The continuous production of bioethanol: One, two and three tank reactor designs

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Talk Outline

- Brief background.
- Model description.
- Results — dynamical & optimal performance.
- Conclusion and future work.

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Background — bioethanol

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- Reduced emissions — greenhouse gas emissions reduced by up to 19%, tailpipe carbon monoxide by as much as 30%
- It takes only six months to harvest a substantial crop for fuel.

Model — biochemistry

A.B. Jarzebski. (1992). “Modelling of oscillatory behaviour in continuous ethanol fermentation”. *Biotechnology Letters*, **14**(2), 137–142.

- Substrate (S).
- Product - ethanol - (P)
- Biomass (*Zymomonos mobilis*)
  - Viable cells (X_v)
  - Non-viable cells (X_{nv}) — non-growing, but still retain the ability to produce ethanol.
  - Dead cells (X_d) — eqn uncouples.

Model — single reactor

$$
\begin{aligned}
V\frac{dS}{dt} &= F(S_0 - S) - V\left(\frac{\mu_v X_v}{Y_{x|s}} + m_s {X_n}^v\right), \\
V\frac{dX_v}{dt} &= -FX_v + V(\mu_v - \mu_{nv} - \mu_d)X_v, \\
V\frac{dX_{nv}}{dt} &= -FX_{nv} + V(\mu_{nv}X_v - \mu_d X_{nv}), \\
V\frac{dX_d}{dt} &= -FX_d + V\mu_d(X_v + X_{nv}), \\
V\frac{dP}{dt} &= -FP + V\left(\frac{\mu_v X_v}{Y_{x|p}} + m_p X_{nv}\right).
\end{aligned}
$$

Model — rate expressions

$$
\begin{aligned}
\mu_v &= \mu_{\max}\frac{S}{K_1+S}\left(1-\frac{P}{P_c}\frac{S}{K_2+S}\right),\\
\mu_d &= -\mu_{\max}\frac{S}{K_1+S}\left(1-\frac{P}{P_c}\frac{S}{K_2+S}\right),\\
\mu_{nv} &= \mu'_{\max}\frac{S}{K_1+S}\left(1-\frac{P}{P'_c}\frac{S}{K_2+S}\right)-\mu_v.
\end{aligned}
$$

- Reaction rates can not be negative.
- Substrate limitation.
- Product inhibition.

Results — ethanol concentration

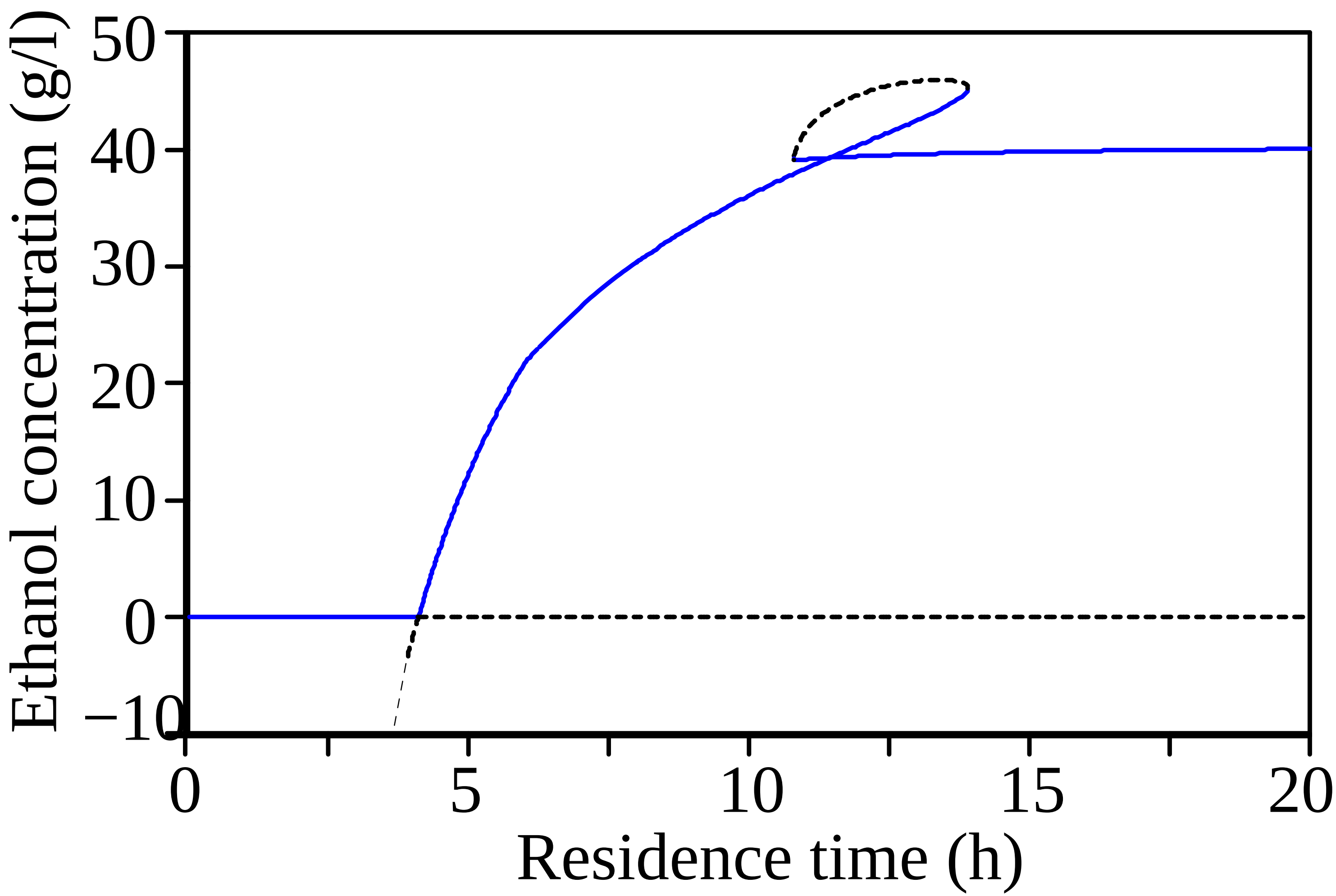

Figure 0: $S_0 = 100\,$g l^{-1}. $\tau_W = 4.12$hr.

Results — productivity ($\mathbf{Pr} = P/\tau$)

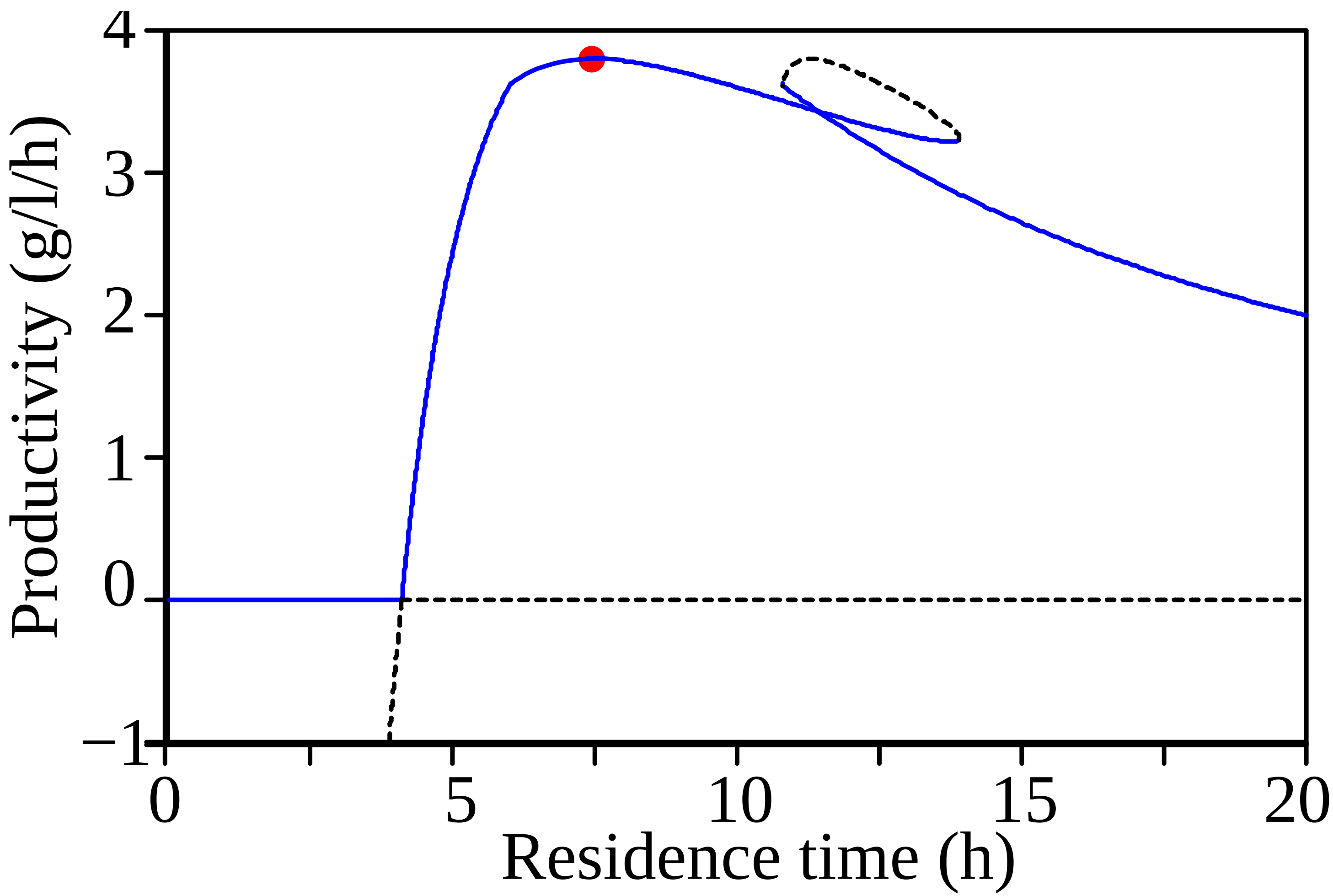

Figure 0: $S_0 = 100\,\mathrm{g\,l^{-1}}$. $\mathrm{Pr}_{\max} = 3.8\,\mathrm{g\,l^{-1}hr^{-1}}$ at $\tau = 7.5\,\mathrm{hr}$.

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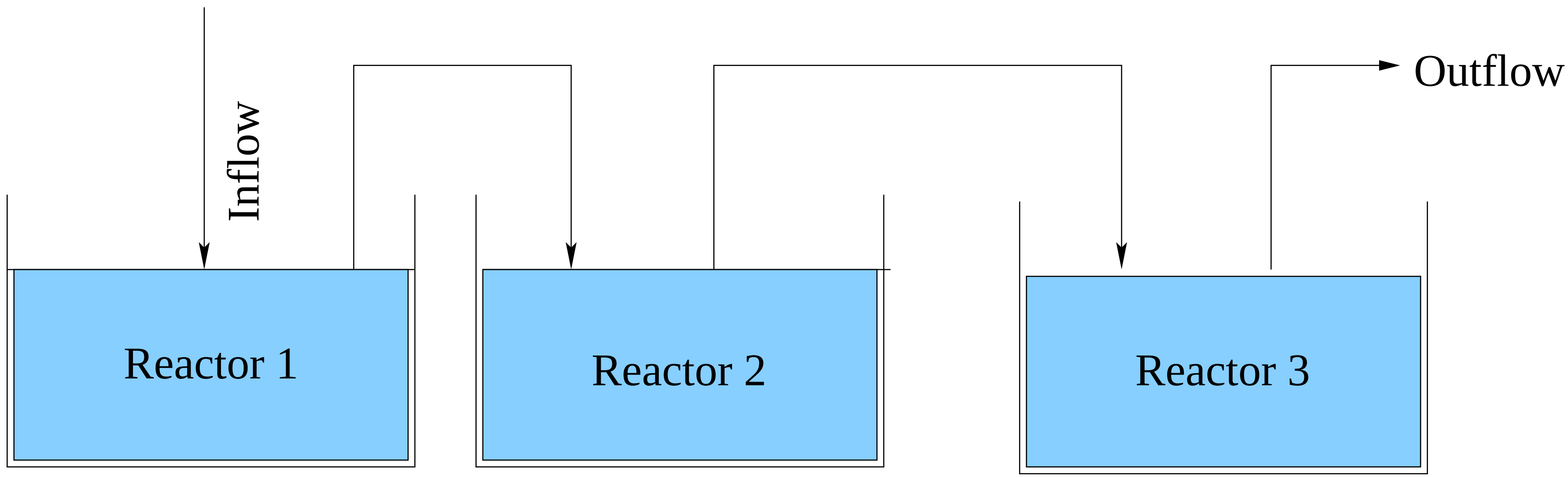
- Maximum productivity: system operated at a static steady-state.
- If $100 \leq S_0 \left(\text{g l}^{-1}\right) \leq 160$ then

$$\text{Pr}_{\text{max}} = 3.8039 \left(\text{g l}^{-1}\text{hr}^{-1}\right) \pm 9.8738 \times 10^{-5}$$

Results — reactor cascade



$$\text{Pr}_2 = \frac{P_2}{\tau_1 + \tau_2}$$

$$\text{Pr}_3 = \frac{P_3}{\tau_1 + \tau_2 + \tau_3}$$

Results — double reactor cascade

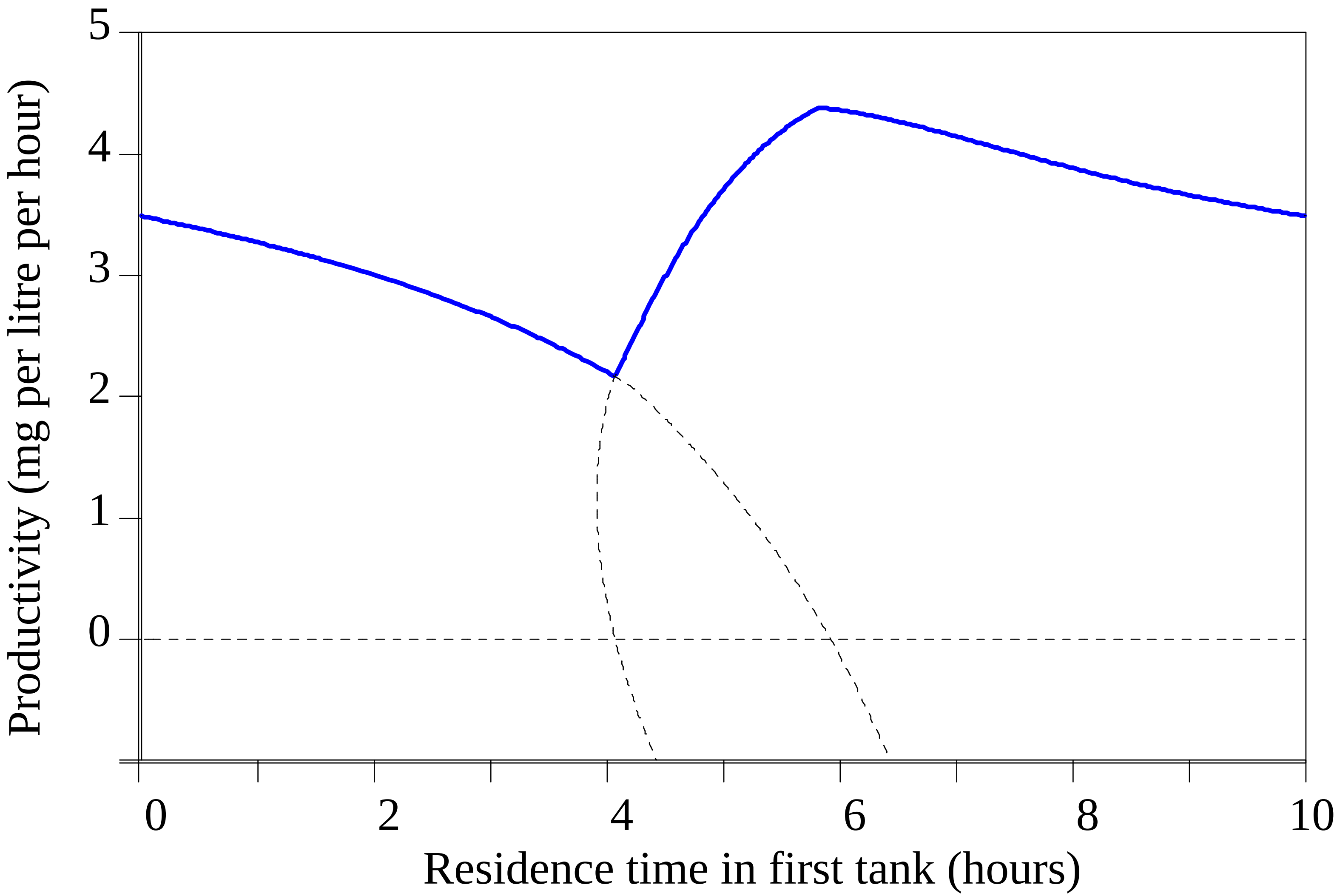


Figure 0: Total residence $\tau_1 + \tau_2 = 10\,(\mathrm{h})$. $S_0 = 100\,\mathrm{g\,l^{-1}}$.

Results - optimal double reactor cascade

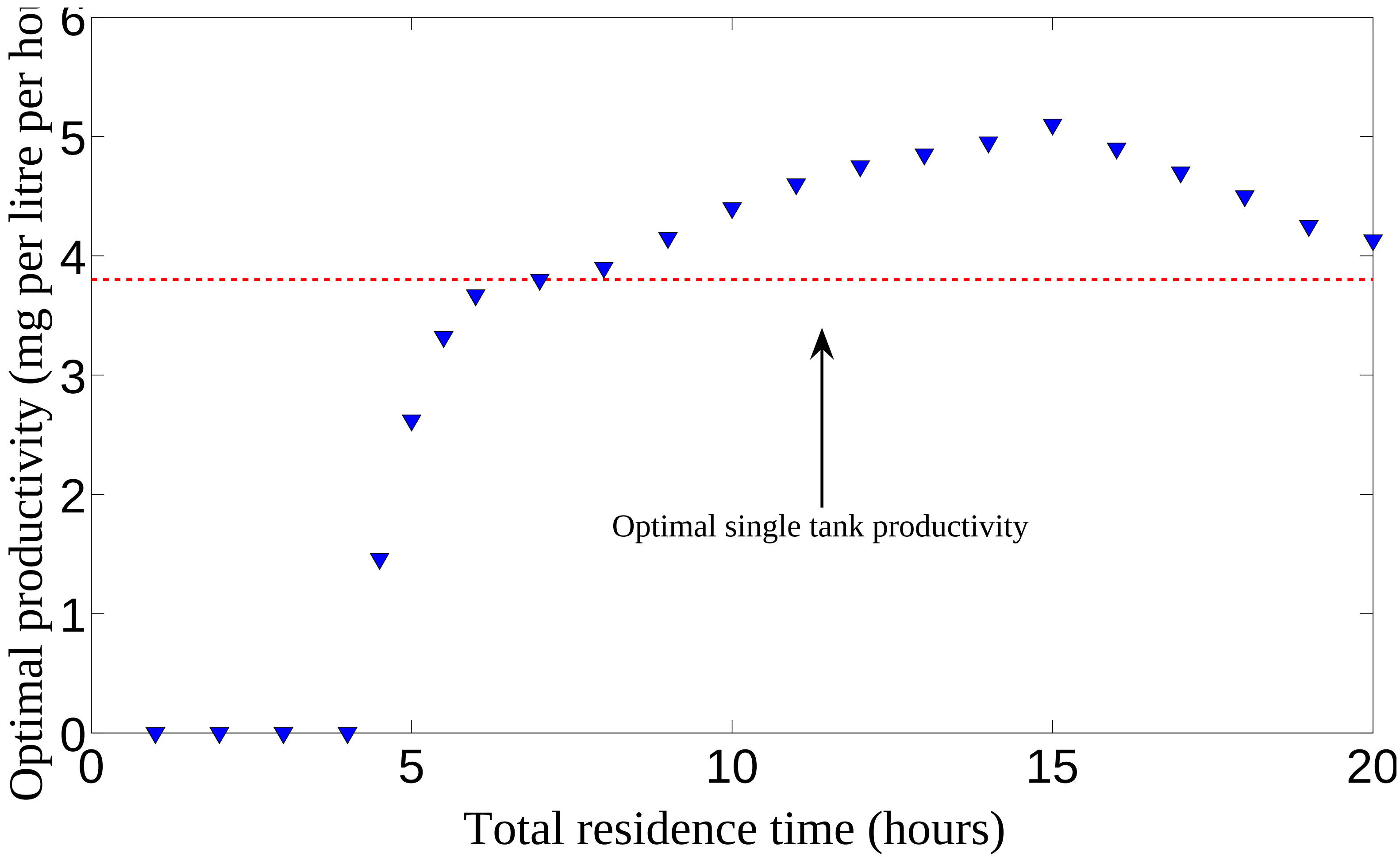


Figure 0: Optimal performance of a cascade of two (un)equal reactors. $S_0 = 100\,\mathrm{g\,l^{-1}}$.

Results — scatter plot

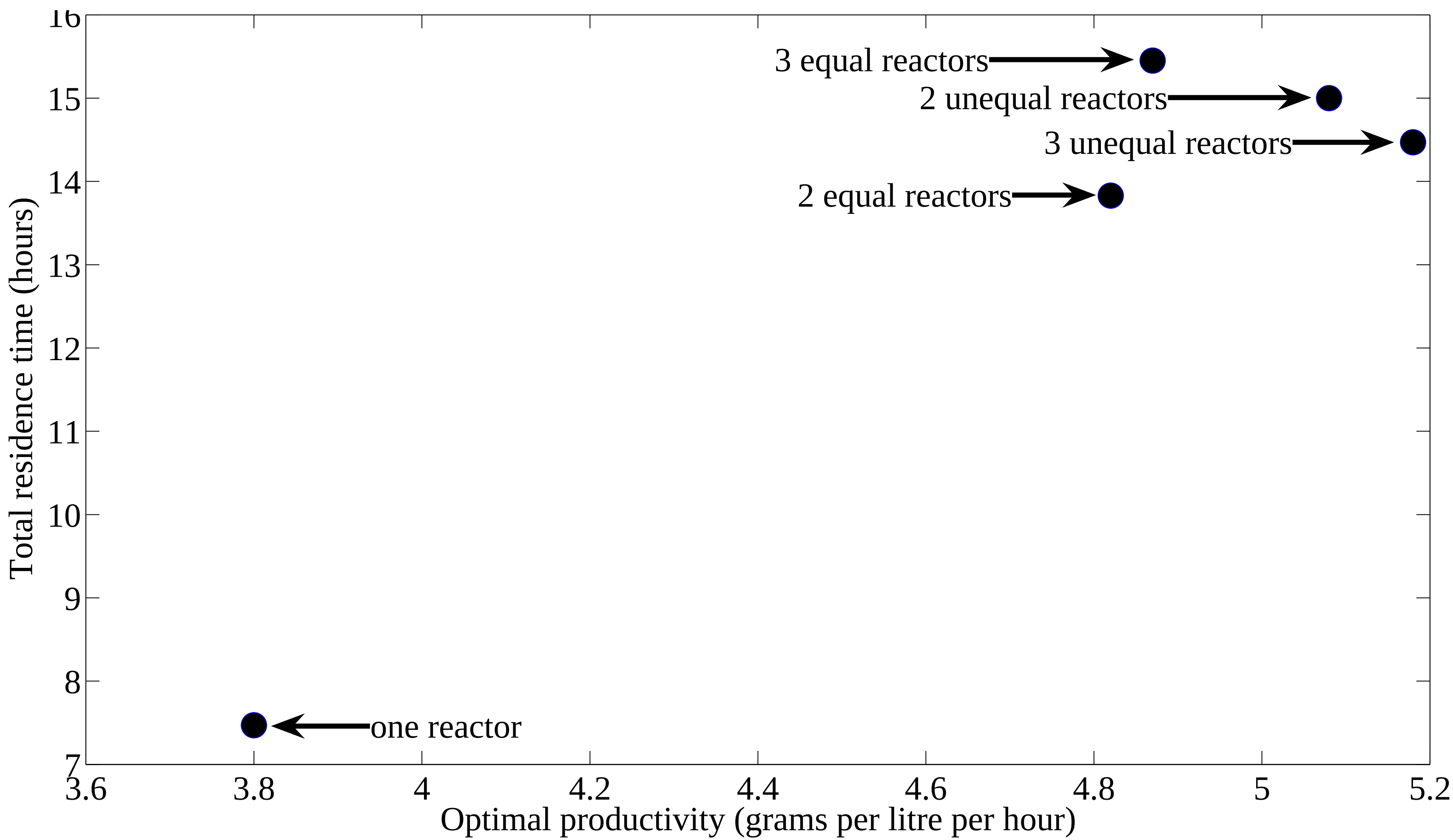


Figure 0: Optimal performance of a cascade of various reactor configurations. $S_0 = 100\,\mathrm{g\,l^{-1}}$.

What's next?

Feed concentration : Extensive investigation.

Reactor costs : Can we afford to optimise production?

Recycle : Improves performance.

Performance : Maximise product concentration.

Undergraduate lab : Department of Chemical Engineering, Monash University.

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6. Equal double reactor cascade can outperform single reactor by 27%.

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