Transport and bacterial interactions of three bacterial strains in saturated column experiments

Christine Stumpp, John Lawrence, Jim Hendry, Piotr Maloszewski

Helmholtz Zentrum München, Institute of Groundwater Ecology, Germany

Department of Geological Sciences, University of Saskatchewan, Canada

Environment Canada, Saskatoon, Canada

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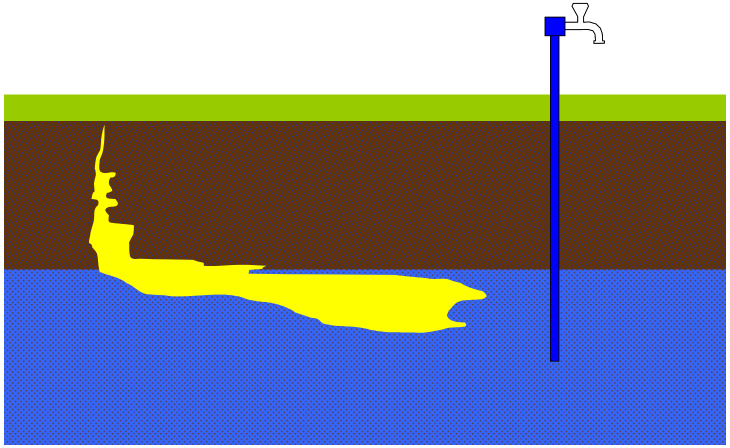
Introduction

Relevance

- riverbank infiltration
- waste water effluents
- animal manure
- bioremediation



→ pathogenic microorganisms can pollute drinking water resources

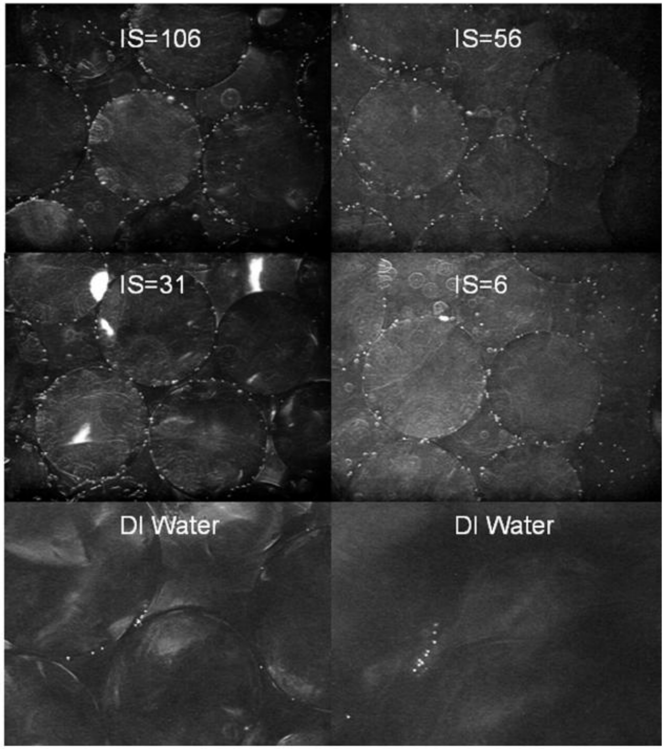
→ prediction of bacterial fate to control the degradation of contaminants

Introduction

Fate of bacteria in groundwater depends on…

- physical factors
- chemical factors
- biological factors

→ factors tested on individual species under controlled conditions

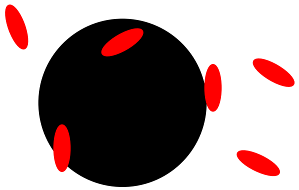


(Torkzaban et al. 2010 ES&T)

Objectives

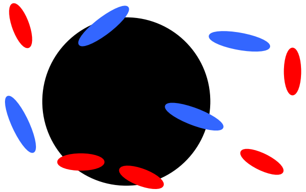
→ …but do we see any difference when more than one species is involved in transport?

How is the …



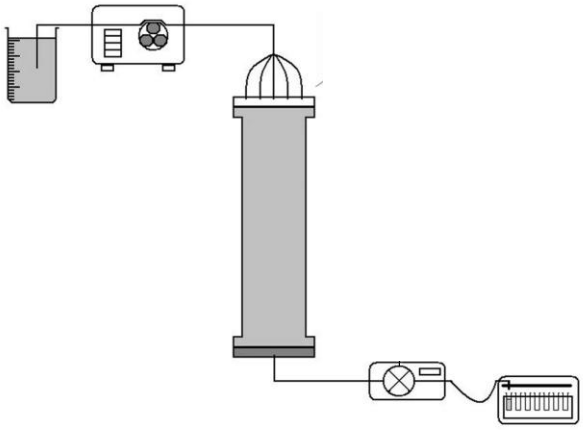
1) impact of **bacteria-solid** interactions

2) impact of **bacteria-bacteria** interactions



… on the transport and sorption parameters?

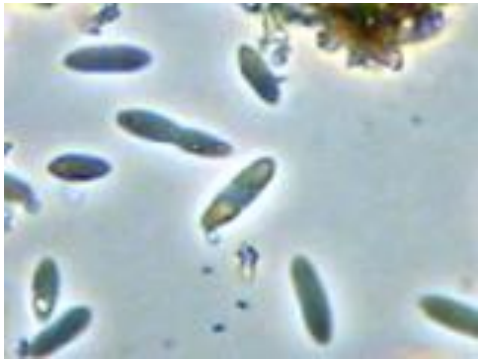
Experimental Setup



Column experiments (L=114 mm; ø=33 mm)

- saturated conditions
- medium to coarse grained silica sand
- constant chemistry
- non-growth conditions
- constant water flow velocity (5.2±0.5 cm h^{-1})
- injection of tracer (Cl^-) and bacteria
  - individual experiments (= 1 strain alone)
  - simultaneous experiments (= 2 strains at the same time)
  - successive experiments (=1 strain after 1 other strain)

Experimental Setup



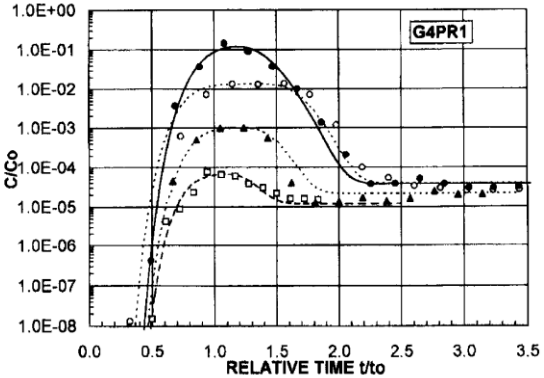
- ***Burkholderia cepacia* G4PR1**
  - cell size: 2±0.5 x 0.9±0.1 µm
  - zeta potential: -17.73±0.89 mV
  - nonmotile organism, slightly hydrophobic
  - candidate for use in remediation of contaminated (TCE) aquifers
- ***Klebsiella oxytoca***
  - cell size: 1.4±0.8 x 0.7±0.1 µm
  - zeta potential: -34.52±0.25 mV
  - nonmotile organism, very hydrophilic
  - potentially create microbial barriers in porous media (EPS production)
- ***Pseudomonas* sp. #5**
  - cell size: 3.1±1.4 x 1.1±0.1 µm
  - zeta potential: -17.56±1.32 mV
  - motile organism, slightly hydrophobic
  - plant pathogen

Mathematical Model

- transport and sorption parameters from breakthrough curves
- advective-dispersion equation with reversible and irreversible sorption

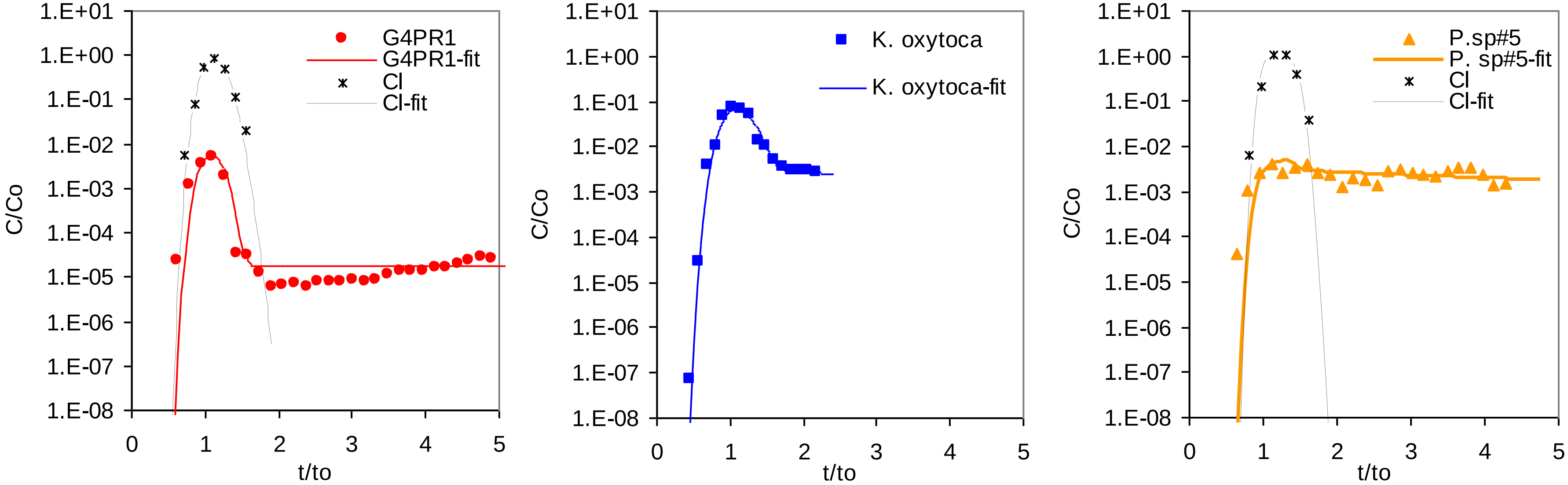
$$\frac{\partial C}{\partial t}+\frac{\rho(1-\varepsilon)}{\varepsilon}\frac{\partial S}{\partial t}=D\frac{\partial^2 C}{\partial x^2}-v\frac{\partial C}{\partial x}-k_{irr}\left[C+\frac{\rho(1-\varepsilon)S}{\varepsilon}\right]$$

$$\frac{\partial S}{\partial t}=\frac{\varepsilon C}{\rho(1-\varepsilon)}k_f-(k_r+k_{irr})S$$



(Hendry et al. 1999 Groundwater)

Results – Individual Experiments



experiment	t_{pulse} (hr)	Q (ml hr^{-1})	v (cm hr^{-1})	α_L (mm)	t_0 (hr)	k_f (hr^{-1})	k_r (hr^{-1})	k_{irr} (hr^{-1})	Recovery (%)
individual									
G4PR1	**0.7**	**14.9**	**4.9**	**0.6**	**2.4**	**1.26**	**0.001**	**-**	**0.6**
K. oxytoca	**1.0**	**12.1**	**3.9**	**1.1**	**2.9**	**0.45**	**0.017**	**0.062**	**10.3**
***Ps.* sp.#5**	**1.0**	**17.1**	**5.6**	**0.3**	**2.1**	**1.65**	**0.195**	**-**	**1.7**

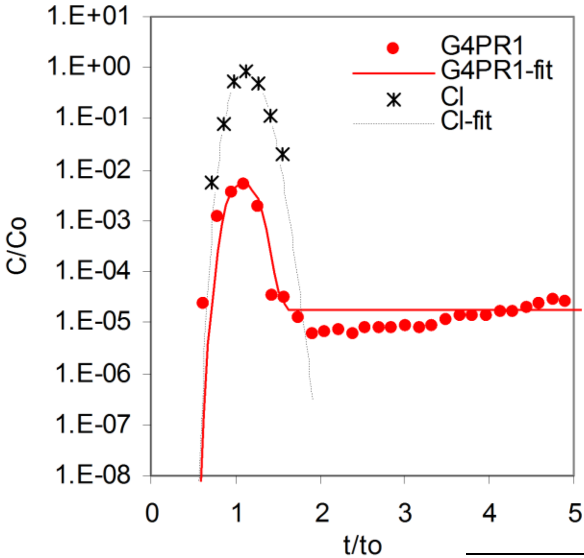
consistent with cell properties

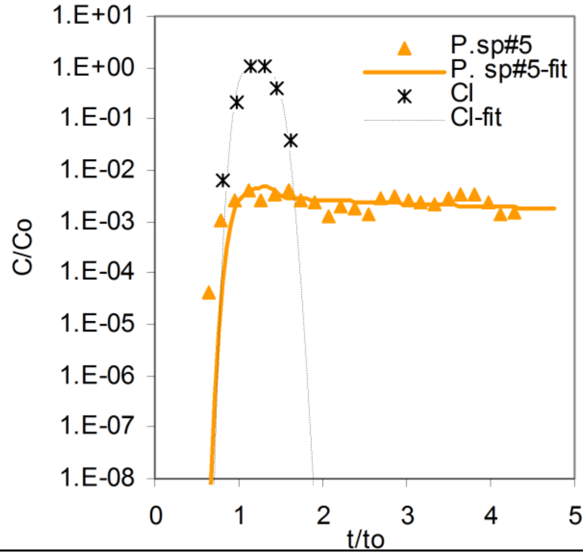
boundary conditions (Q, v) — tracer BTC (α_L, t_0) — bacteria BTC (k_f, k_r, k_{irr})

(Stumpp et al. 2011 ES&T)

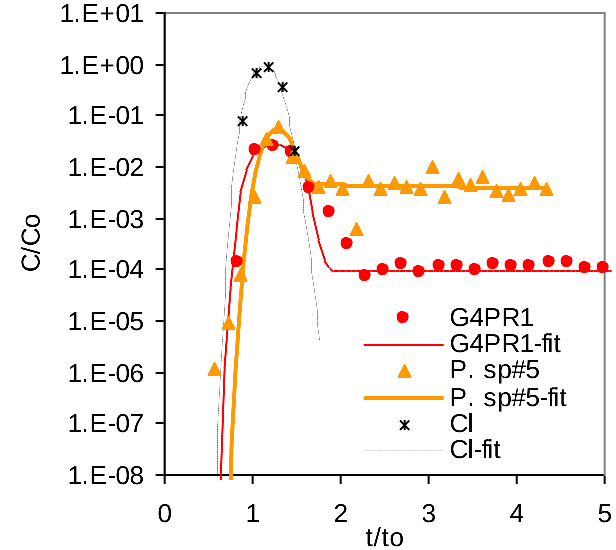
Results – Simultaneous Experiments

individual experiments



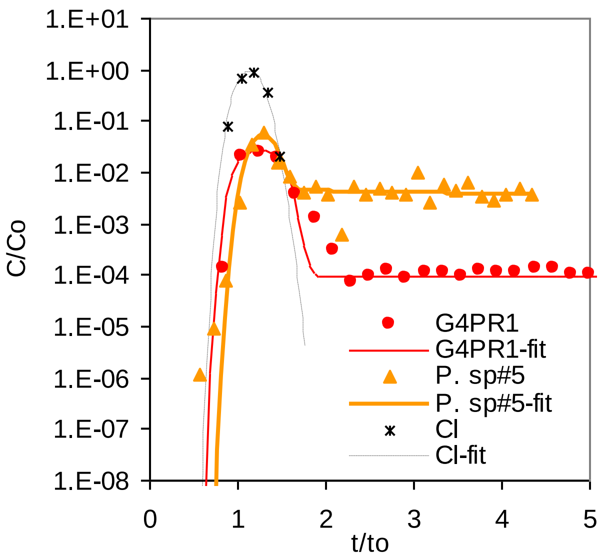


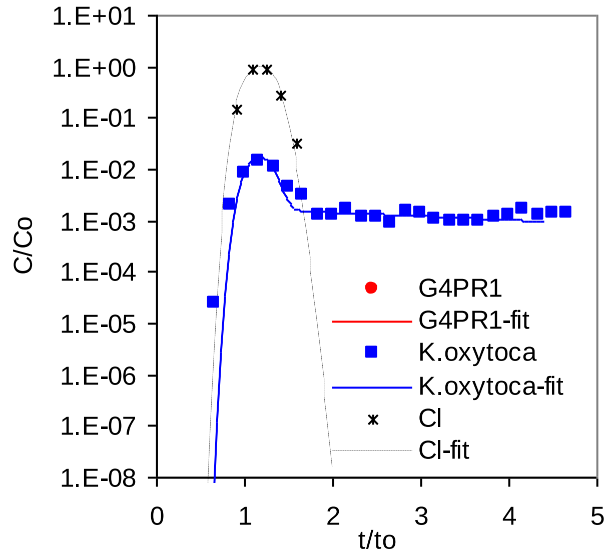
simultaneous experiment

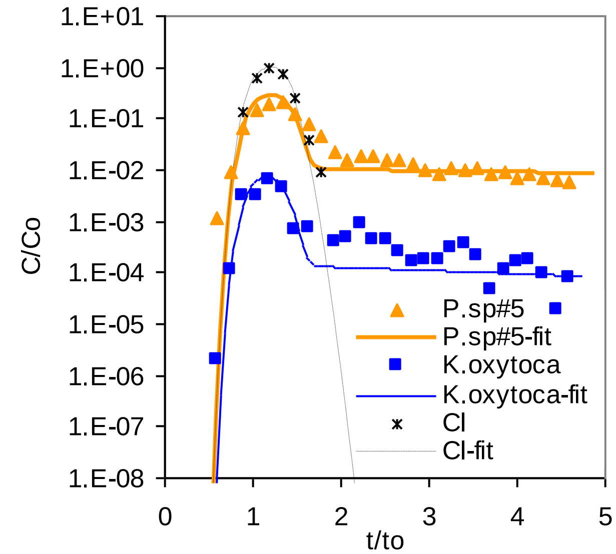


experiment	k_f (hr^{-1})	k_r (hr^{-1})	k_{irr} (hr^{-1})	Recovery (%)
individual				
G4PR1	**1.26**	**0.001**	**-**	**0.6**
***Ps*. sp.#5**	**1.65**	**0.195**	**-**	**1.7**

Results – Simultaneous Experiments

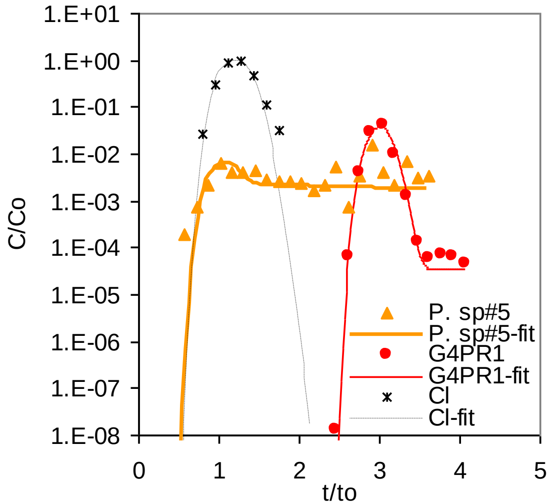


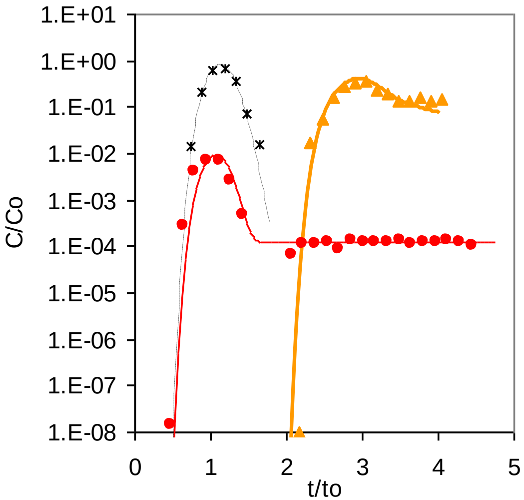




experiment	k_f (hr^{-1})	k_r (hr^{-1})	k_{irr} (hr^{-1})	Recovery (%)	
simultaneous					
G4PR1	**0.93**	**0.001**	**-**	**2.7**	
***Ps.* sp.#5**	**0.73**	**0.040**	**-**	**9.6**	→ increased
G4PR1	**-**	**-**	**-**	**0.0**	?
K. oxytoca	**1.13**	**0.035**	**0.062**	**2.7**	↘ decreased
K. oxytoca	**1.24**	**0.004**	**0.062**	**0.8**	↗ decreased
***Ps.* sp.#5**	**0.33**	**0.027**	**-**	**33.6**	→ increased

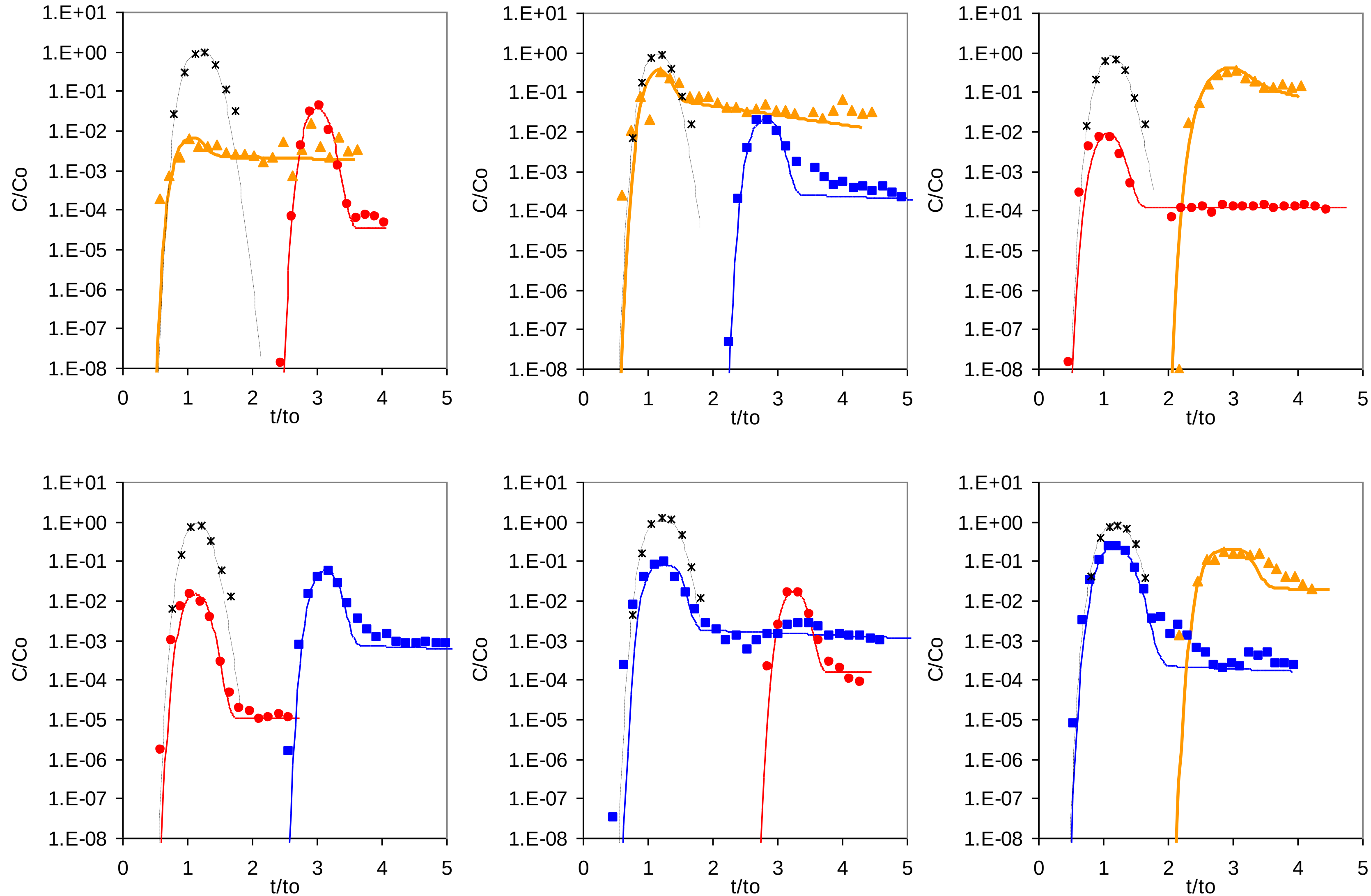
Results – Successive Experiments





experiment	k_f (hr^{-1})	k_r (hr^{-1})	k_{irr} (hr^{-1})	Recovery (%)
individual				
G4PR1	**1.26**	**0.001**	**-**	**0.6**
***Ps.* sp.#5**	**1.65**	**0.195**	**-**	**1.7**
simultaneous				
G4PR1	**0.93**	**0.001**	**-**	**2.7**
***Ps.* sp.#5**	**0.73**	**0.040**	**-**	**9.6**
successive				
***Ps.* sp.#5**	**1.45**	**0.095**	**-**	**0.2**
G4PR1	**0.77**	**0.0004**	**-**	**4.4**
G4PR1	**1.19**	**0.004**	**-**	**1.2**
***Ps.* sp.#5**	**0.25**	**0.444**	**-**	**61.7**

Results – Successive Experiments



Conclusions

- **G4PR1** sorption parameters are **independent** of the presence of *Ps*. sp. #5 or when injected after *K. oxytoca*
- ***K. oxytoca*** is **more competitive** for the sorption sites when simultaneously injected with the other bacteria
- ***Ps*. sp. #5** (motile) has **more variable** transport parameters; parameters indicate the **potential of long travel distances**

- **bacteria-bacteria interactions influence bacterial migration**
- **recovery rates** can only be explained by **cell properties** when **one strain is present**
- results from studies performed with only **one bacterial strain** should **not be generalized** and may not be applicable to more complex and/or field conditions

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