A toilet system based on hydrothermal carbonization

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BILL & MELINDA GATES foundation

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FSM2

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WATER RESEARCH COMMISSION

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The rest of the Loughborough team

- Sohail Khan – WEDC
- Richard Holdich – Chemical Engineering
- Andrew Wheatley – Civil Engineering
- Diane Gyi – School of Design
- Eric Danso-Boateng – PhD student

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Outline

- RTTC
- HTC
- Chemical effects.
- Energy balance
- Batch versus CF
- Coatings
- Inclusive design

RTTC

- Call to develop new technology for handling and processing of human waste into useful products
- $0.05/user/day
- Process complete in ~24 hours
- Off grid
- Make the toilet a pleasant and safe experience

Meeting the challenge at Loughborough

- No one research group with required expertise
- Loughborough University has a mechanism for bringing together expertise across the university– Interdisciplinary Research Schools
- A team from across the university was put together to see if a useful bid could be put together.

Meeting the challenge

- Realistically liquid/solid separation will be difficult
- Aim for a system that works in liquid/solid mixtures
- Anaerobic digestion is too slow
  - Not easy to install in many locations
  - Effluent still needs to be dealt with
- Hydrothermal Carbonization?
  - Works for vegetation based biomass what about sewage?

Hydrothermal Carbonization

- Works via dehydration of carbohydrates:

$$C_6H_{12}O_6 \longrightarrow C_6H_6O_3 + 3H_2O \longrightarrow C_6H_2O + 5H_2O + \text{Energy}$$

- With biomass get other products:
  - Soluble/volatile organics, some gas
- Main product is a lignite like material – coal
- Key points:
  - Process works in water
  - Process is exothermic–creates own heat*

*~1MJ/mol

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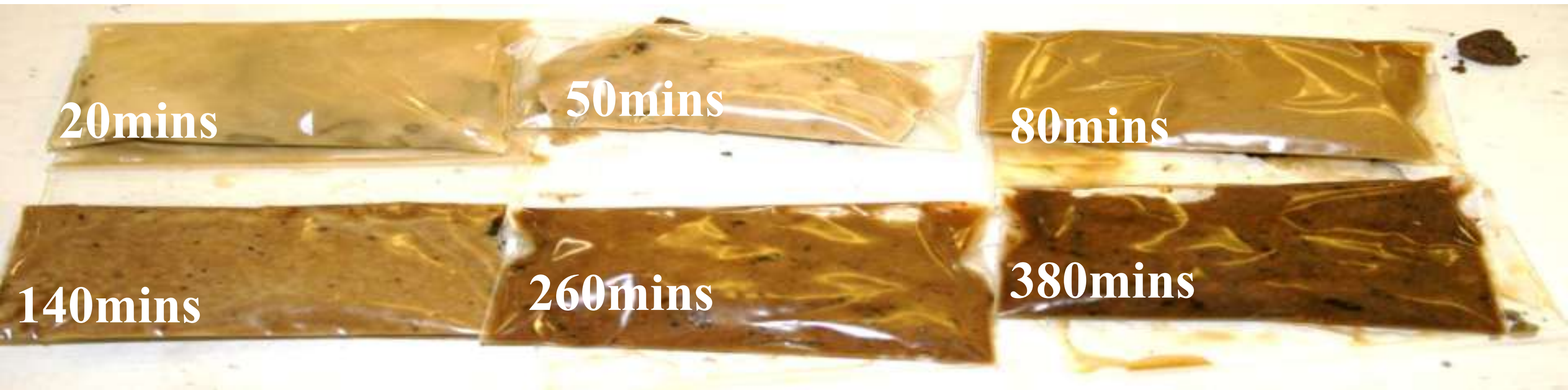
Understanding the process

- Simulant* and sludge from sewage works processed

- Batch based measurements
  - Solid loadings: 5-25% (by weight)
  - Temperatures: 140-200˚C
  - Conversion times: 0-6 hours

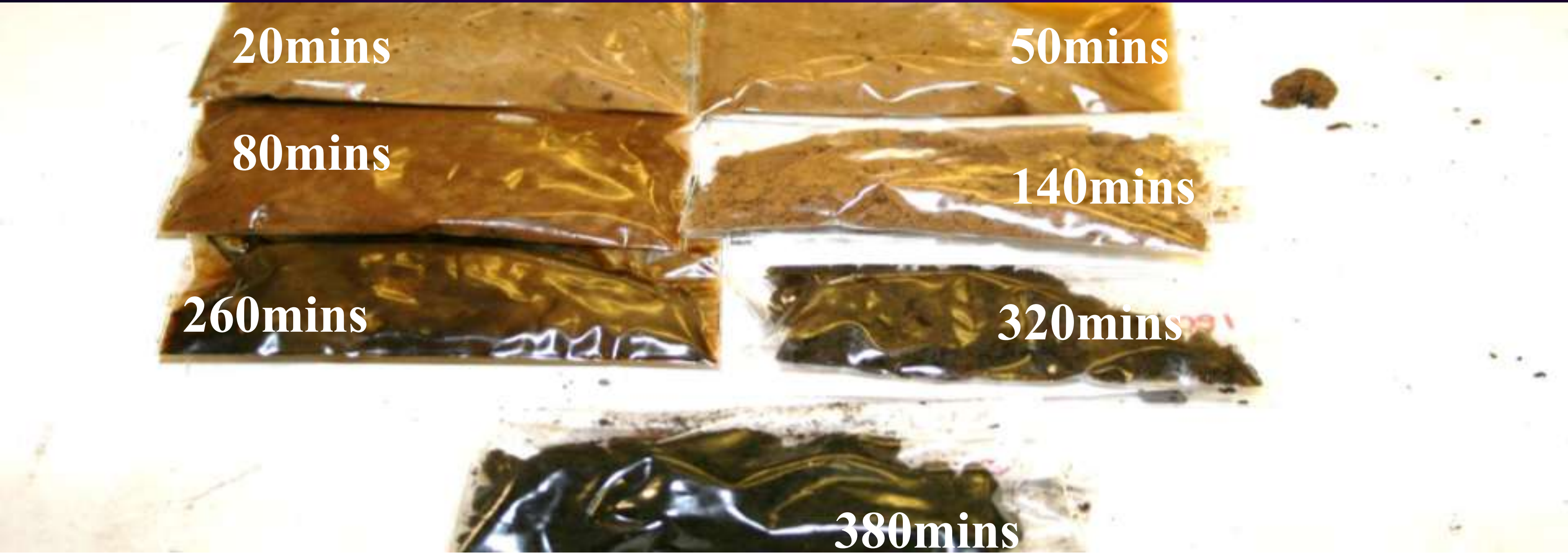
*Wignarajah et al (2006)

140° C



- **Maximum pressure = 7.5bar (Saturated pressure=2.6bar)**
- None of the experiments carbonised
- Some products became slightly darker
- Product cannot be filtered
- From 2 hours, water can be poured off as product and liquid in clear layers in vessel7

160° C

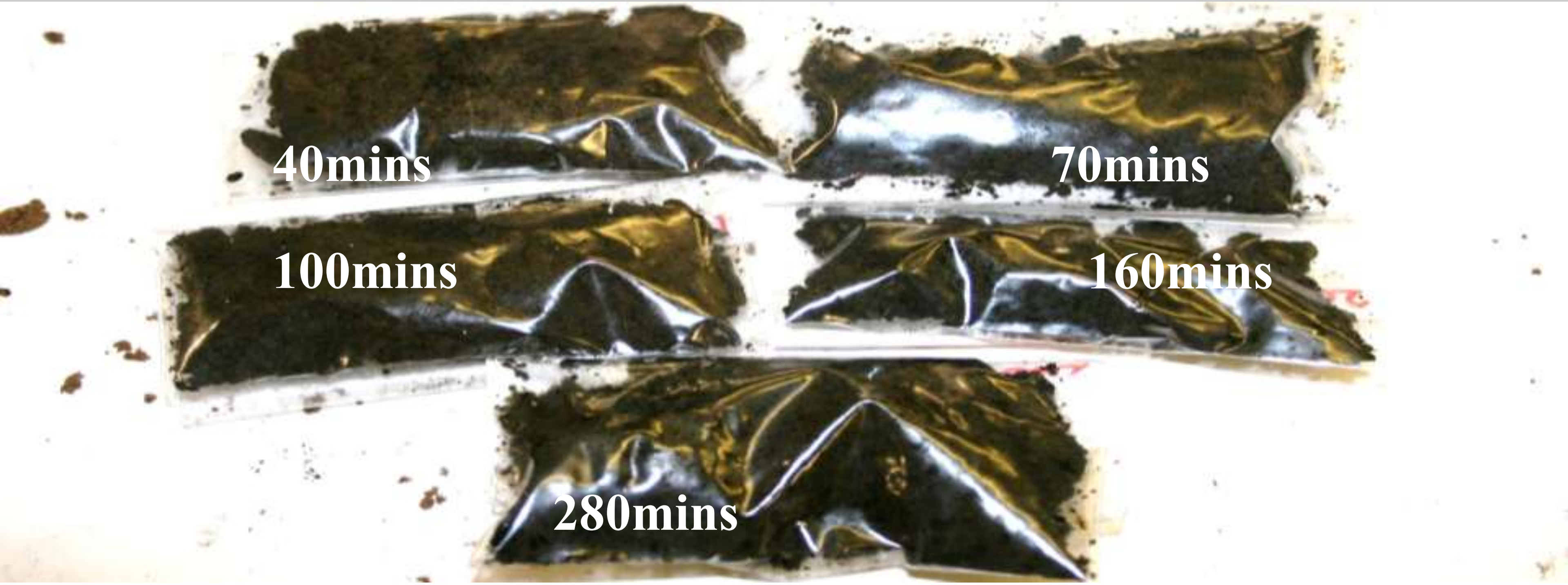


- OBSERVATIONS
- **Maximum pressure = 12bar (Saturated pressure=5.2bar)**
- Product carbonised after 6 hours
- Some products became slightly darker
- Carbonised product is easily filterable

180° C

- **Maximum pressure = 16bar (Saturated pressure=9bar)**
- Product fully carbonised from 2 hours
- No visible reaction immediately after heating
- Much darker after 30minutes, with black flecks starting to appear (initial stages of carbonisation)

200° C



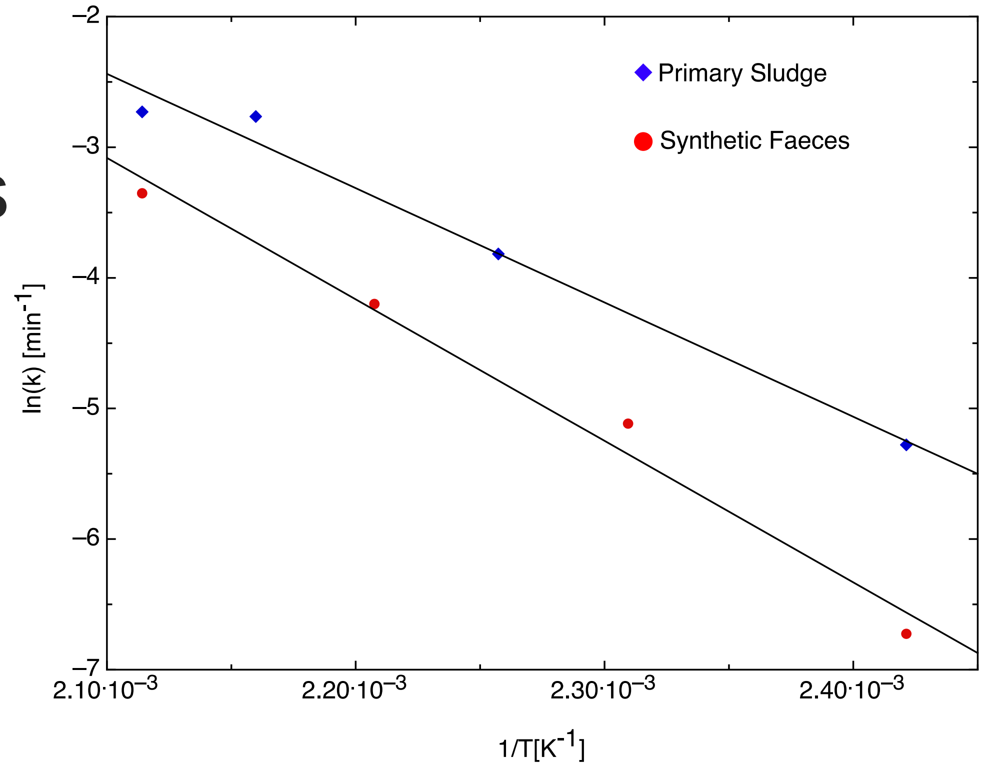
- **Maximum pressure = 20bar (Saturated pressure=14.5bar)**
- All products carbonised
- Slightly greater mass loss at longer times

HTC analysis

- Compared mass of char material to original mass of solids

$$m = m_0 \exp^{-k_B T}$$

- Use Arrhenius analysis:
  - Obtain rate constant and activation energy



Activation energies

Simulant: 90.0 kJmol^{-1}

Sludge: 72.7 kJmol^{-1}

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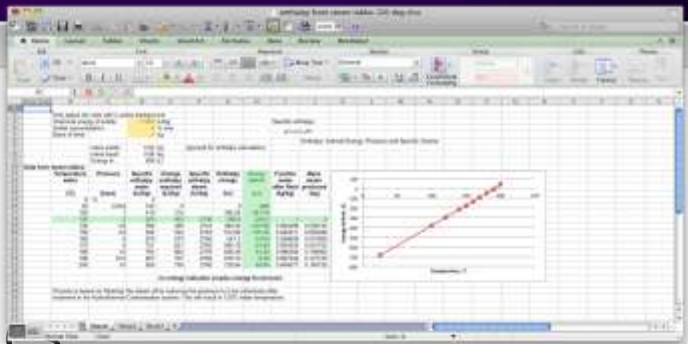
HTC analysis

- HTC works on synthetic faeces and primary sludge
- Other work has looked at C:H:O ratios – fits with observations
- Find that have sterile, easily filterable material after 15 minutes at 200˚C
- No need to go further – wastes energy

HTC analysis–the energy balance

- The process works in water ✔
- Water has a high heat capacity
  - It costs a lot of energy to heat the water to the required temperature ✗ ?
  - Weight for weight about 4X the energy for organic materials
- Is there enough energy in the char to drive the system?

Thermodynamics can help us

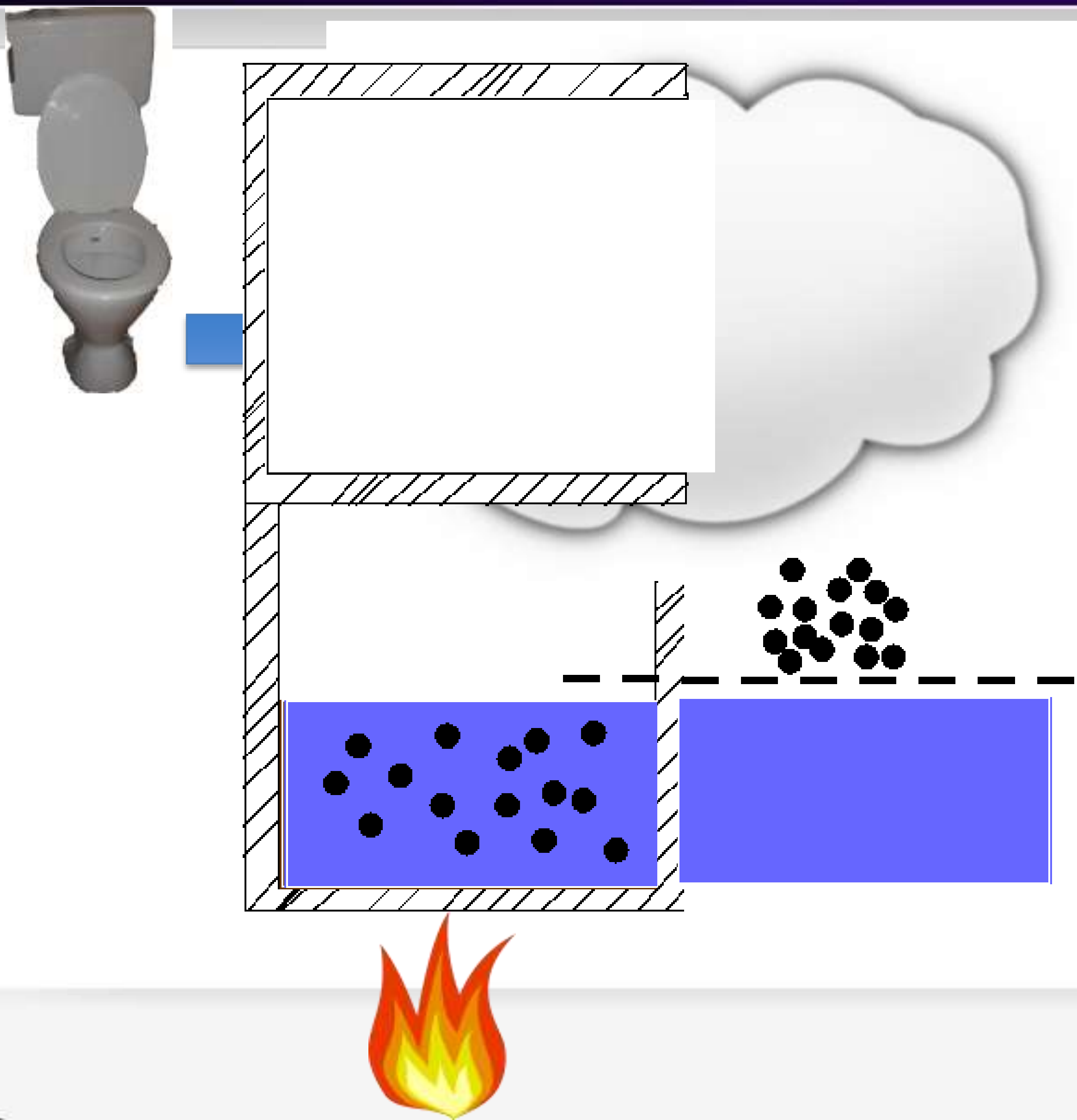


- We know:
  - heat capacities of water, most organics
  - Temperature change required
- Use spreadsheet to investigate breakeven conditions:
  - Investigate the effect of energy value of the solids and the concentration of the solution

Energy balance

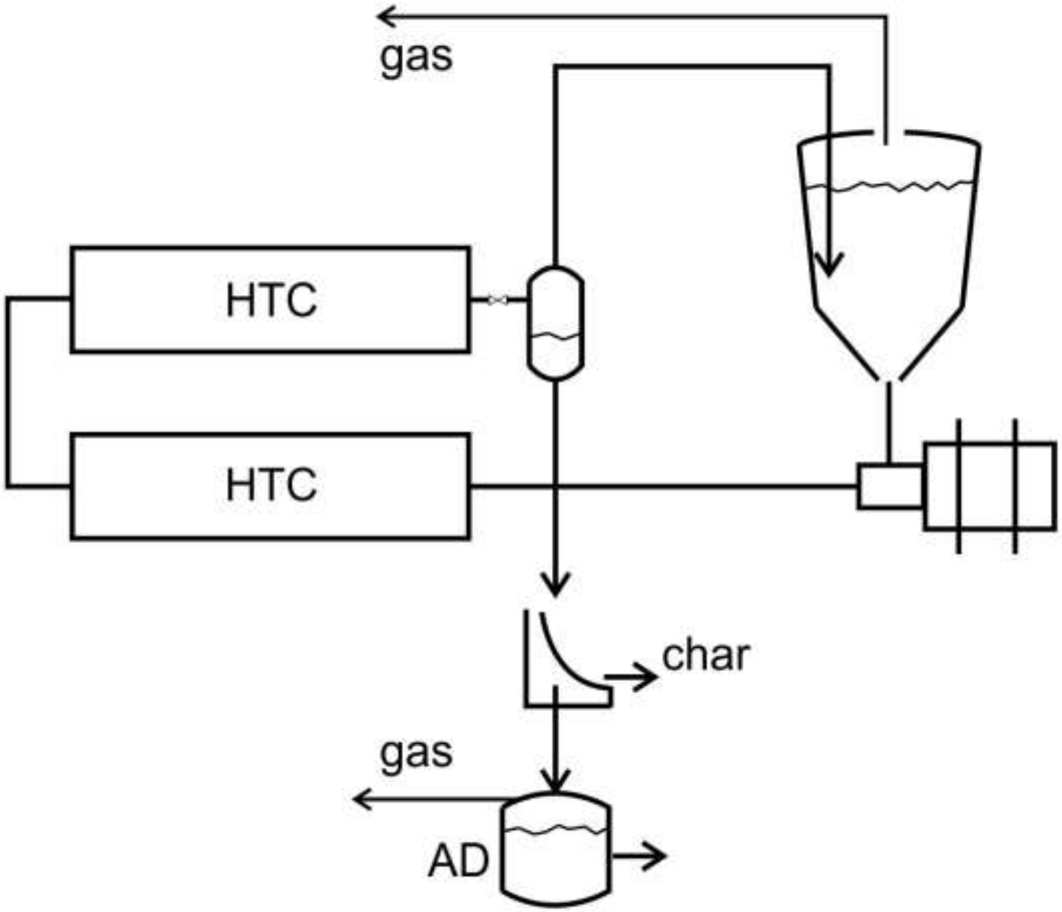
- For solids energy values ~17MJ/kg get excess energy at 5% solids and 200˚C
- For lower energy values have to move to higher solid concentrations
- Extreme case: 4MJ/kg➔16% solids
- The energy is there – will have to be careful with flush volumes

Initial concept – batch processing



1. Input raw materials
2. Seal/pressurize + heat
3. Release pressure
4. Separate

Our current concept–continuous flow



Use flash off steam to pre-heat material

Char solids easily separated by filter

Liquids processed by rapid AD (small molecules➔3-4 hours)

Reduced thermal cycling – extends lifetime

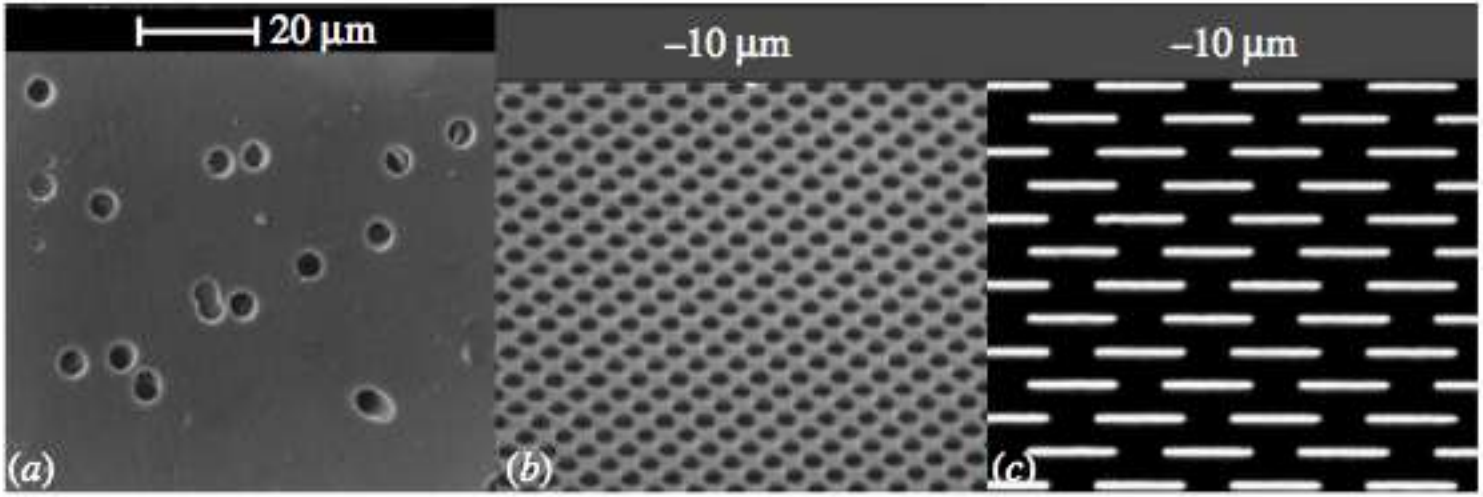
Ideally use gas as fuel – can adjust output ratios via temperature/pressure

CF HTC system

- Products are sterile
- Some of the water can be used for flushing
- Generates own fuel–off grid
- Once up to heat can be close to self-sustaining
  - Need to make sure that heat is recycled
- Hydro char can:
  - Supplement fuel supply
  - Be used as soil conditioner
  - Be used as fuel for cooking/heating

Filtration

- Use microslot filter:



- Operates much better than circular filter holes
- Optimize aspect ratio for application
- Low clogging

Holdich et al., Philo. Trans 2006 (1834) 161.

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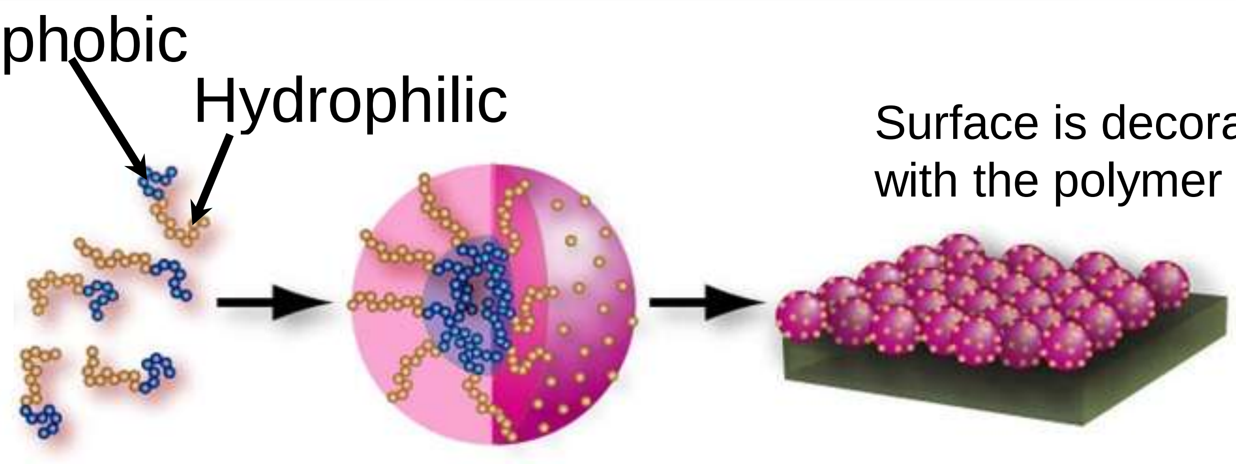
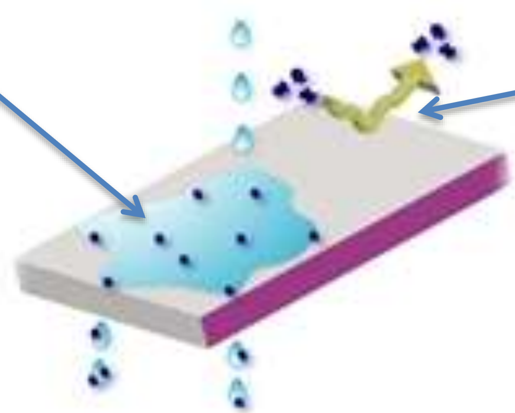
Chamelic layers–block copolymers



Surface is decorated with the polymer

In water - forms micelles



The polymer causes water to spread out on the surface washing dirt away

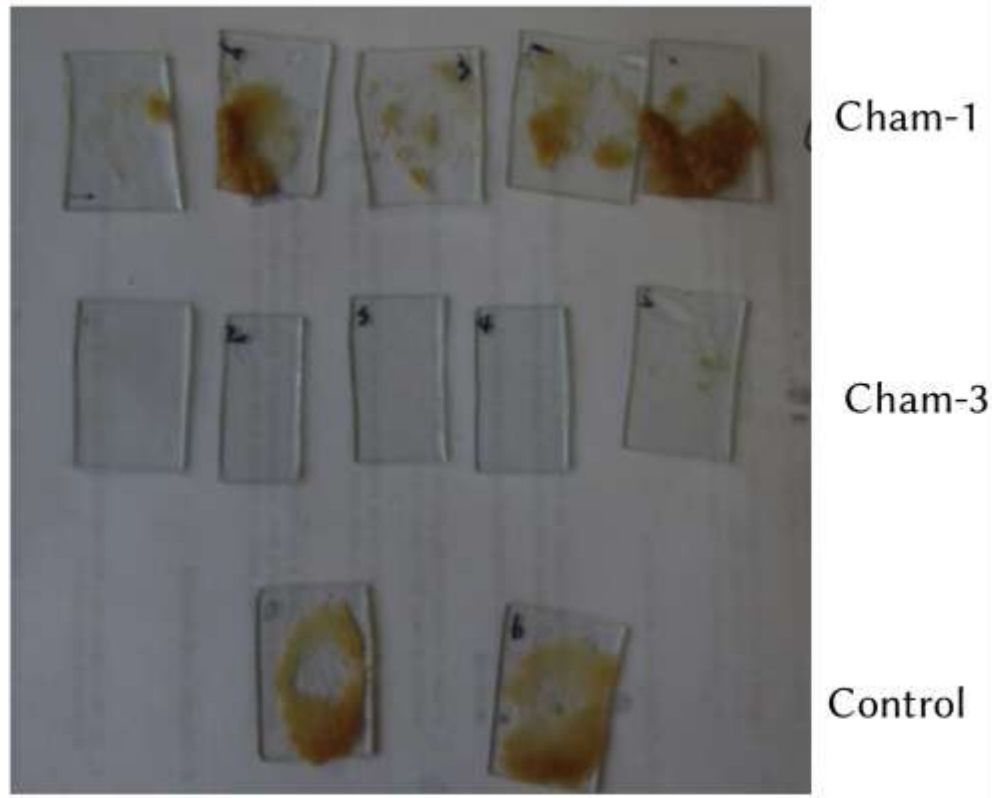
When dry the charges on the polymer repel dust

Responsive layers – results

Flush samples with water at flow rates similar to toilet flush

Before

After



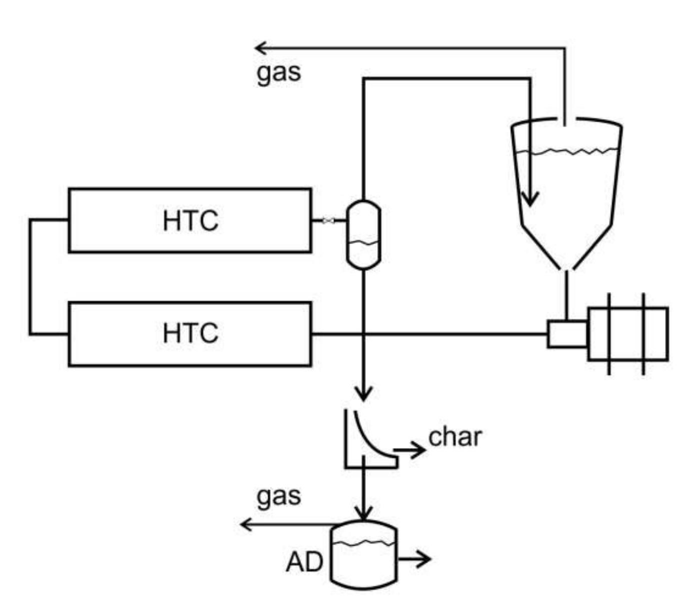
Design–the "User interface"

- Design research and development underway
- Inclusive design principles at heart of process
  - User engagement paramount – age, gender, culture, education, local sanitation behaviours
  - Primary and secondary users
- Solutions to the 'design challenges' explored
  - specification, prototyping and testing of full mock-ups

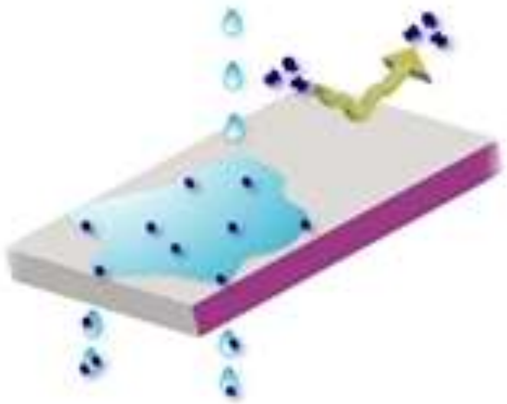
Water treatment

- Some water will be used for flush
- The remaining water is sterile
- Intend to use electrochemical treatment to further purify.

Conclusions



- HTC is a viable route to processing human waste
- Water:solid ratio is very important
  - Responsive layers can help
- Inclusive design principles being used to develop “human interface”



Thank you – Any questions?

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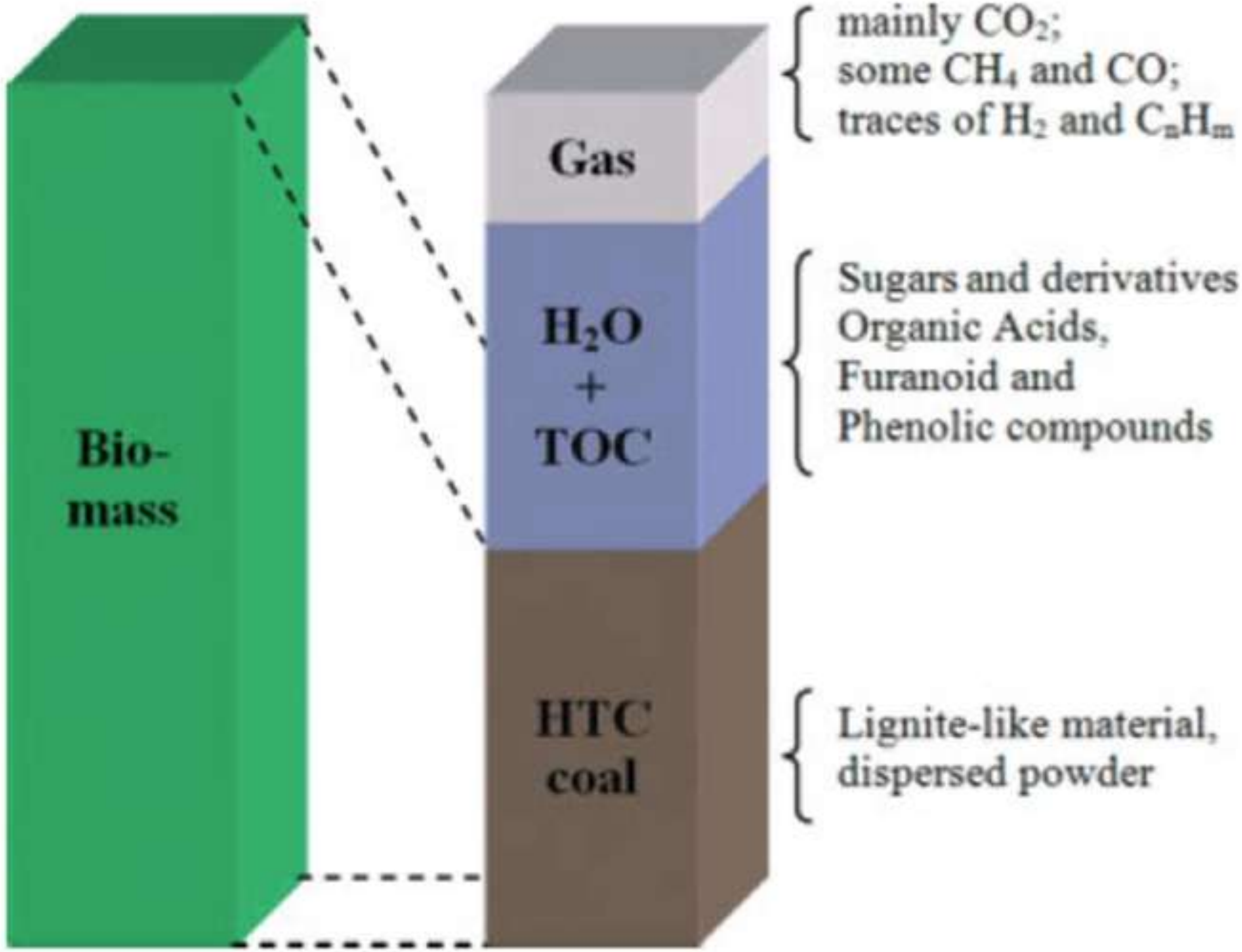
Products of HTC



Funke et al. 2010

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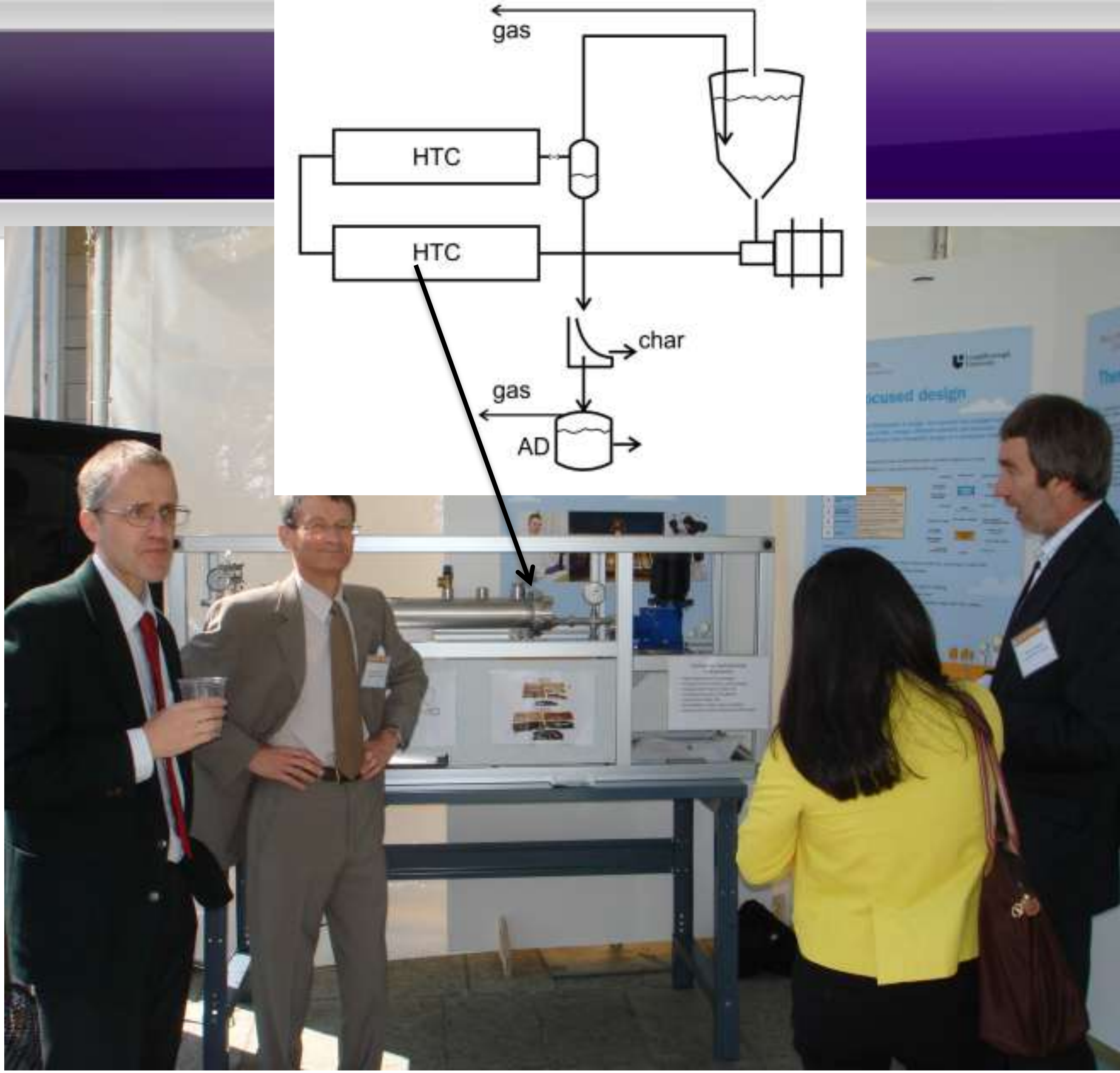
gas
HTC
HTC
char
gas
AD