Performance evaluation of ethanol production through continuous fermentation

H.S. Sidhu[1], J. Kavanagh[2], S.D. Watt[1] and M.I. Nelson[3]

(1) School of Physical, Environmental and Mathematical Science, UNSW at ADFA, Canberra, AUSTRALIA

(2) School of Chemical and Biomolecular Engineering, University of Sydney AUSTRALIA

(3) School of Mathematics & Applied Statistics, University of Wollongong, AUSTRALIA.

Talk Outline

- Background
- The Model
- Results
- Possible impact of work – Economic analysis
- Conclusions and Future work

Background

- Kyoto Protocol and recent surge in oil prices has renewed interest in biofuels
- Largest ethanol fuel industries exists in Brazil (based on sugarcane) and USA (based on corn).
- In Brazil: 50% of all cars are able to use 100% ethanol fuels and gasoline sold contains at least 20% ethanol.
- The energy content of ethanol is approximately two-thirds that of petrol by volume.
- It takes only six months to harvest a substantial crop for fuel.

The Model — biochemistry

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

- Substrate (S) - glucose.
- 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.

Jarzebski (1992) estimated parameter values using experimental data from Perego *et al* (1985).

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).
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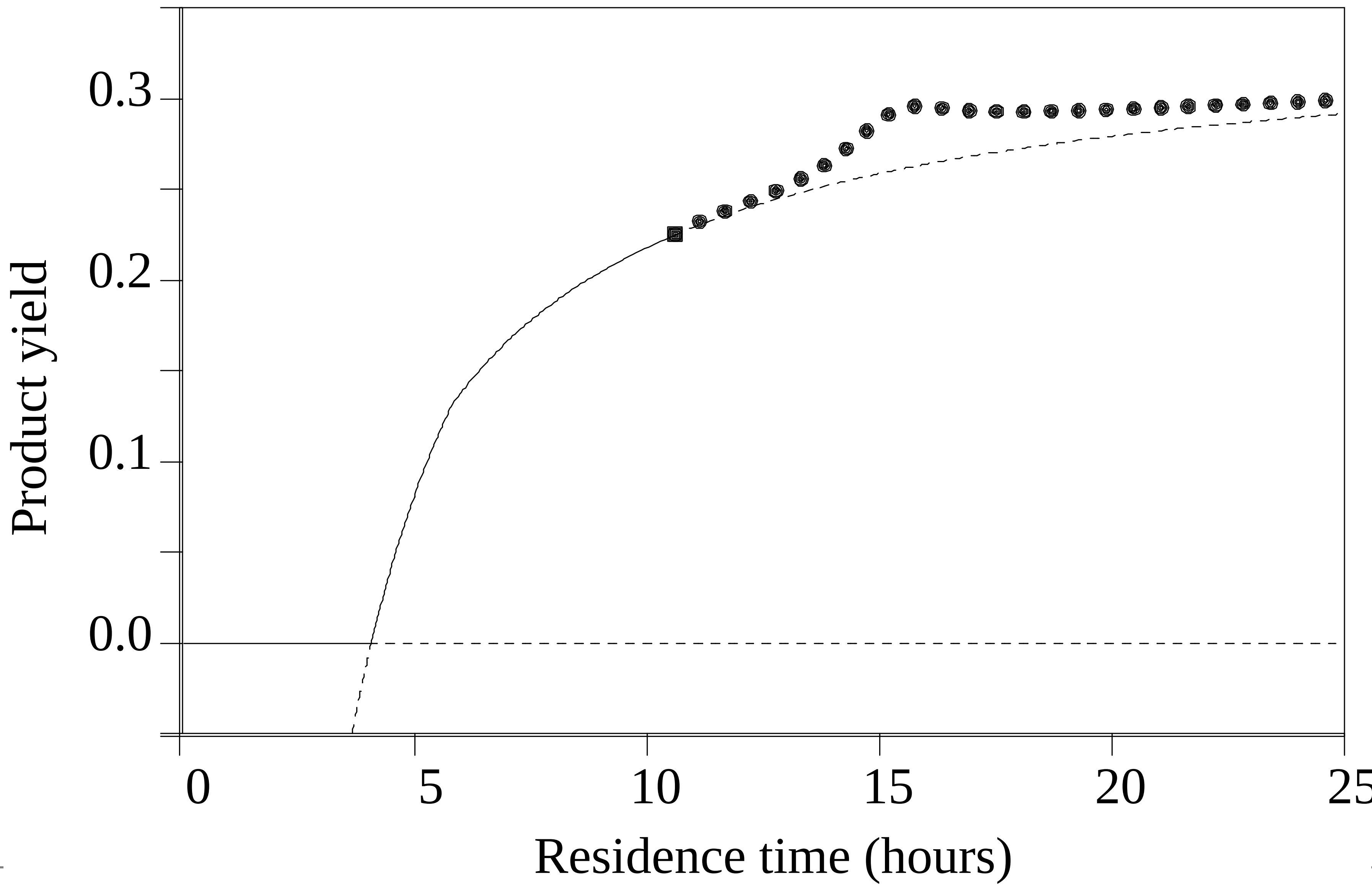
Performance (1)

We characterise the performance of the reactor system by its product yield at the outlet:

$$\text{Ethanol yield} = \frac{P_i - P_0}{S^0}$$

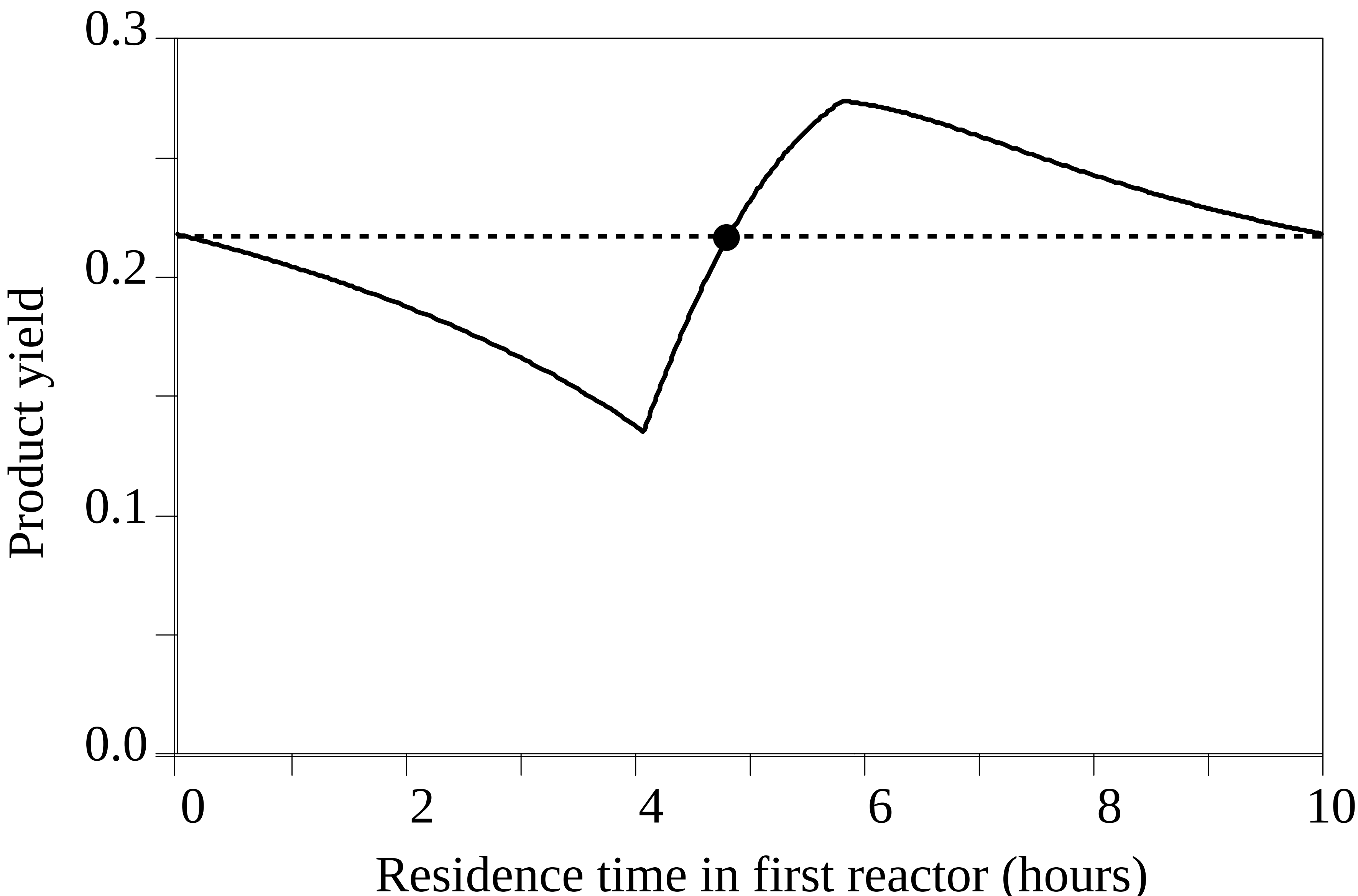
We assume that the concentration of ethanol at the influent of the fermenter is zero, ie. $P_0 = 0$.

Performance: single fermenter



Performance: a two-reactor cascade (1)

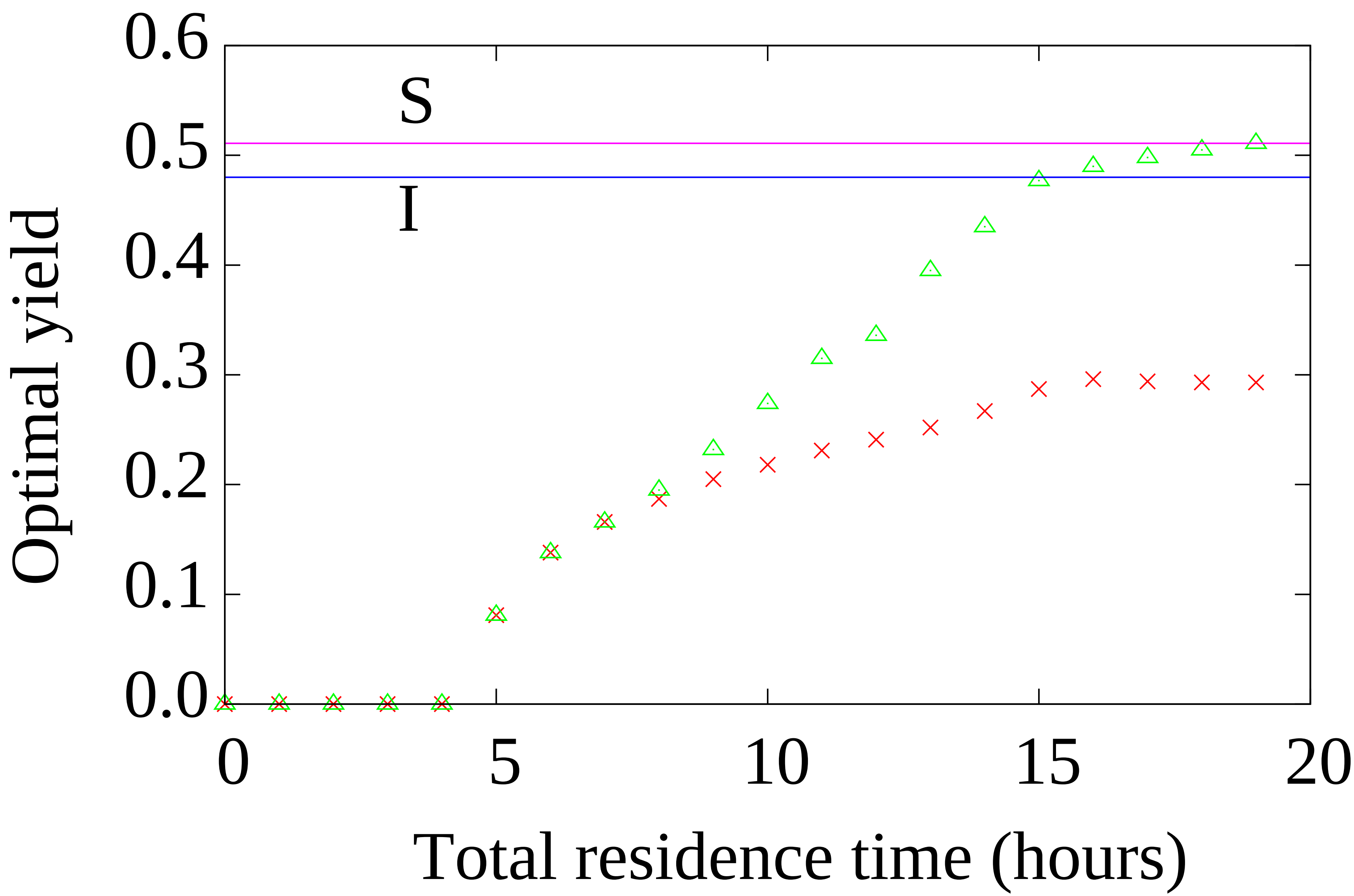
($\tau_{\text{cr}} = 4.83$)



Performance: a two-reactor cascade (2)

$Y\left(\tau_{total} = 15.23\right) = 0.48$

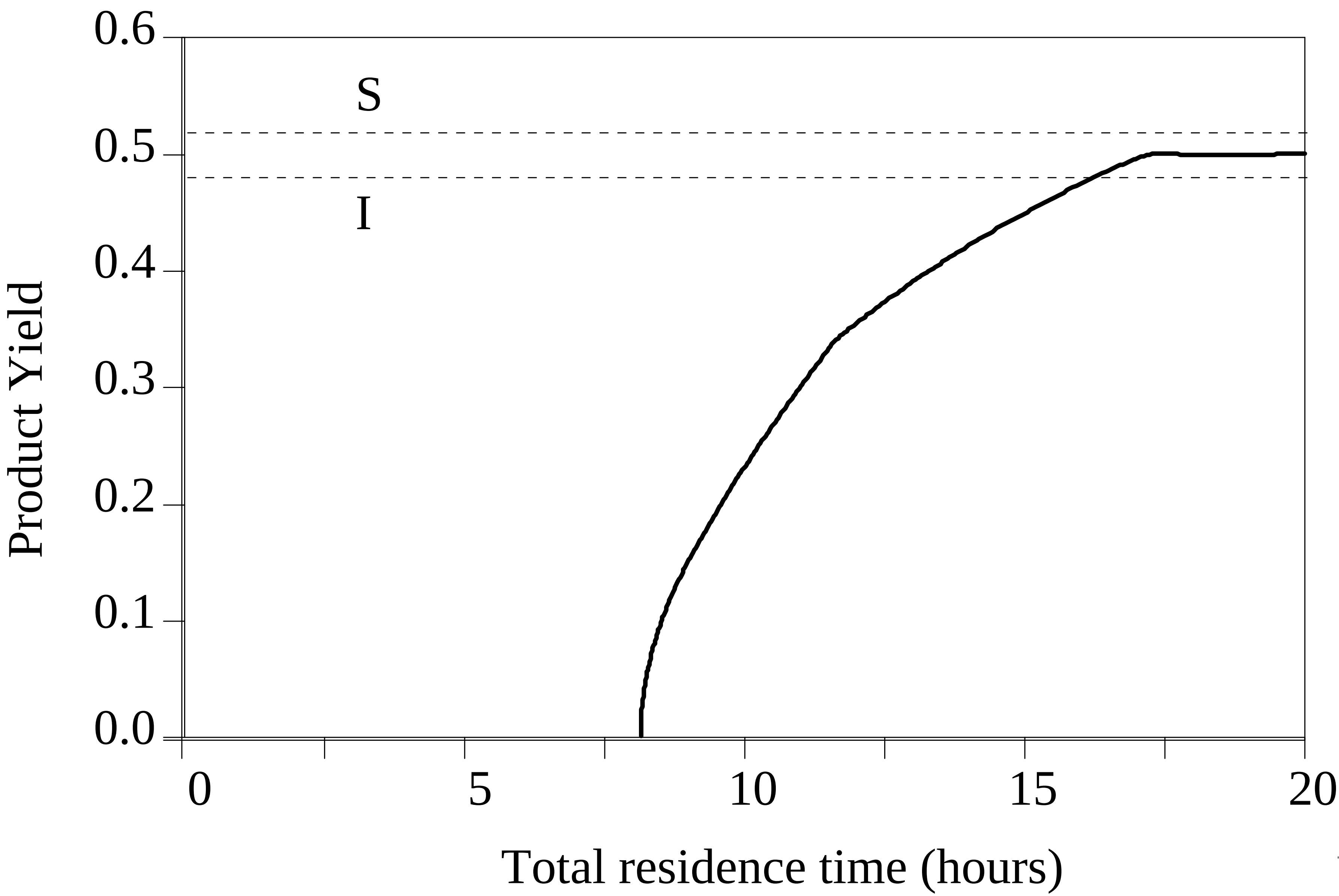
Approaches stoichiometric values for $\tau_{total} = 19$ hours



Double reactor cascade $(\tau_i = \tau_t/2)$

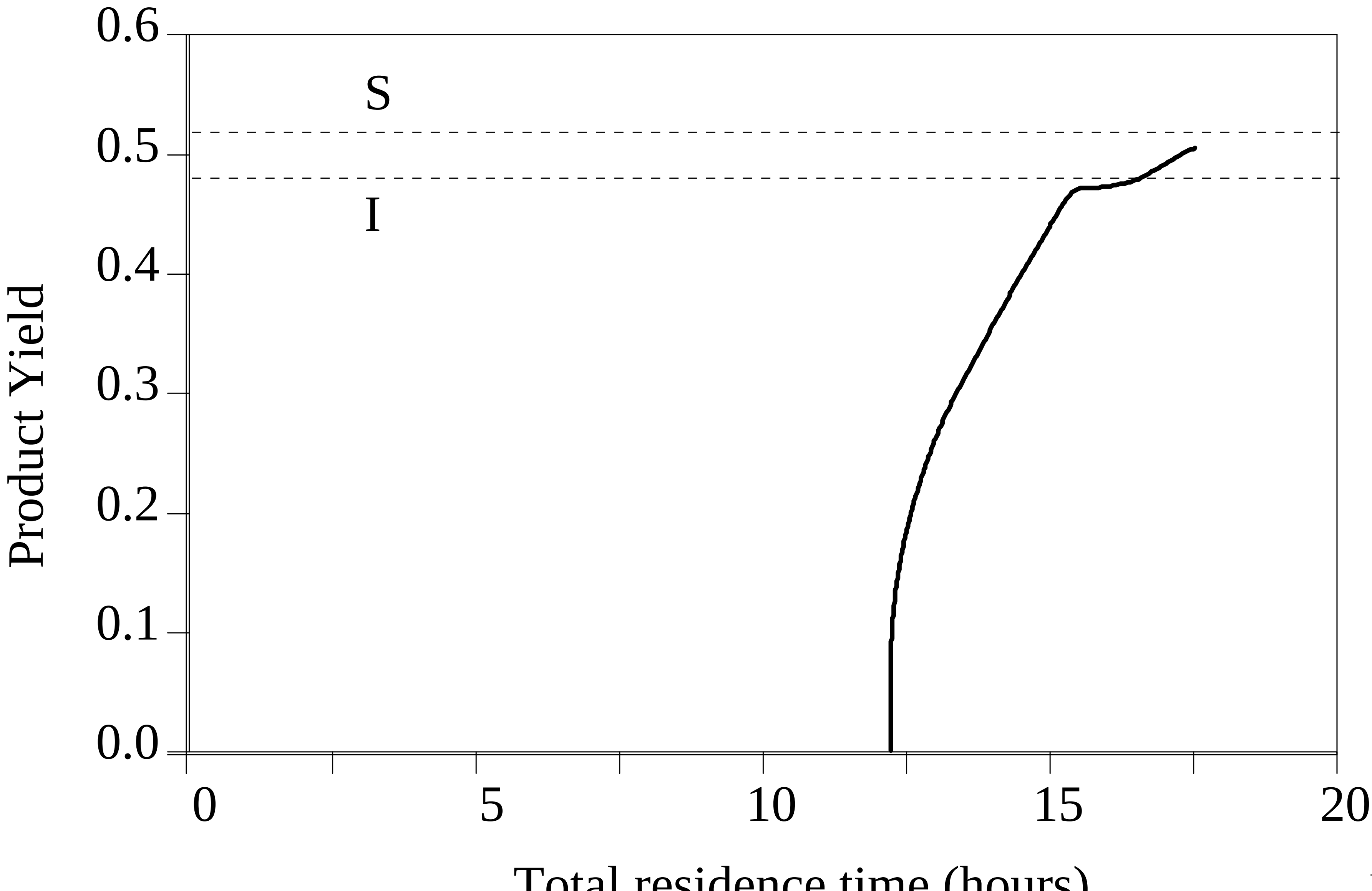
$Y\left(\tau_{total} = 16.22\right) = 0.48$

Approaches stoichiometric values for $\tau_{total} = 20$ hours



Triple reactor cascade $(\tau_i = \tau_t/3)$

$Y(\tau_{total} = 16.29) = 0.48$ Approaches stoichiometric values for $\tau_{total} = 17.55$ hours



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- For sufficiently large total residence times, the cascade can outperform the single reactor.
- Determined reactor designs which can give product yield higher than 0.48.
- Simulations were able to achieve product yields close to the stoichiometric values.
- Main contribution is not the specific reactor designs that were found to give yields over 0.48 but the systematic approach of using path following methods.

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- The use of a permselective membrane module and a cell/substrate separator to separate the cell and unused substrate from the exit stream to be recycled back into the first tank.