Process Intensification

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History

- **Pioneered by Colin Ramshaw at ICI in the late 1970s, largely via rotating equipment:**
  - **Spinning disc reactors (SDRs)**
  - **Rotating packed beds (RPBs)**

P. I. in the UK: PIN

- "PIN" the Process Intensification Network. Managed by:
  - *Prof David Reay* *Heriot Watt University*
  - *Prof Colin Ramshaw* *Cranfield University*
  - *Prof Adam Harvey* *Newcastle University*

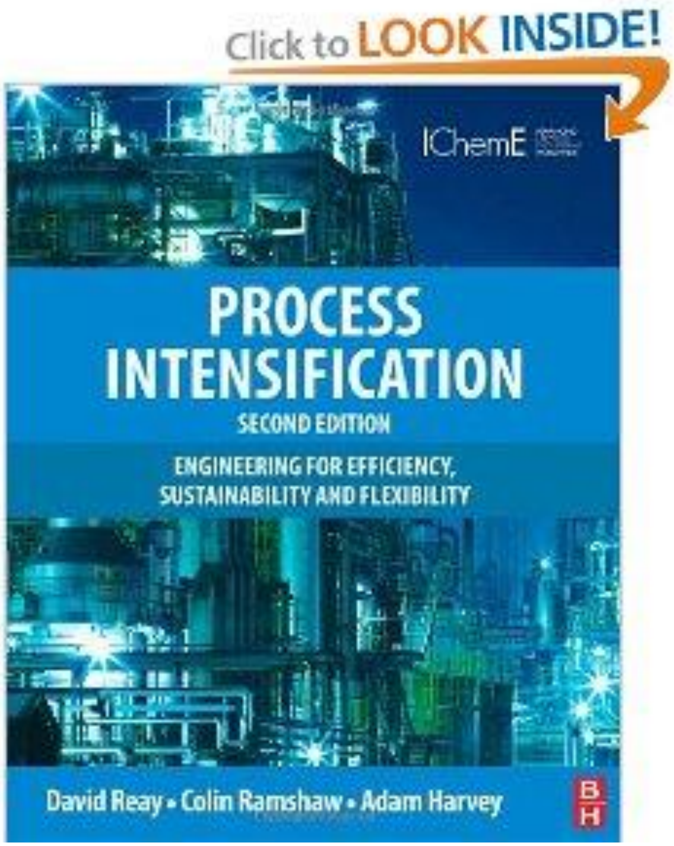
- 22nd Meeting: May 2014, Newcastle University
- 23rd Meeting: May 2015, Newcastle University
- ~300 on the mailing list: industry, academia, UK and overseas
- Email dareay@aol.com or adam.harvey@ncl.ac.uk to join

Process Intensification Group [PIG]

- 9 academic staff
- 12 research associates
- 28 PhDs

http://pig.ncl.ac.uk

RESOURCES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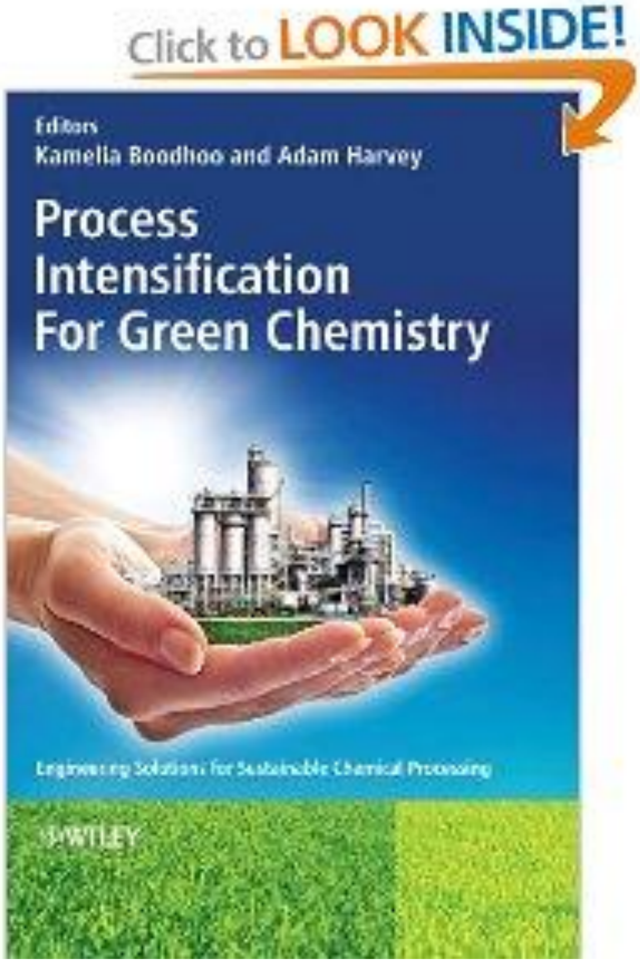
IChemE
PROCESS INTENSIFICATION
SECOND EDITION
ENGINEERING FOR EFFICIENCY, SUSTAINABILITY AND FLEXIBILITY
David Reay • Colin Ramshaw • Adam Harvey
B H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Editors
Kamelia Boodhoo and Adam Harvey
Process Intensification For Green Chemistry
WILEY

PIG Technologies

Technologies
Oscillatory Baffled Reactors (OBRs)
Spinning Disc Reactors (SDRs)
Rotating Packed Beds (RPBs)
Heat Pipes
Reactive Extraction (RE)
Non-thermal plasmas

“P.I.” Process Intensification

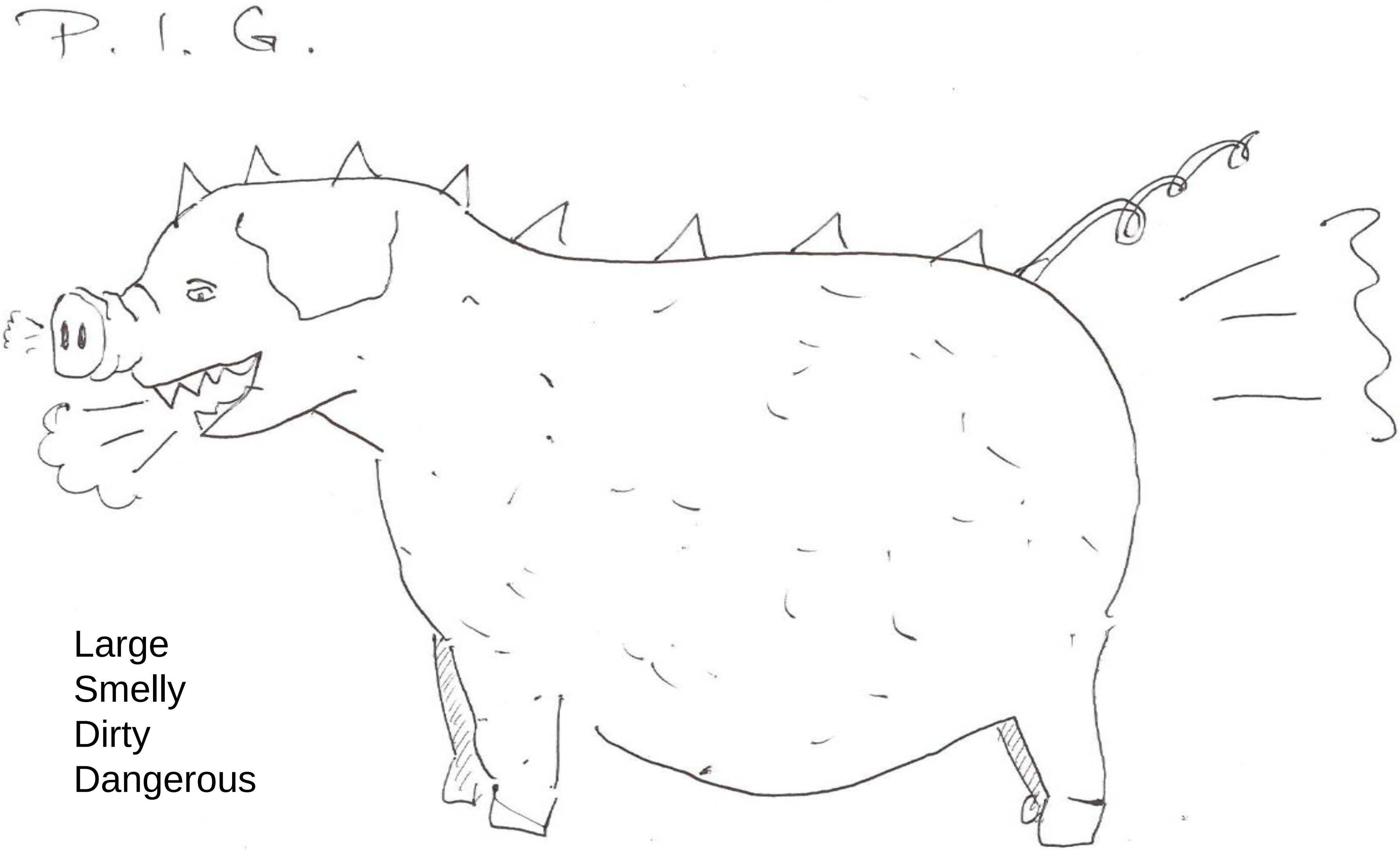
“The strategy of making dramatic* reductions in the size of process plant items by re-examining the fundamentals of their heat and mass transfer”

***at least an order of magnitude**

“A novel design approach where fundamental process needs and business considerations are analysed and innovative process technologies used to meet these optimally”

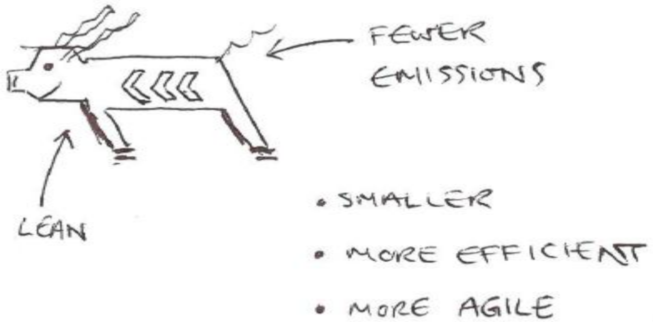
Safer, Cleaner, Smaller

Conventional Chemical Process
(NB: this is a metaphor)



Large
Smelly
Dirty
Dangerous

After



Smaller
Leaner
More efficient
Reduced Emissions

Concept

A significant reduction of the size of process equipment in a chemical plant (without affecting production target) means reductions in:

- **Pipework**
- **Footprint**
- **Civil engineering**

➔ reduced capital cost

Why use PI?

Business drivers	Process drivers	Environmental drivers
• Miniaturised plant • Reduced operating costs • Distributed manufacturing • Process flexibility • New product introduction • Speed to market	• Improved selectivity and product purity • Improved yield • Improved process safety • Wider processing conditions	• Reduced energy usage • Reduced waste • Reduced solvent use • Smaller plants less obtrusive on landscape
Responsive processing	Process improvement	Sustainable development

How is PI achieved?

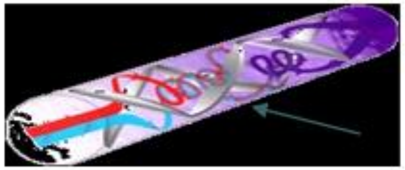
1. **Active Enhancement,** input of energy by various means:

    - Agitation
    - Vibration
    - Rotation
    - Ultrasound
    - Microwaves
    - Electric fields
    - Etc…

How is PI achieved?

2. Structural Enhancement:

- Fins
- Roughened surfaces
- Static mixers

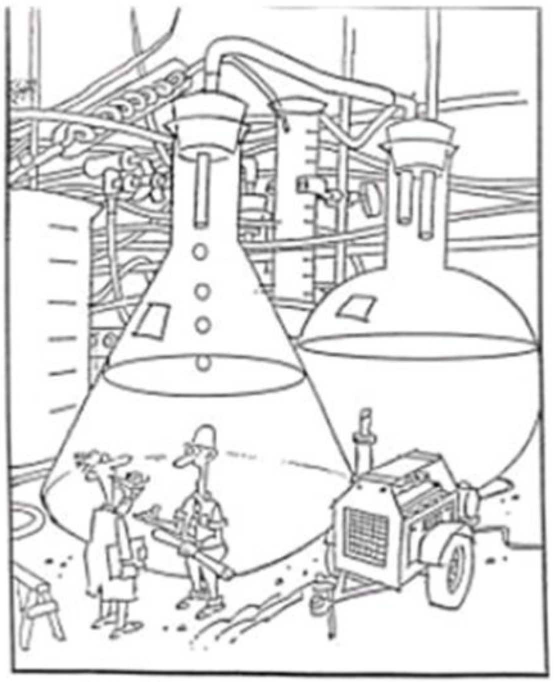


STATIC MIXERS

How is PI achieved?

3. Moving from batch to continuous processing

- Continuous operation equipment smaller in size than batch (lab scale may be closer to full scale)
- Reduced reactor inventory, hence safer operation
- Ability to vary conditions quickly, hence opportunity for rapid grade change
- Problems with scale-up of batch processes minimised



Got a few problems going from lab scale up to full scale commercial

How is PI achieved?

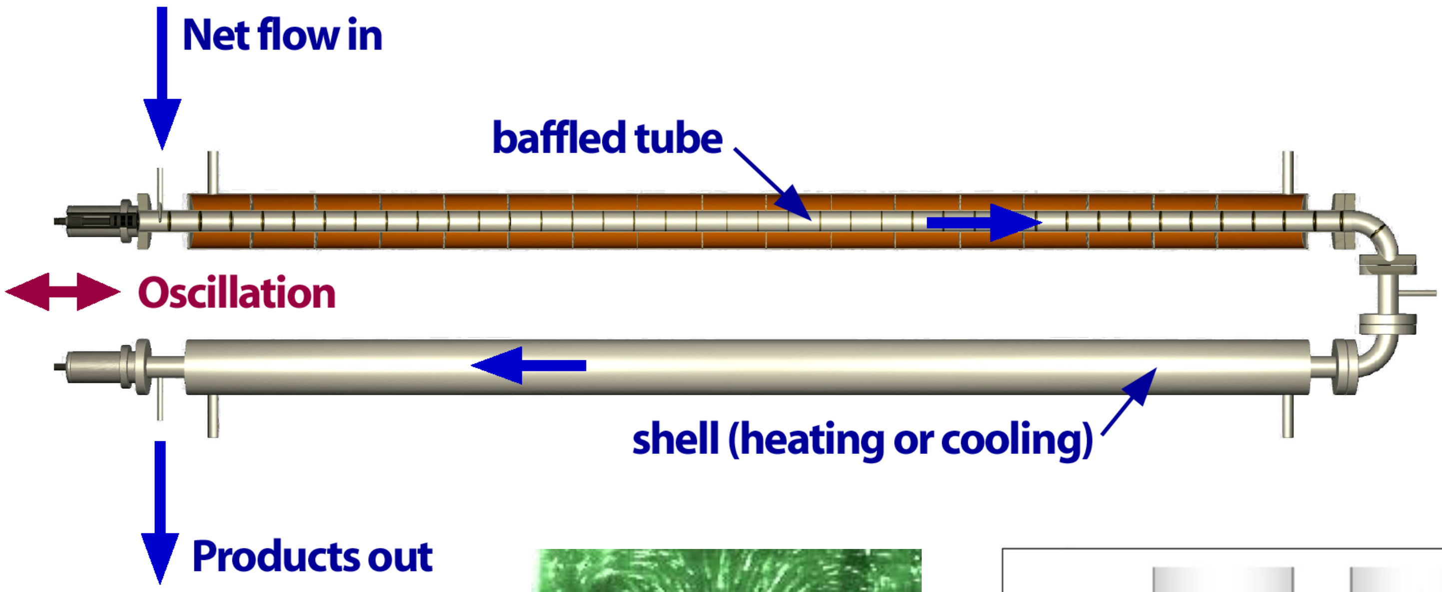
4. Hybridisation of Unit Operations

- Membrane reactors
- Reactive extraction
- Reactive Distillation
- Etc

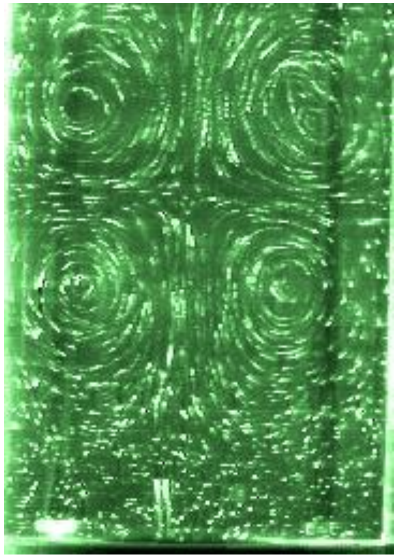
Example: Reactive Distillation

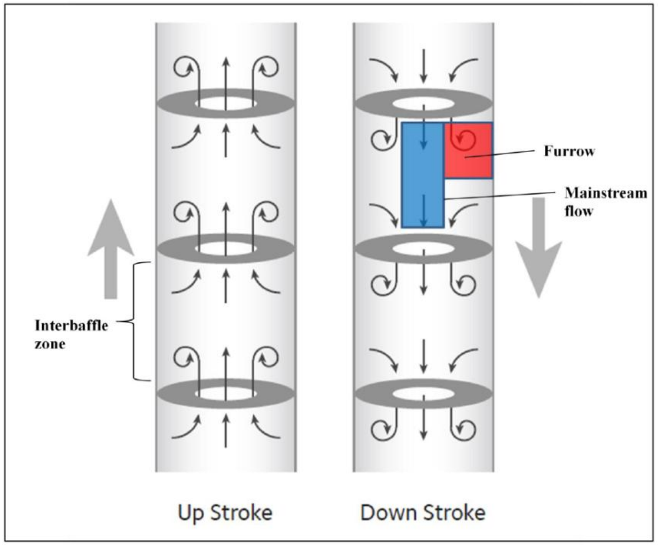
(Eastman Kodak) "successfully used reactive distillation to replace 11 distillation vessels (with associated condensers and reboilers), with just 3 RD vessels"

Case Study: A Saponification reaction in an Oscillatory Baffled Reactor



Achieves plug flow by tanks-in-series rather than net flow turbulence





OBR characteristics

Long residence times in a compact reactor, whilst maintaining plug flow and good two phase mixing.

Niche

BATCH → CONTINUOUS

For "long" processes

The Reaction

Hydrolysis of a naturally occurring mixture of alkyl and steryl stearates, using concentrated sodium hydroxide in an ethanol and water solvent.

- **75 m^3 Batch Reactor [50 m^3 fill]**
- **115 ^oC**
- **2h "reaction time" in a 24h batch cycle**
- **Molar ratio ~ 0.9**

Incentives for Change

1. SAFETY

2. Product quality

3. Energy savings

Experiments Conducted

Temperature fixed at 115 ºC

Molar ratios in the range 0.6 - 1.05

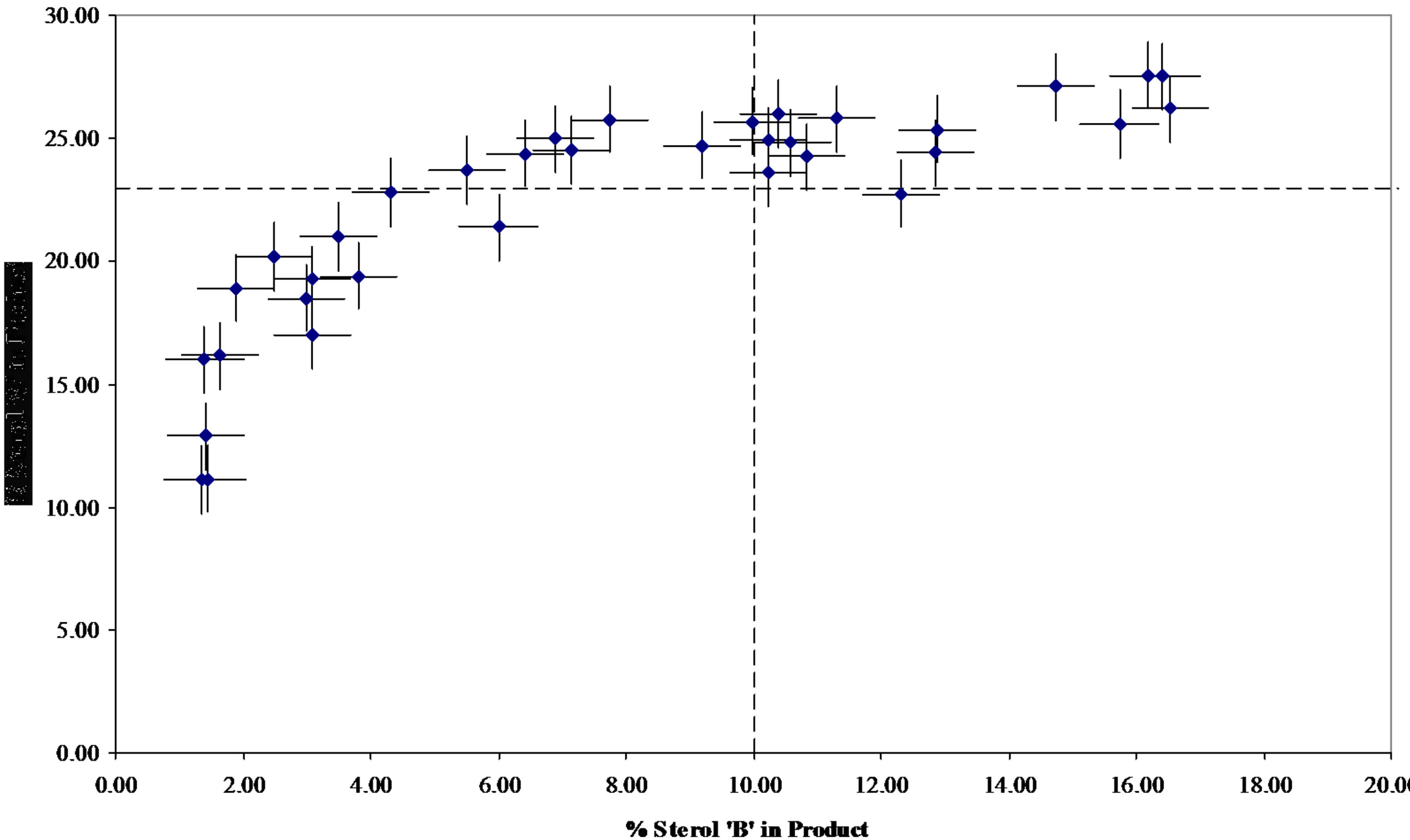
Residence times in the range 8 - 25 minutes

TARGET PRODUCT

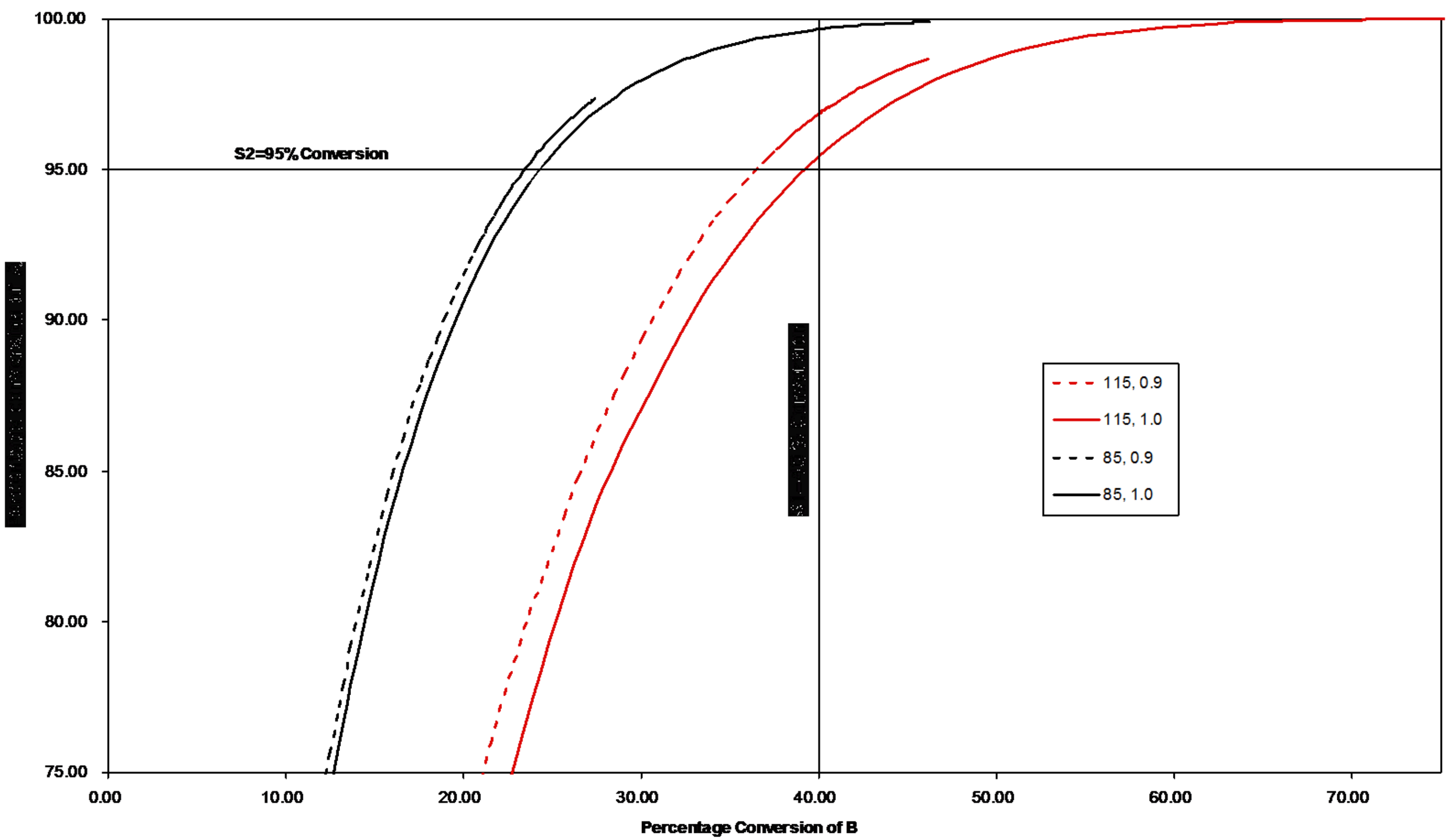
Desired product, sterol A > 23 %

Undesired product, sterol B < 10 %

Can it be done ?

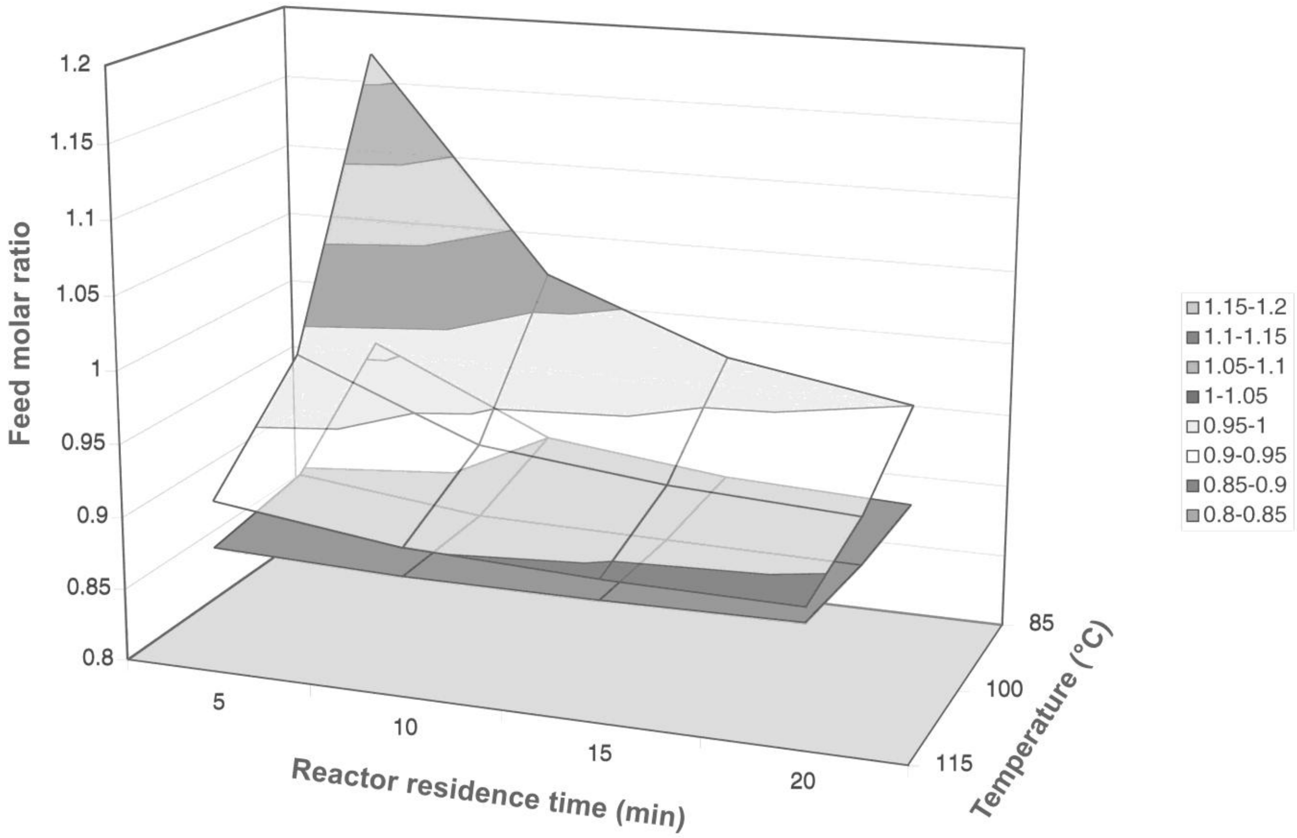


Effect of Temperature (modelling)

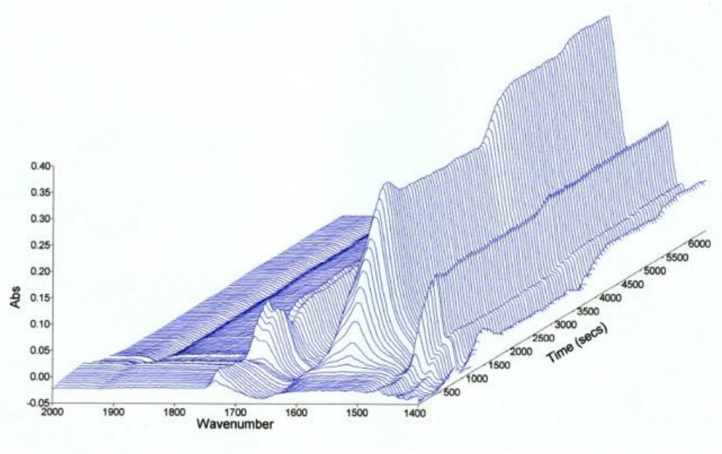


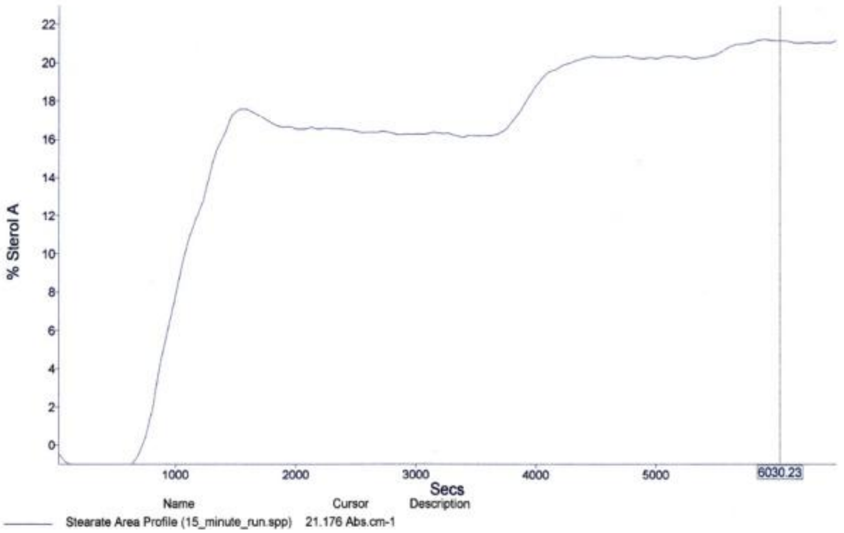
(+ the modelling wasvalidated by experiment!)

Operating Windows



Monitoring: FTIR ATR Cell





SUMMARY: OBR Saponification

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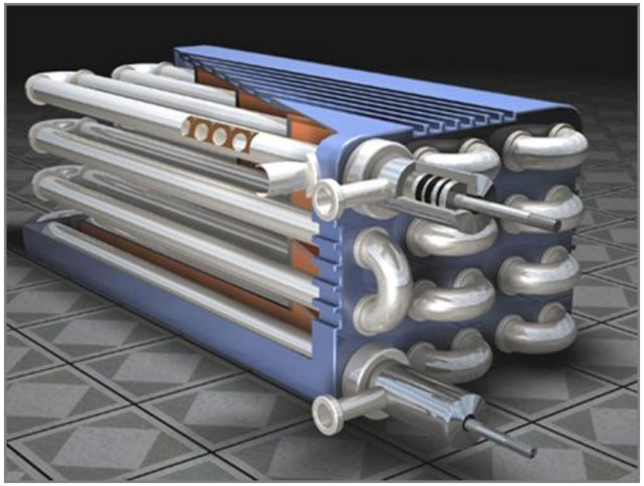
The OBR could be used to perform the reaction:

- ..at lower temperature (safer, reduced energy)
- ..with improved product quality
- ..more consistently
- ..in 1/10th the reaction time (inherent kinetics)
- ..in a reactor less than 1/100th the volume
- The product can be monitored online
- Operation is flexible (wide operating window)

Was the reactor built?

No!



- “Champion” made redundant
- No "risk takers“ remaining
- Lack of understanding (company dominated by chemists...)

Examples of PI technologies:
(i) Non-thermal Plasmas

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Plasmas can be "thermal" and "non-thermal".

Thermal Plasmas

$$T_e = T_N = T_{ion}$$

- The thermal plasmas are hot (**10,000 to 20,000K**);
- Ionization is due to electron collisions with preliminary excited hot atoms and molecules;

- **Not chemically selective**.

Arc Plasma, Plasma Torch

Non-thermal Plasmas

$$T_e >> T_N = T_{ion}$$

- The electron temperature is from **10,000 to 100,000K;**
- They operate **close to room temperature;**
- Ionization is mostly provided by electron collisions; with "cold" excited atoms and molecules;
- **Selective to chemical reactions**.

Corona, RF Plasma, DBD, Microwave plasma

CO_2 Decomposition in Non-thermal Plasma

$$e + CO_2 \longrightarrow CO + O + e \quad (1)$$

(CO_2 dissociation energy: 5.5 eV)

$$e + CO \longrightarrow C + O + e \quad (2)$$

(CO dissociation energy: 11.1 eV)

*DBD plasma cannot dissociate CO/CO_2 to C
Thermal plasma would require 700 ^{o}C

Examples of PI technologies …

(ii) The Rotating packed bed

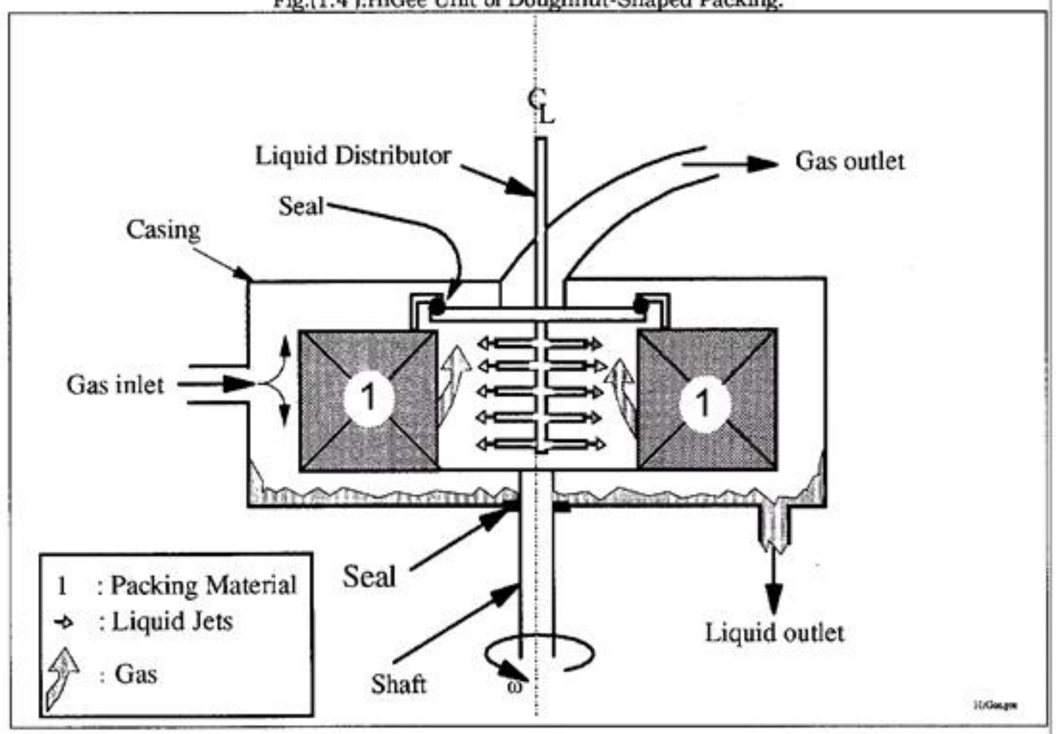
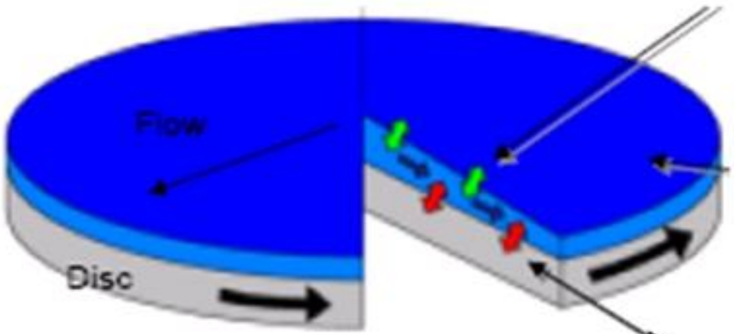
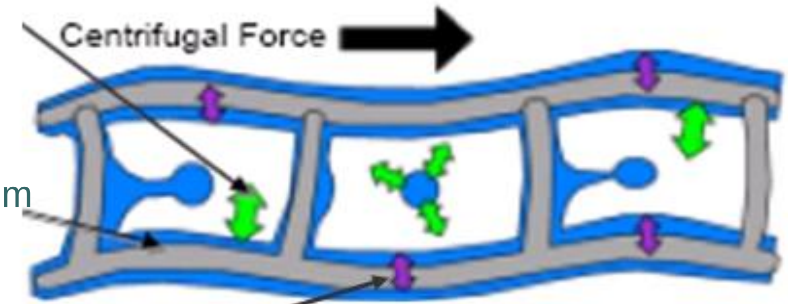


Fig.(1.4):HiGee Unit of Doughnut-Shaped Packing.

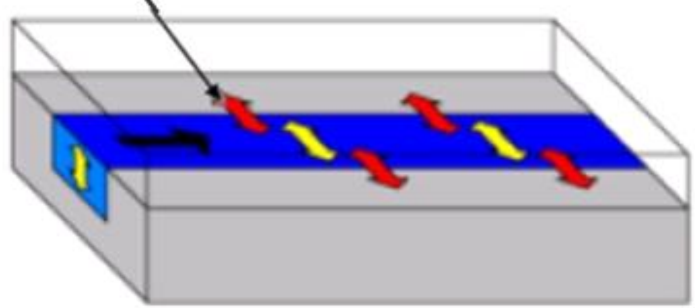
Examples of PI technology
(iii) Spinning Disc Reactor



Spinning disc reactor



Rotating packed bed



Microreactor, catalytic plate reactor

- Short path lengths for rapid molecular diffusion, hence enhanced mixing and mass transfer
- High surface area per unit volume for enhanced heat transfer, even on scale-up

Challenges to P.I.

- Industry conservatism
  - Novel field involves risks
    - Culture of “rushing to be second”?
- Finding the right information easily
  - Being aware it exists
  - Exemplars/Demonstrator units
- Step changes in equipment design and operation involved

Opportunities

- New industries
  - Biofuels?

- New areas?
  - Generic pharmaceuticals
  - Water
  - Food

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