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Institute of Food, Nutrition and Human Health

A Mathematical Model for Thermophile Contamination in a Tubular Heat Exchanger

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Te Kunenga ki Pūrehuroa

Topic of discussion

- Mathematical model for microbial contamination in a liquid food processing line
- Aim of model:
  - Predict microbial contamination trends
  - Decide when to start cleaning
  - Estimate run length
- Case study: Thermophile contamination in a milk tubular heat exchanger

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Microbial contamination and adhesion

- In most food process lines
  - Product residence time is short (1/2 hr)
  - Not enough time for large bacteria growth
  - Surface attachment necessary to allow growth over extended periods
- Two possible methods of attachment
  - Biofilm formation
  - Entrapment in fouling layers

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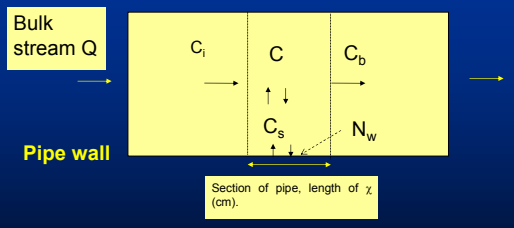
Model Configuration



N_w surface population

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Principle of model

- Rate of increase in surface numbers $\frac{dn_w}{dt}$ =
  - rate of growth on surface $\mu.n_w$
  - + rate of deposition from bulk stream $k_a.C_s$
  - - rate of loss from surface to stream $\mu.n_w\beta$

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Rate of bacteria change on wall

$$\frac{dn_w}{dt} = \mu.n_w.(1-\beta) + k_a.C_s$$

- β proportion of bacteria lost from wall to stream
- μ specific rate of growth of bacteria
- K_a adhesion rate constant

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Rate of contamination to stream

$$\frac{dC_b}{dt} = \frac{Q}{V}(C_i - C_b) + \frac{A}{V}(\beta.\mu.n_w - k_a.C_s) + C.\mu$$

- Rate of change in bulk flow
- Net flow in and out of section
- Rate of release from wall
- Rate of attachment to wall
- Rate of growth in the bulk flow

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Differences with previous work

- Principle applies to all interactions between surface deposits and liquid streams
  - Not confined to thermophiles
  - Applies to both biofilms and fouling layers
  - Only surface population interacts with stream
  - Total population in fouling layer irrelevant
    - Langeveld et al (1994) unsuccessful use of total population
  - Nature of surface does not impact
    - De Jong and Aantrekker models for biofilms only

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How to apply the model (1)

1. Estimate surface population n_w
2. Estimate bulk contamination C_b

- Data input
  - Flowrate Q
  - Inlet concentration C_i
  - Hold up V

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How to apply the model (2)

- Parameters determined by independent experiments
  - β proportion of bacteria lost from wall to stream
  - μ specific rate of growth of bacteria
  - K_a adhesion rate constant

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Equipment

- Milk powder pilot plant
  - 40-60 l/h whole milk feed
  - Fully computerised and Fix-D-Macs display
  - Fouling rig with 6 MPHE for surface enumeration
  - 2 parallel banks of 3 each THE
  - Quick heating by DSI to focus growth on fouling rig and THE
  - Up to 24 hrs runs
  - Up to 2000 plate counts per run

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Materials and methods

- Surface enumeration
  - Swabbing
    - Incomplete (low) recovery
    - Not representative of surface
      - higher numbers with fouling layers than biofilms
  - Confocalscanning laser micrography
    - Dye with Syto 13
    - Good distribution of bacteria
    - Poor resolution from small fouling fragments (initiation period)
    - Underestimate
      - Only counts large colonies
    - Expensive and time consuming

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Materials and methods

- Impedance measurement
  - Equipment: MiniTrac 4000 impedance monitor (SyLab, MBH, Purkersdorf, Austria
  - Efficient
  - Reliable (large amount of data for statistical analysis)
- Enumeration in liquid samples
  - Plate count

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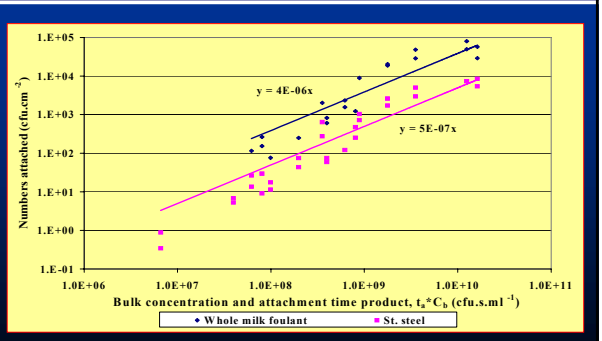
Surface attachment



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Adhesion and growth rates

$$k_a = \frac{n_w}{t_a . C_s}$$

$$\mu = \frac{\ln 2}{g}$$

- Adhesion rate determined by measurement of surface numbers vs time and concentration
- Growth rate obtained from doubling time g

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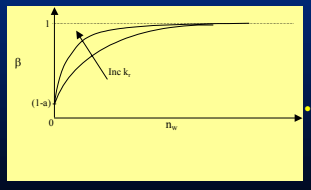
Release proportion

$$\beta = 1 - a.e^{(-k_r . n_w)}$$



- Release proportion a function of surface population n_w
- a = lumped parameter accounts for
  - convective forces, and
  - rate build up of the surface population at time zero
- k_r= release constant.
  - reflects change in β with surface population n_w

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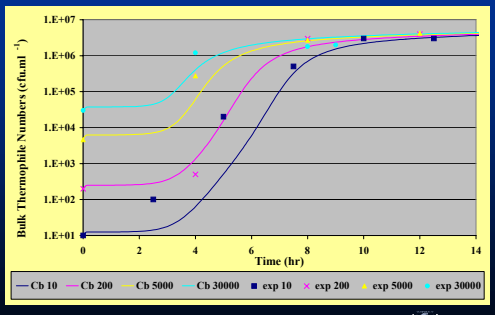
Bulk contamination from biofilms



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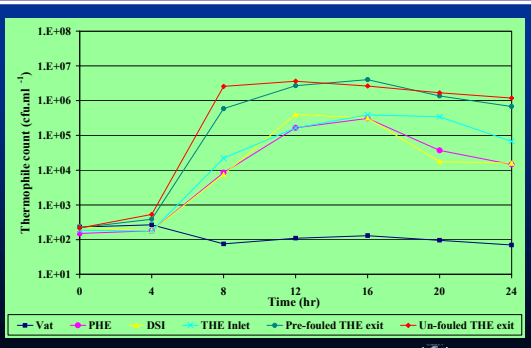
No difference between clean and sanitised fouled surfaces



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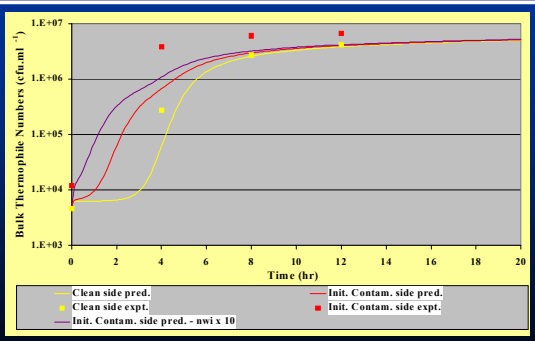
Effect of residual fouling



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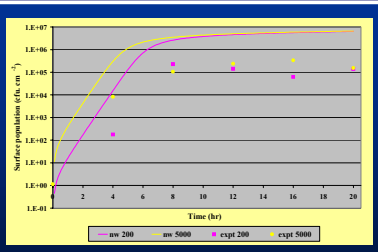
Surface numbers



- Predictions one decade higher than measurements

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CLSM method

- Only detects relatively large colonies
- Good illustration of distribution of bacteria on surface
- Bacteria gathers in sheltered area

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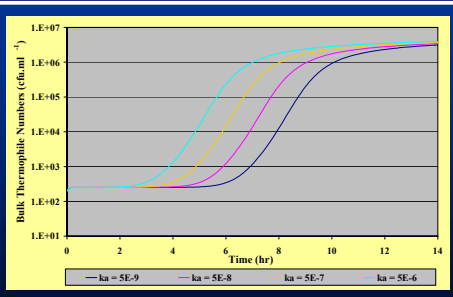
Changing adhesion constant



- Example: Surface conditioning (e.g. Parkar *et al.*, 2003)

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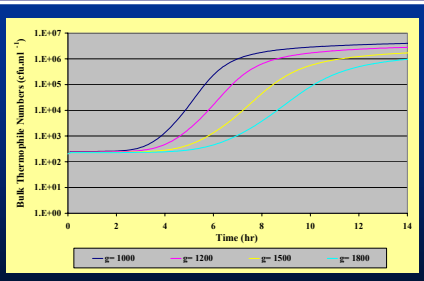
Effect of generation time



- Change in species
- Or change in growth environment

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Conclusions

- Model
  - Allows successful prediction of run length
  - Overestimates surface numbers
- Applies to
  - both foulant and biofilms
  - Thermophiles (this case study) and psychrototrophs
- Better method of surface enumeration needed
  - Less disturbance of surface in sampling
- Thank you for your attention

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