0.9	-17.0 ± 0.5
1 : 1.5	32.2 ± 0.5	10.8 ± 0.5	8.04 ± 0.2	-13.7 ± 0.5

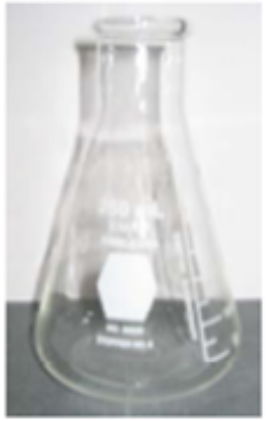
E. coli Surface Properties

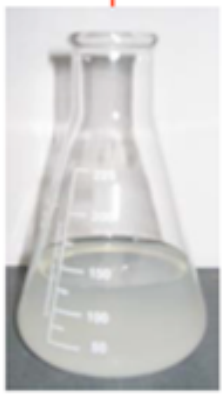
C:N	γ^+	γ^-	γ^{LW}
	Logarithmic		
5 : 1	0.72	57.2	39.6
30 : 1	0.47	59.2	37.4
1 : 1.5	0.79	53.4	42.5
	Stationary		
5 : 1	0.61	59.1	39.1
30 : 1	0.38	61.4	37.2
1 : 1.5	0.72	56.2	43.1
	Decay		
5 : 1	0.54	57.9	39.6
30 : 1	0.29	59.2	38.4
1 : 1.5	0.67	55.4	43.3

Functional Groups on *E. coli* Surfaces

	5:1 L	30:1 L	1:1.5 L	5:1 S	30:1 S	1:1.5 S	5:1 D	30:1 D	1:1.5 D
RCOH	18.6	24.7	16.2	35.2	38.9	32.4	28.6	32.4	24.2
RCOR	24.5	29.4	20.3	43.2	56.1	39.2	34.6	41.1	16.7
RCOOH	N/A	18.1	N/A	N/A	20.5	N/A	N/A	20.1	N/A
$RCOO^-$	30.4	36.2	26.4	48.7	51.0	43.1	38.2	43.4	34.2
CH_3CO^-	53.7	47.2	55.2	57.6	52.4	59.4	55.6	48.2	58.1
-CO-NH-	43.1	34.1	46.2	43.4	36.1	47.6	49.4	38.5	52.4
$-CH_2-O-$	58.7	45.3	60.7	61.6	42.4	63.5	67.8	44.6	67.1
CH_3-O-	N/A	N/A	16.4	N/A	N/A	18.7	N/A	N/A	17.5
-C-O-C-	61.4	39.6	67.8	59.8	37.6	63.4	71.7	42.2	72.5
-CH=CH-	60.7	52.4	62.4	61.5	50.3	65.2	61.5	52.3	60.5
$>C=CH_2$	77.6	66.7	76.2	74.8	61.2	73.2	77.7	64.3	77.4
$-CH=CH_2$	77.1	63.5	77.2	77.7	62.7	76.4	77.2	63.7	77.1

Column Experiment





Bacterial Suspension

Column

Luminometer

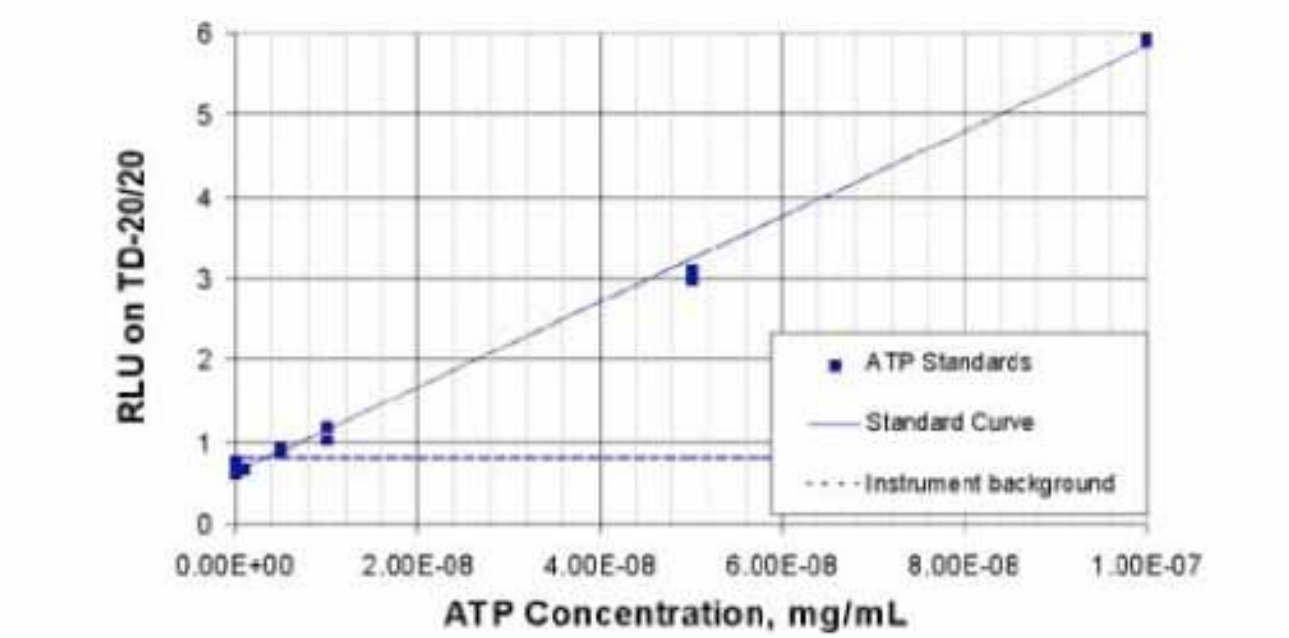
Luciferin & Luciferase

Syringe Pump

ATP Measurement

$$\text{Luciferin} + \text{ATP} + O_2 \xrightarrow{\text{Luciferase, } Mg^{2+}}$$

$$\text{Oxyluciferin} + \text{AMP} + CO_2 + PP_i + \text{Light (560 nm)}$$



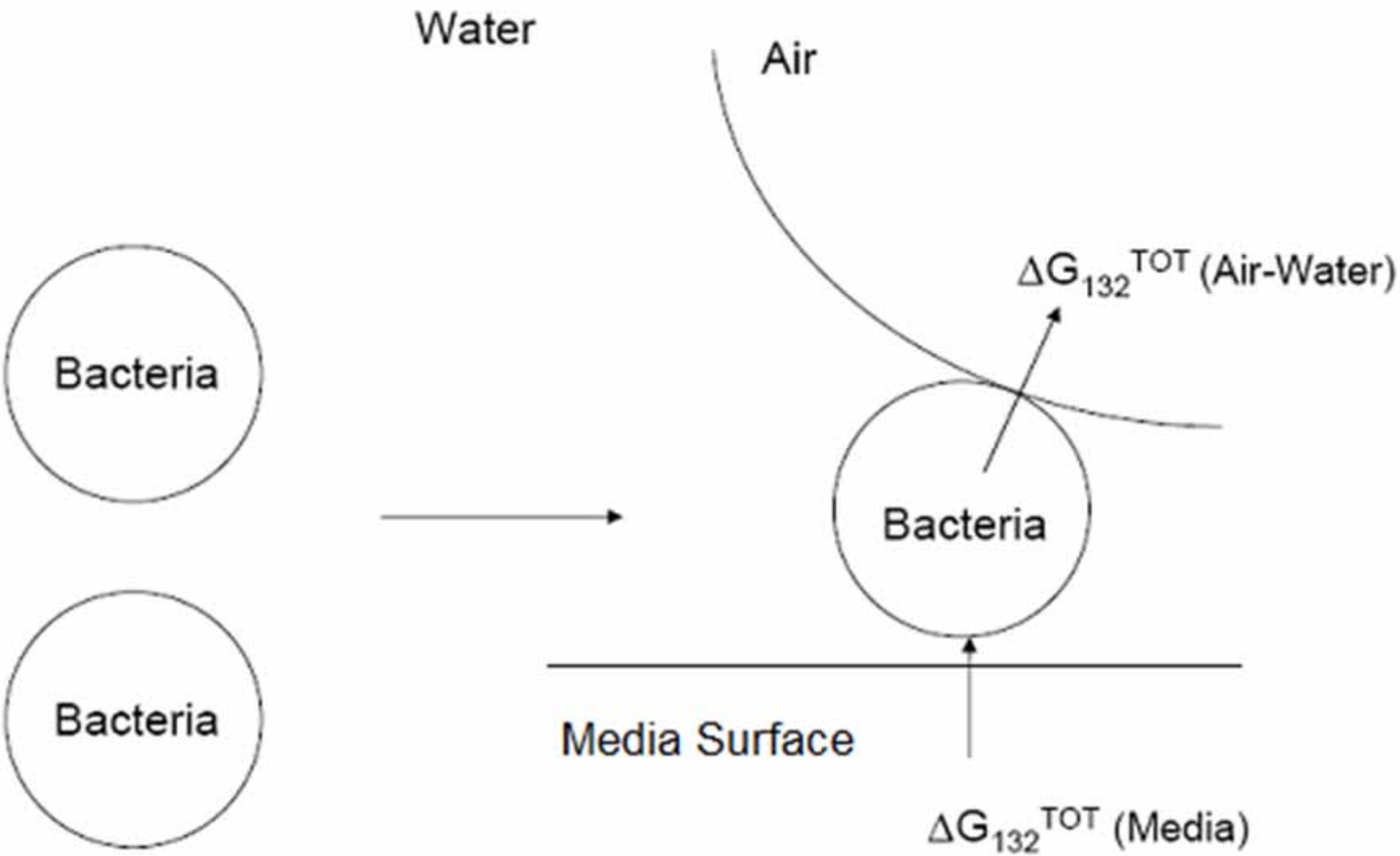
Bacterial Transport Modeling

$$\frac{\partial}{\partial t}[\theta_m C] = \frac{\partial}{\partial z}[D_z \theta_m \frac{\partial C}{\partial z}] - \frac{\partial}{\partial z}[qC] - k_1 \theta_m C + k_{des} \frac{\rho_b S}{S_e} C_r$$

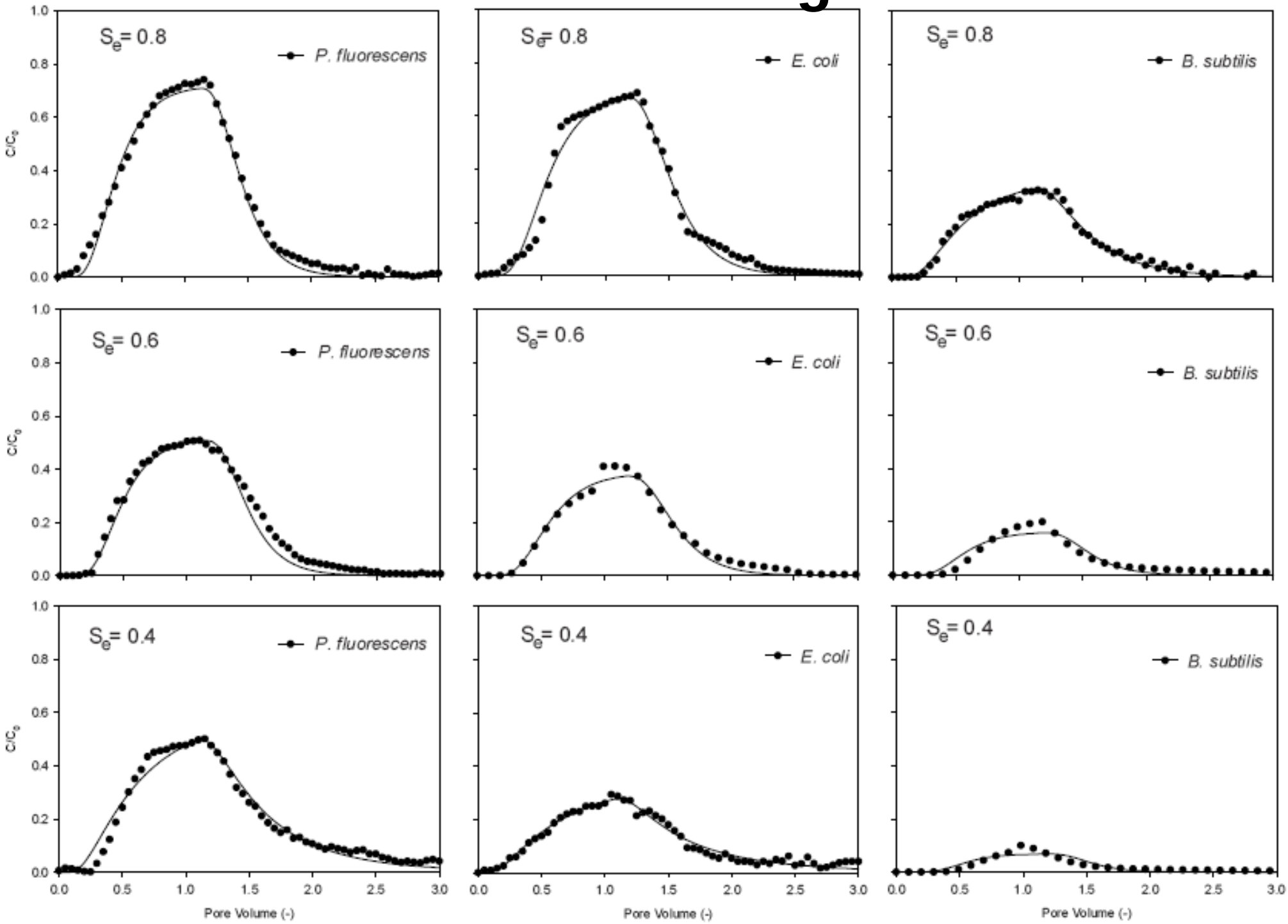
$$\frac{\partial C_r}{\partial t} = k_1 \frac{\theta_m S_e}{\rho_b S} C - k_{des} C_r$$

C — bacterial concentration in the solution (cells/m^3)
C_r — retained bacterial concentration [cells/(g)(m^2/m^3)]
D_z — apparent dispersion coefficient (m^2/sec)
θ_m — moisture content (m^3/m^3)
q — specific discharge (Darcian fluid flux) (m/sec)
k_1 — deposition coefficient (sec^{-1})
k_{des} — desorption coefficient (sec^{-1})
ρ_b — bulk density (g/m^3)
S — air-water interfacial area (m^2/m^3)

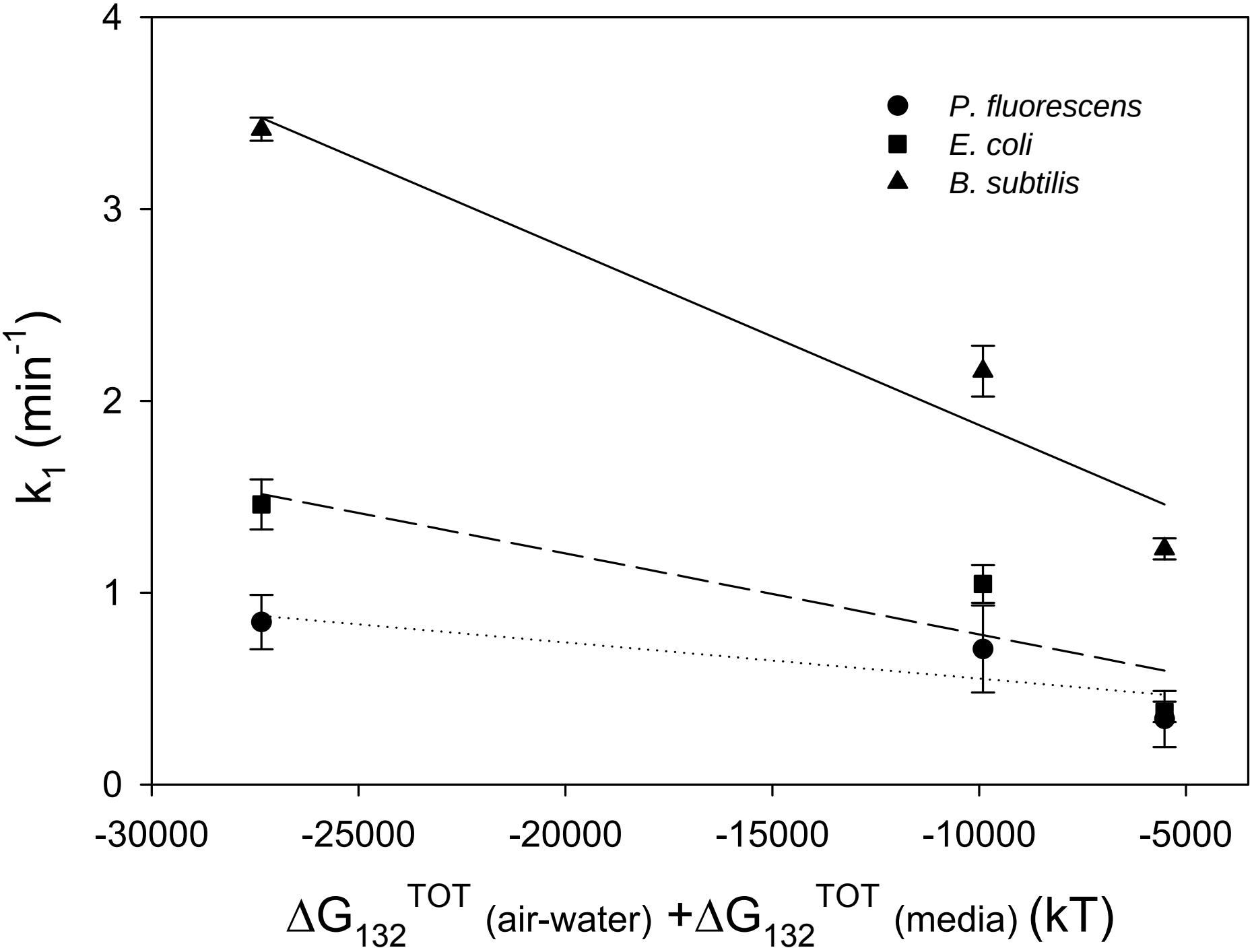
E. coli Retention Mechanism



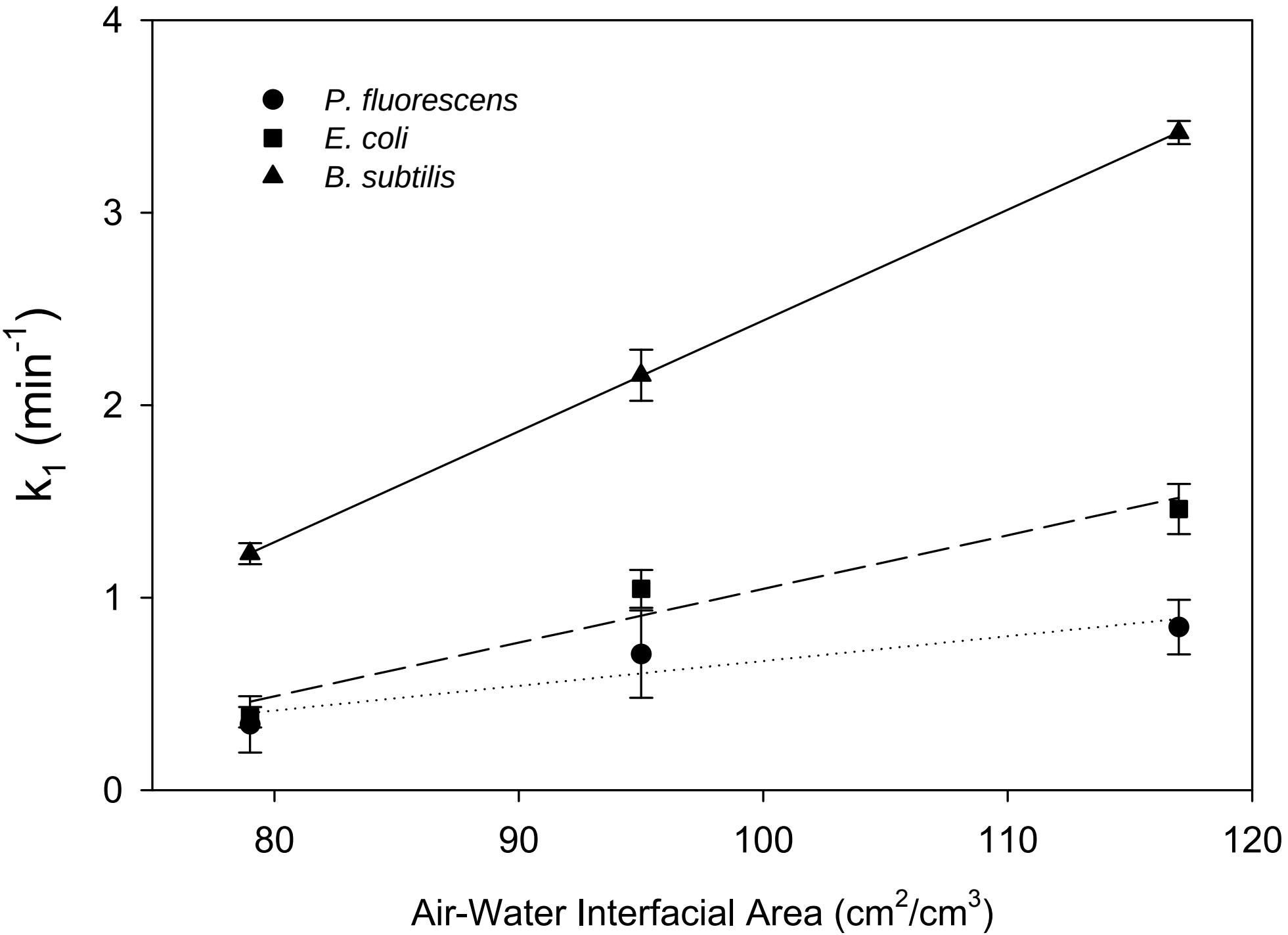
E. coli Breakthrough Curve



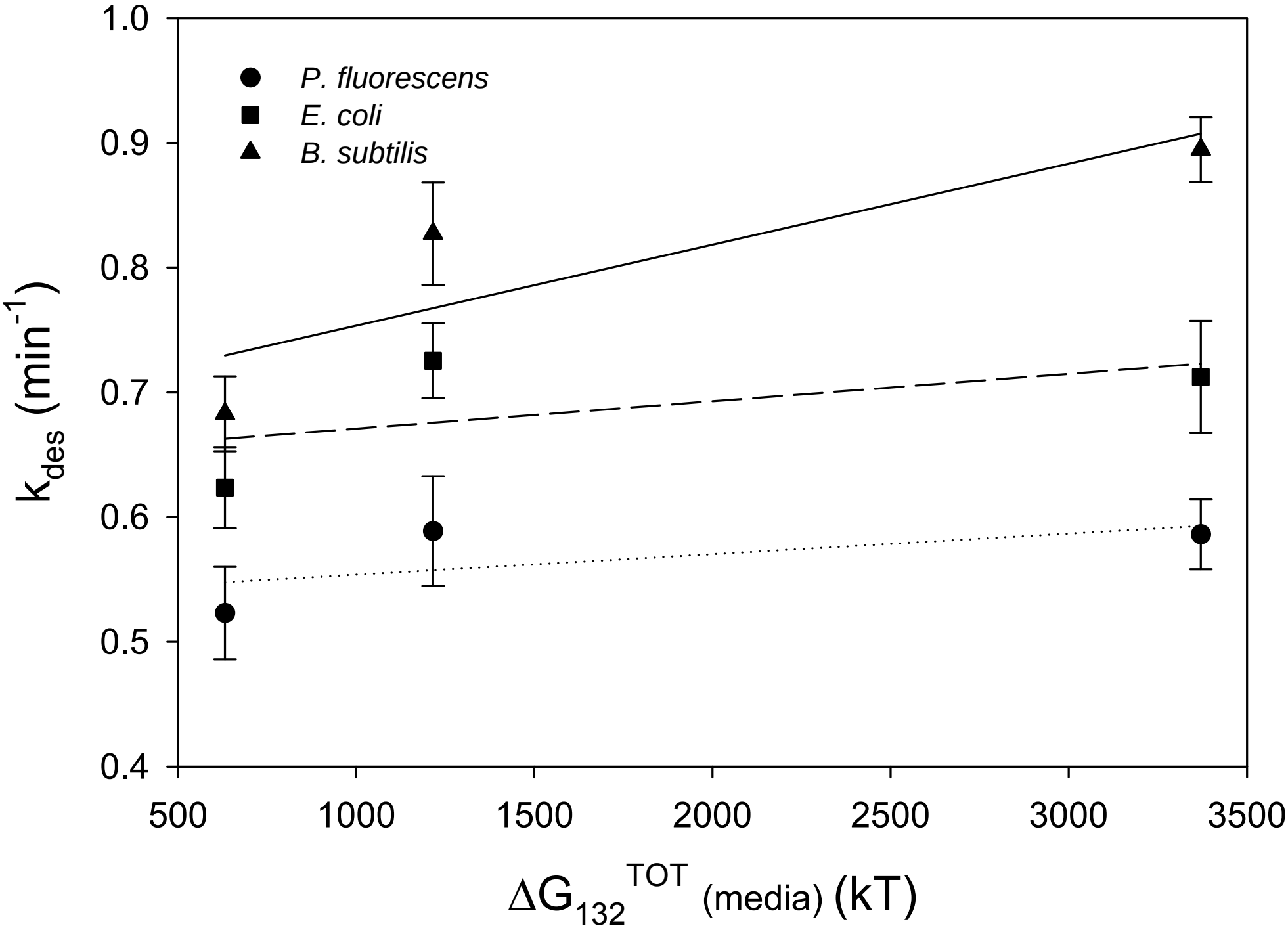
Deposition and Bacterial Interactions



Deposition and Interfacial Area



Desorption and Bacterial Interactions



Acknowledgements

The work was supported by the National Research Initiative of the USDA Cooperative State Research, Education and Extension Service, Grant No. 2007-35102-18111 to Florida A&M University.

Questions?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