COMSOL CONFERENCE ROTTERDAM 2013

Modeling of energy efficient continuous sterilisation of animal by-products (ABP) from food waste

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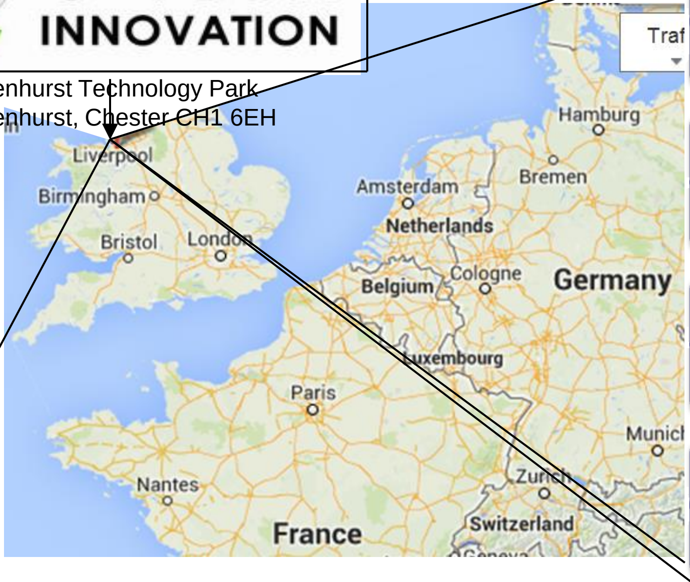

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- ✓Business Innovation
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- ✓Monitoring and sensors
- ✓Novel processing
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Ohmic heating –an introduction

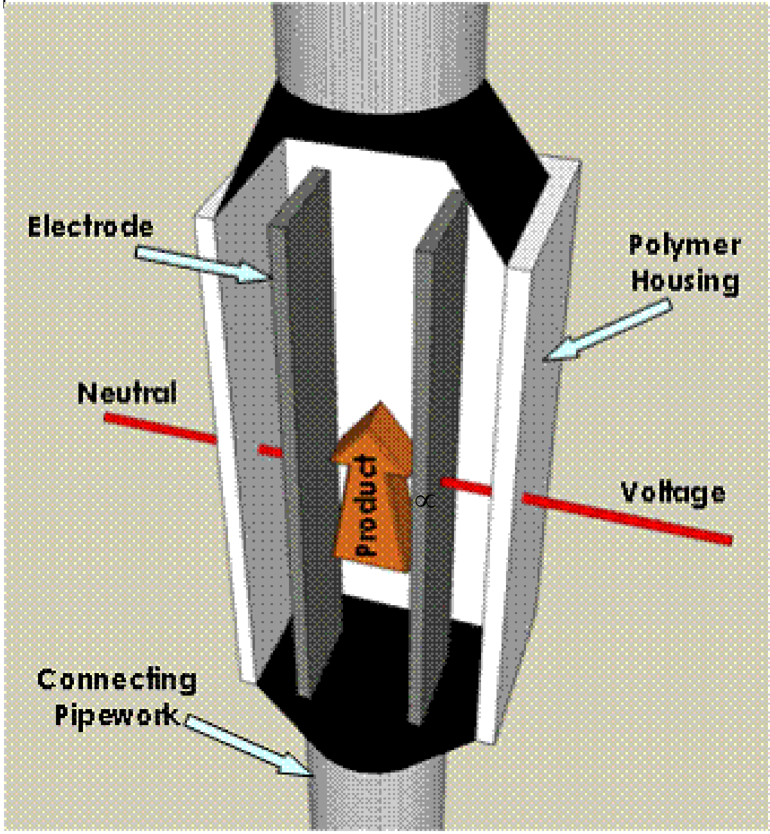


Fig. Diagramatic representation of a generic ohmic heater

1) AC Voltage applied across the product by electrodes
2) Current passes through the conductive path of the product
3) Heating occurs within the product with a power density of
   power=electrical conductivity *Electric field^2

Thus expect power density to be dependent on
▪voltage applied
▪Geometry of electrodes (plates)
▪Electrical conductivity of product

With the advantages of the heating being:
✓Highly responsive
✓ Volumetric
✓Efficient
✓Located in the product rather than the electrodes= clean system maintenance

✓Ohmic heating was first developed as a viable processing option (for food processing) by ECRC (now C-Tech) in the 1980’s

C-Tech Innovation were required to perform a feasibility study of an ohmic heater for the purpose of sterilisation of animal by-products (ABP).

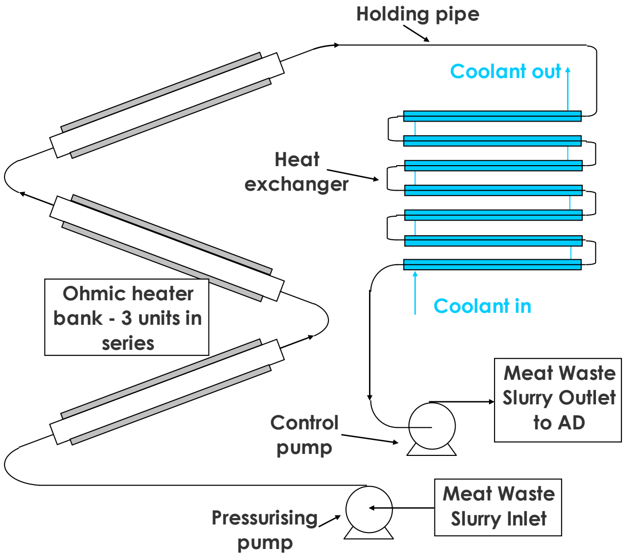


Fig. Process flow sheet of ohmic heating process.

Fig. Ohmic Heater Pilot Equipment

There are numerous components which make this a challenge to model:

1) **ABP is highly viscous** and so laminar flow (with velocity tending to zero at the walls) is expected. How will this affect the velocity and therefore the temperature distribution?
2) **ABP is inhomogeneous**, including fat, meat and bone with differing electrical conductivity, specific heat capacity and density. How will this affect the temperature distribution?
3) Heat flow through conduction will depend upon thermal conductivity, and **time history** of surrounding materials.
4) C-Tech Innovation in house trial data showed ABP to have an **electrical conductivity which increases approximately linearly with temperature**. Thus positive feedback (thermal runaway) effects are expected too.
5) **Non uniformity of field is expected near the electrode edges** and commands rigorous electromagnetic modeling
6) The entirety of the ABP is required to be held at **>150 Celsius at the outflow**. Will heat flow allow the non-uniform temperature distribution to sufficiently equalise by the outflow?
7) The proposed ohmic heater has three square cross section heating sections and intermediary circular cross section piping. But will the intermediary piping be of sufficient length for adequate temperature equilibration? And will the change between square and circular cross sections cause problems?

General Approach

“Simplify” 1 Simplify geometry, simplify material properties, simplify boundary conditions, use DC throughout

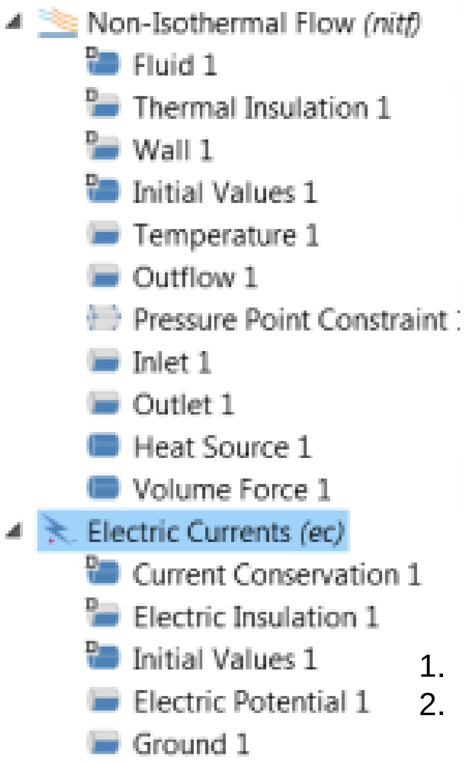
“Isolate” 2 Solve for physics modules independently

“Recycle” 3 Harvest results of all investigation and use them to adapt the approach

“Integrate” 4 Solve simultaneously for non-isothermal flow and electric currents

“Evolve” 5 Evolve the model towards the required complexity with the full CAD geometry, temperature dependent properties and boundary conditions where appropriate

Dynamic study – involving ABP taken as homogeneous



- Non-Isothermal Flow *(nitf)*
  - Fluid 1
  - Thermal Insulation 1
  - Wall 1
  - Initial Values 1
  - Temperature 1
  - Outflow 1
  - Pressure Point Constraint
  - Inlet 1
  - Outlet 1
  - Heat Source 1
  - Volume Force 1
- Electric Currents *(ec)*
  - Current Conservation 1
  - Electric Insulation 1
  - Initial Values 1
  - Electric Potential 1
  - Ground 1

Fig. Modules used for the Multiphysics approach

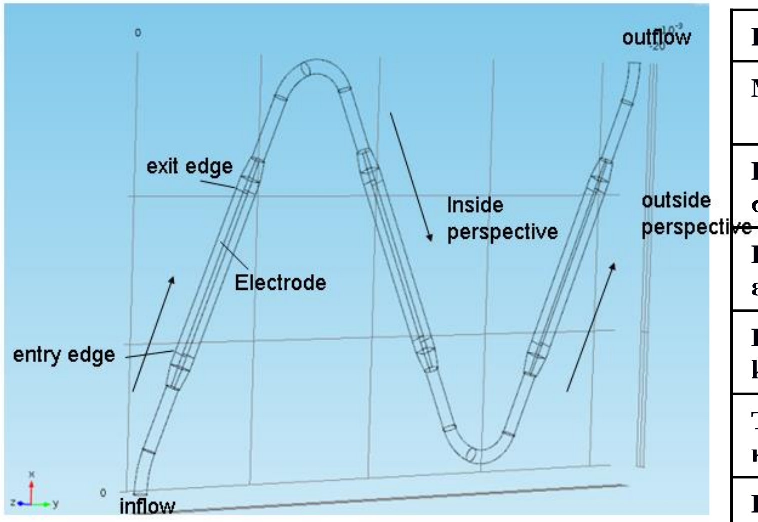


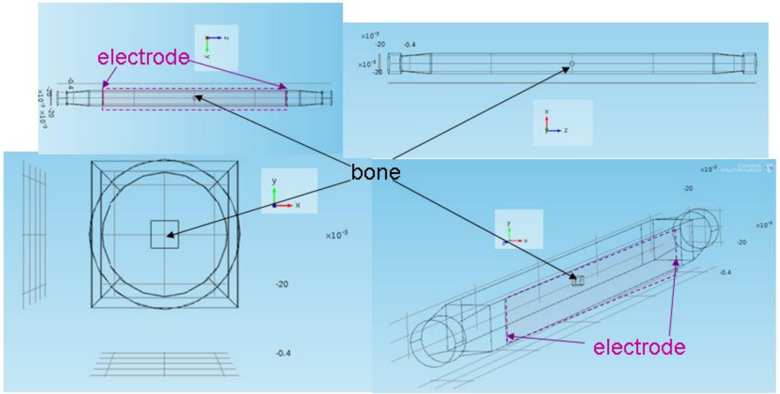
Fig. CAD model of proposed design

Feature of model	Combined fluid
Material	Macerated raw chicken, bones and offal
Electrical conductivity σ(S/m)	**0.07+(0.01*T(degC)-25)**
Dielectric constant $\varepsilon`_r$	**66**
Density kg/m^3	**1050**
Thermal conductivity κ(Wm^{-1}K^{-1})	**0.5**
Heat capacity C(JK^{-1})	**3500**

Table. Material properties

1. “Import” CAD imported of single heater and complete triple heater design
2. “Simplify” model for preliminary investigation. Take ABP as homogeneous in dynamic model. consider the ABP as a single material with properties averaged across the constituents
3. “Model conditions”
   - ➢ Set the inlet at room temperature and the walls as thermally insulated
   - ➢ Employ laminar flow analysis, set flow rate 100kg/hour, set outlet zero.
4. “Temperature dependence” incorporate the temperature dependence of electrical conductivity from in house trial data
5. “Fine tune” The applied voltage was adjusted until the average temperature at the outflow was ~190 Celsius

Static study – involving a bone cube within the ABP



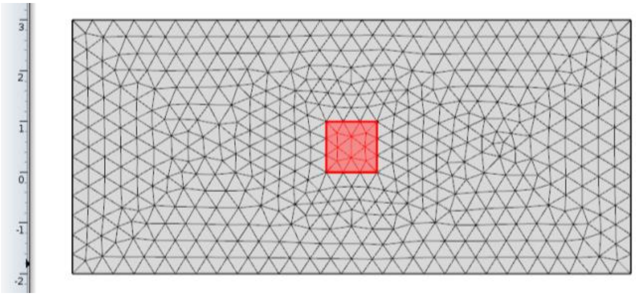
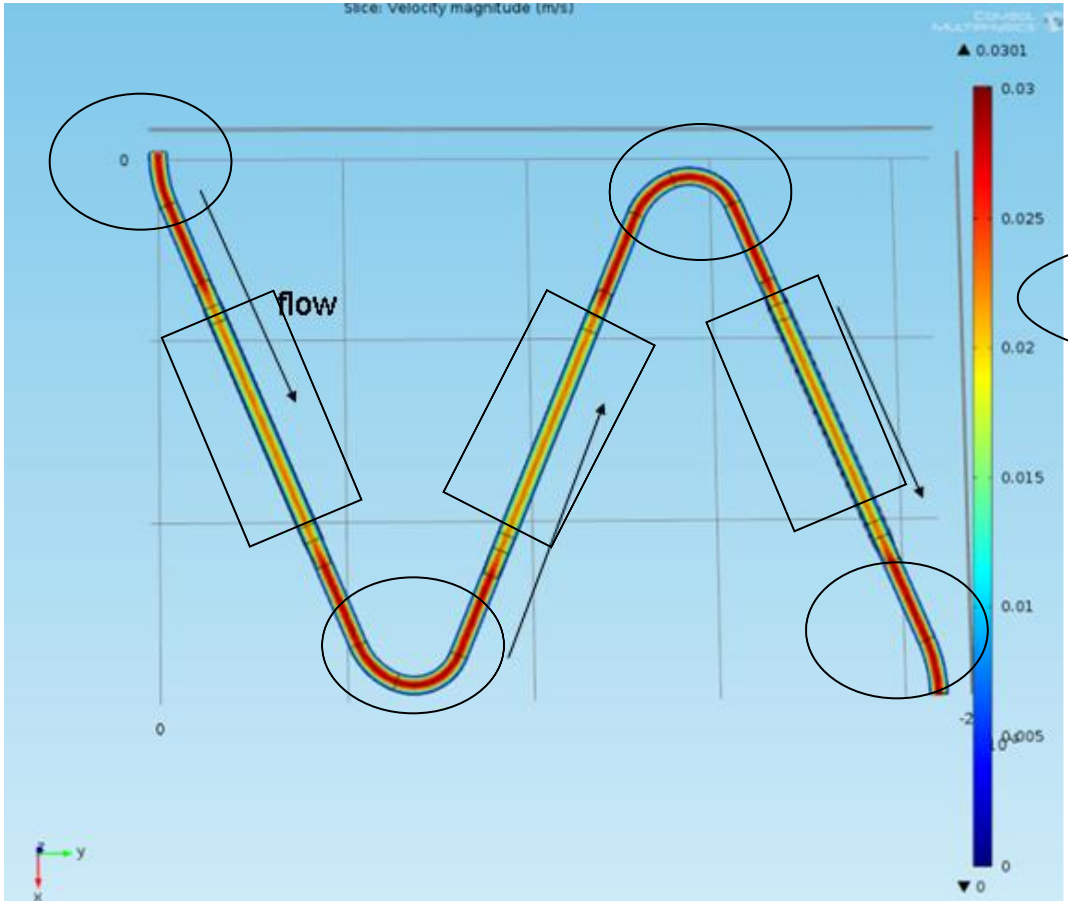


Fig. 2D model for static parametric sweep study

Fig. CAD model of single heater section with bone cube constructed in COMSOL

1. “Preliminary” observe flow velocities expected. (the flow rate of the system is taken to be 100kg/hr which for a 5cm by 5cm square cross section corresponds to ~1cm/sec.)
2. “Treat as static” perform static modeling of cubes with reduced electrical conductivity
3. “Treat cube as non-ohmic” Because preliminary results suggested that little ohmic heating would occur directly within cubes of reduced electrical conductivity, we proceeded with the model from the perspective of conductive heating from the surrounding ABP
4. “Parameter sweep” perform parameter sweep with variation in cube size to observe heat flow effects

Slice of velocity distribution of full model



The speed is quickest in the centre of the circular equilibration pipelines

The speed at the centre of the square cross section heater sections is reduced in comparison to the equilibration sections

Fig. Complete model with velocity distribution shown from a slice through the pipeline axis

Cross sectional velocity profile within heater section

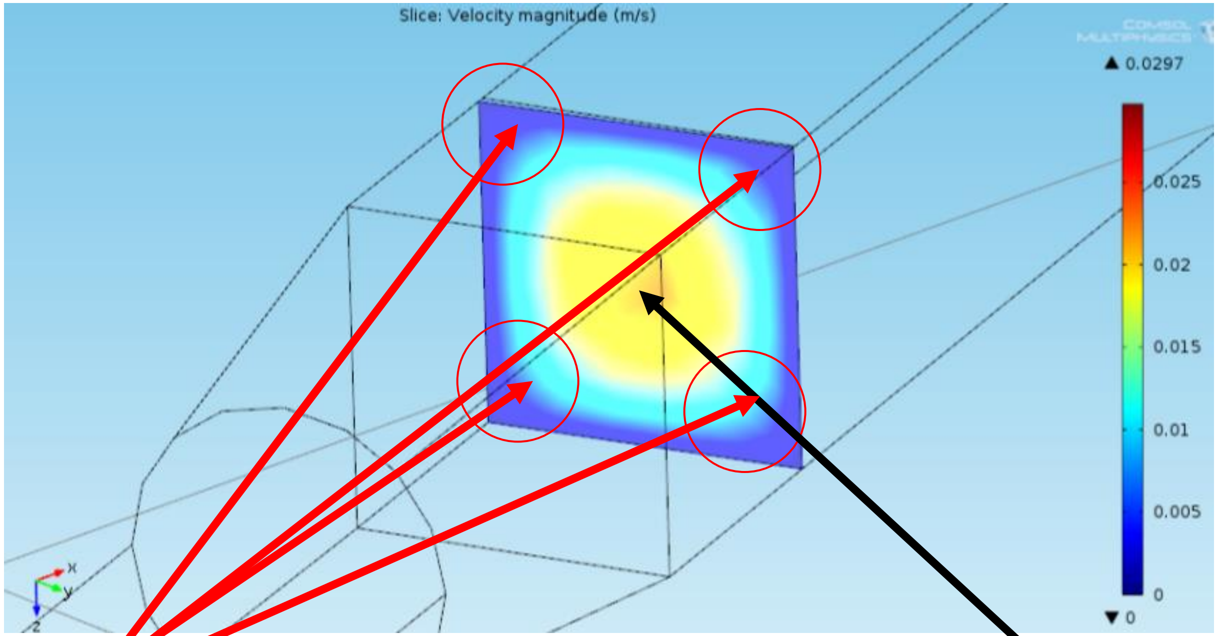


Fig. Cross section of velocity in heater

Very slow moving regions of significant size in corners of square heater cross section

An increased flow velocity in the centre of the piping in comparison to the flow velocity closer to the walls.

- Slow velocity will contribute to overheating particularly in the corners of the cross section. Suggested modification to make heater cross section circular
- Peak velocity in centre of cross section, typical of laminar flow. Peak velocity can be reduced by increasing the heater cross section (as is the case in the proposed model). In general we must be careful that the equilibration phases are long enough to account for reduced heating of the central product.

Isosurface temperature profile at final heater section

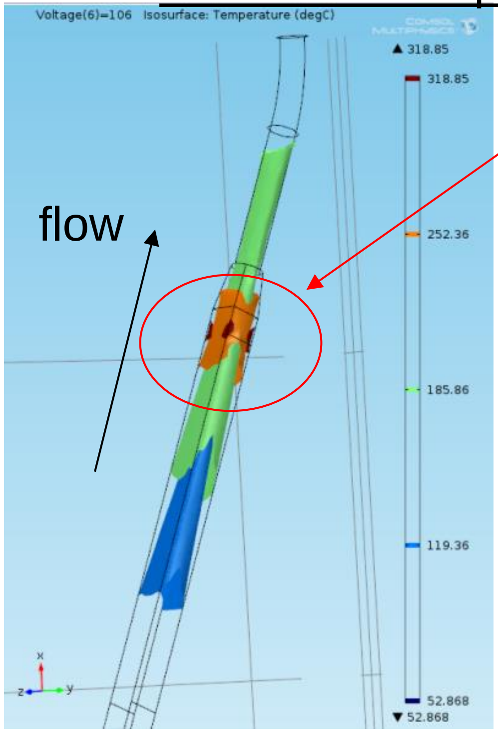


Fig. Temperature distribution expected at final heater exit

Very extreme overheating expected at final heater exit.

Combination of

1. Increased electric field at electrode edges (particularly at electrode corners)
2. Positive feedback of elevated temerature in turn elevating electrical conductivity
3. Slow regions of fluid flow in the corners of the square heater cross section

Peaks correspond to electrode corners

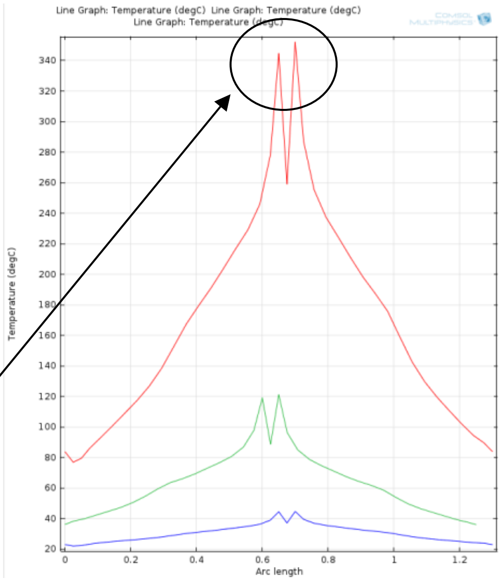


Fig. Temperature along electrode edges. Red final heater, green second heater, blue initial heater

The results suggest future work should aim to:

1. Reduce field intensity by rounding of electrodes
2. Reduce regions of slow flow by opting for circular cross section within the heaters

Temperature within the pipeline centre

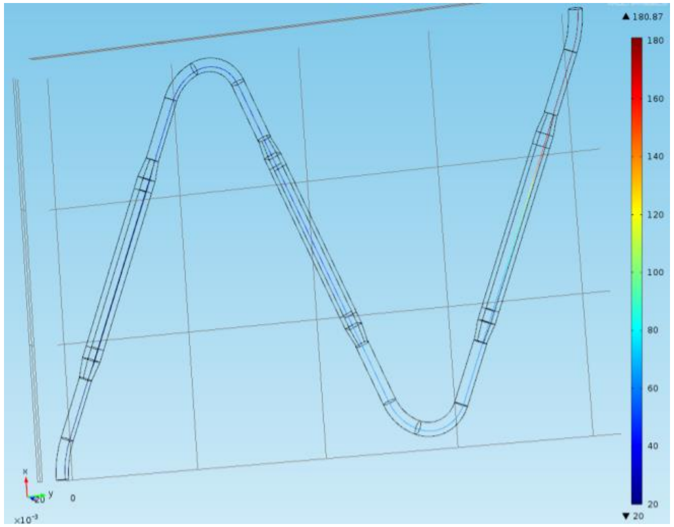
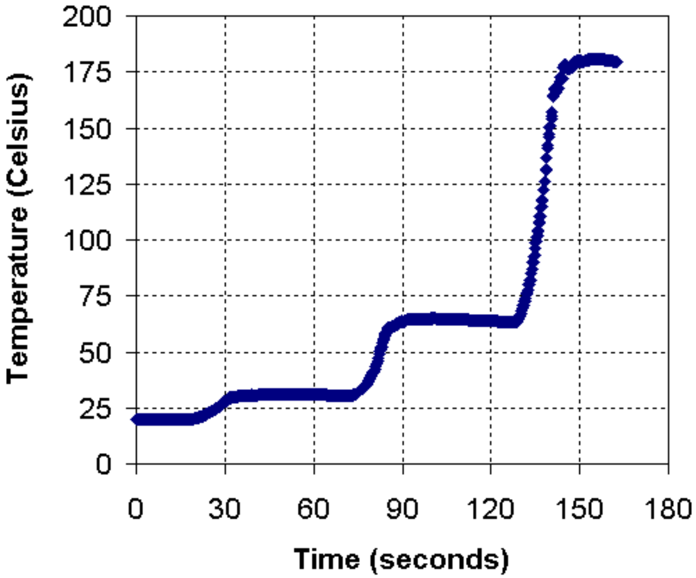
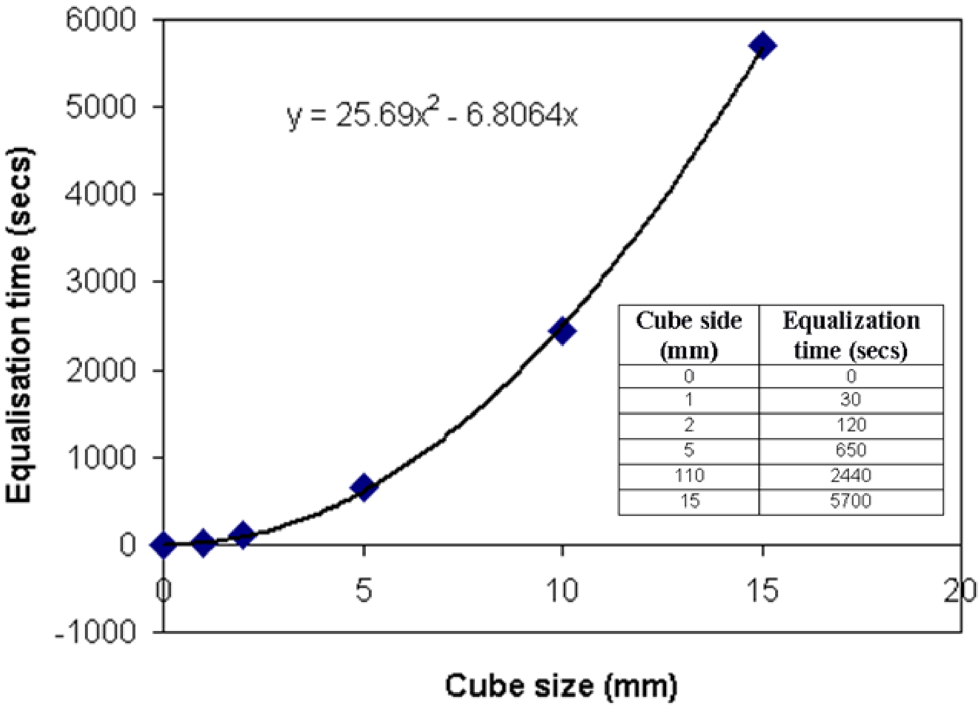


Fig. Spatial distribution expected of ABP passing down the pipeline centre



- ➢The dominant temperature elevation is expected to occur in the final heater section. This is attributed to the strong linear increase of electrical conductivity with temperature.

Effects of particle size on equilibration time



Cube side (mm)	Equalization time (secs)
0	0
1	30
2	120
5	650
110	2440
15	5700

Fig. Dependence of equilibration time on cube size

- ➢The equilibration time is expected to be highly dependent on fragment size
- ➢For a particle size of 1cm diameter which is practicle, the equilbratioin time is expected to be of the order of a few minutes which is practical within the design

Variation in electric field

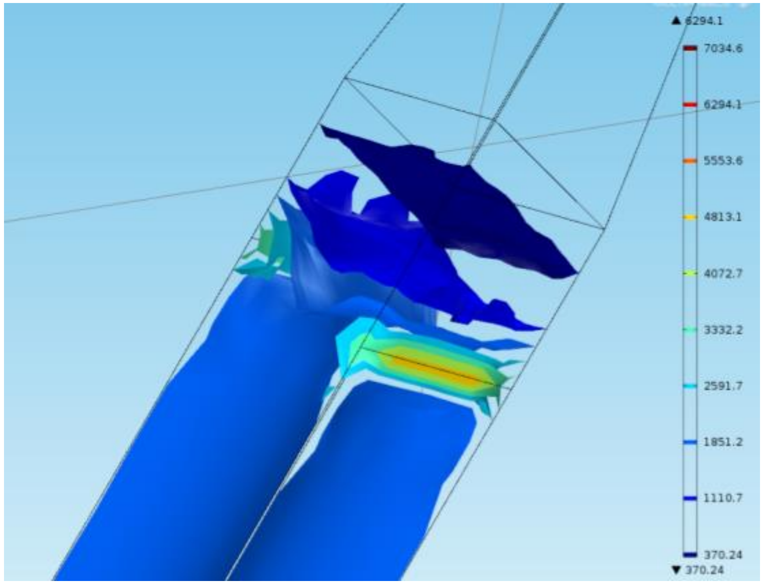


Fig. Spatial distribution of electric field at exit of final heater

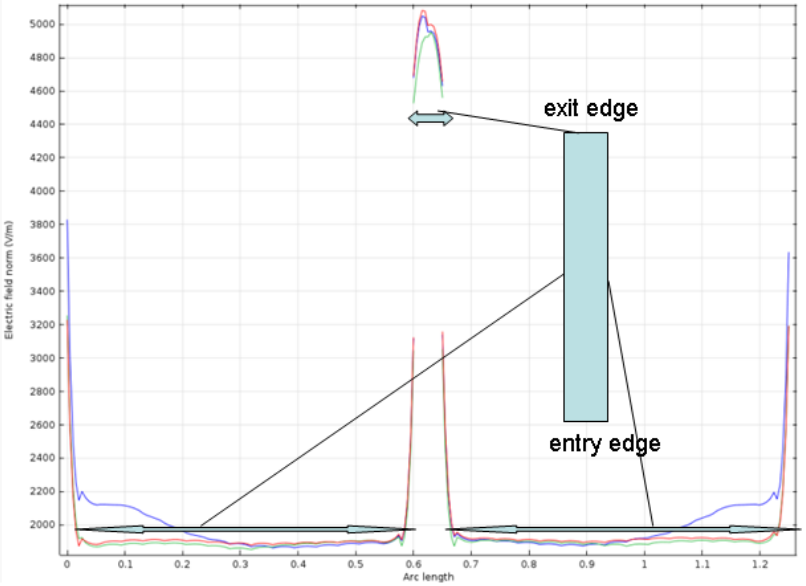


Fig. Quantification of variation in electric field along electrode edge

- ➢Very significant increase in electric field along the exit edge of heater electrode

Dependence of outflow temperature on votage applied

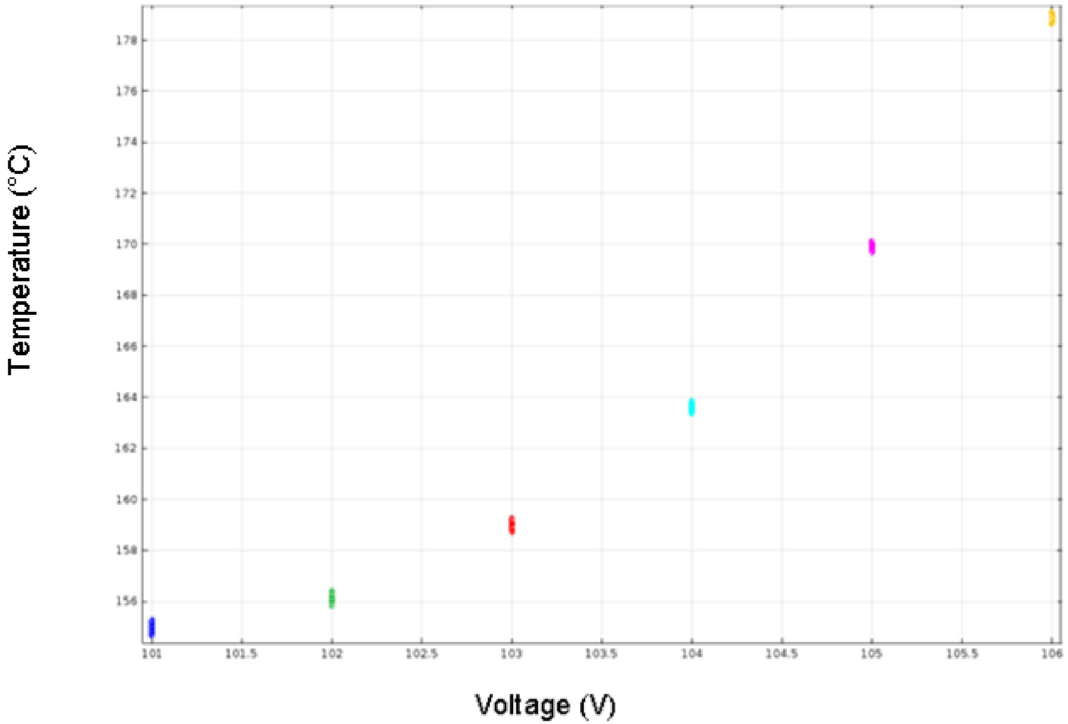


Fig. Voltage dependence of outflow temperature

- ➢Desired outflow temperature ~180-190 Celsius achievable with practical voltages with the feasibility study design
- ➢There is a strong dependence of outflow temperature on small variation in voltage applied, which commands attention from a process monitoring and control perspective

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In summary…

- The feasibility study was successful and has secured further funding for an imminent next phase
- The Multiphysics nature of COMSOL was crucial in solving our expected temperature distribution.
- We have learned that the equilibration regions are adequate to sufficiently reduce the temperature differential at the outflow.
- However, the very significant raising of electric field close to the electrode edges must be addressed in the next stage of the development process.
- We acknowledge excellent technical assistance from COMSOL UK
- We are grateful for funding from the Department of Energy and Climate Change, Department for Environment Food and Rural Affairs, and SBRI
- Please feel free to approach me during the rest of the conference, or at C-Tech Innovation

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