Prediction of Biogas Production Using a Computational Fluid Dynamic Model

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Conventional Open Lagoon

European Anaerobic Digestion Plant

Case Study System

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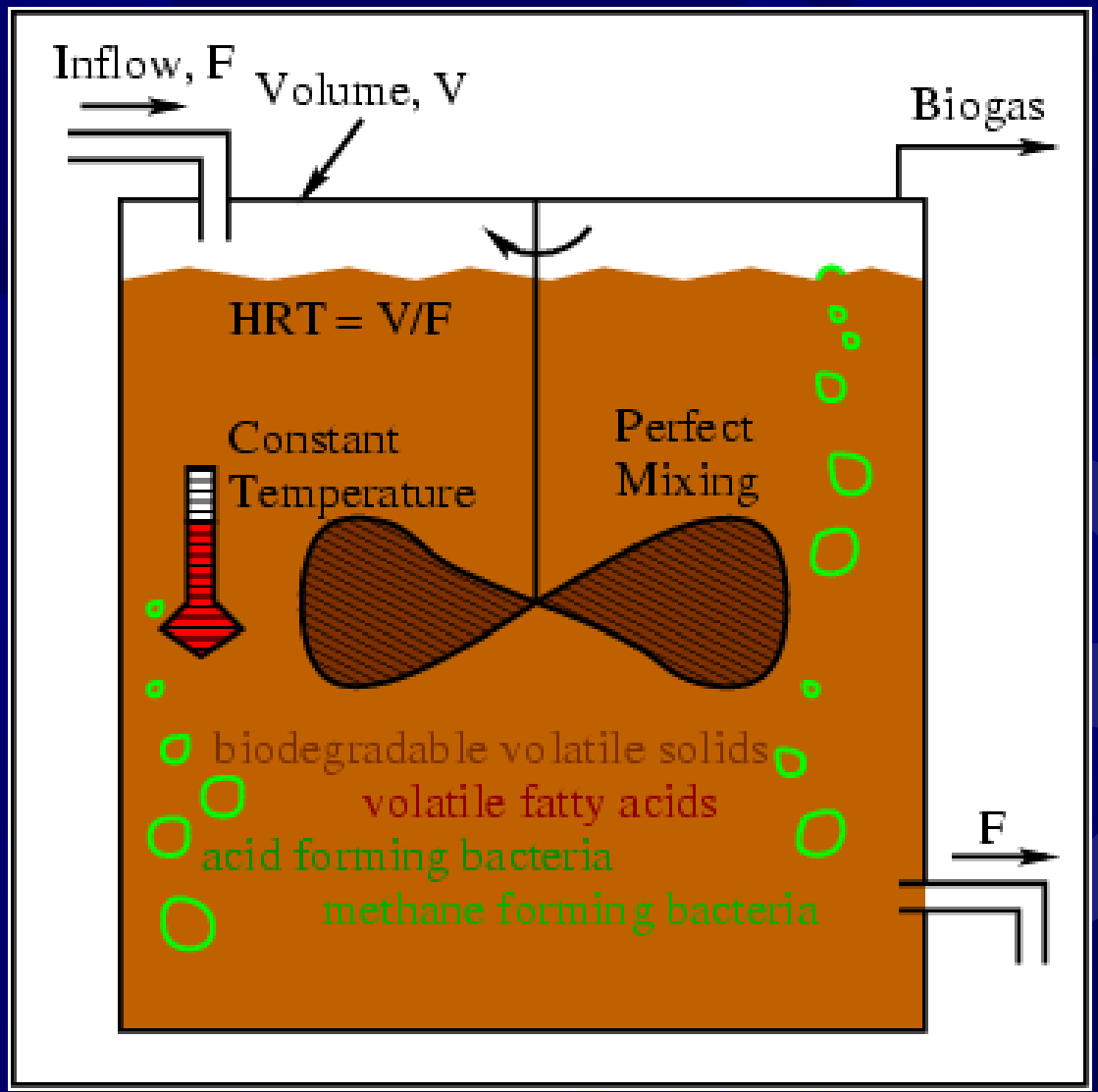
Case Study System Summary

- 4,000 sow farrow-to-wean hog farm in central North Carolina
- Lagoon cover 80mx80m HDPE plastic
- Biogas capture: 10k-40k LPH, 70% CH_4
- 88% Volatile Solids (94% COD) destroyed (Cheng et al., 1999)
- Capital cost: $248,600 (15 year lifetime)
- Annual savings $36,000 electricity, propane
- Annual O&M cost $6,000
- **Over designed** (140 day HRT)

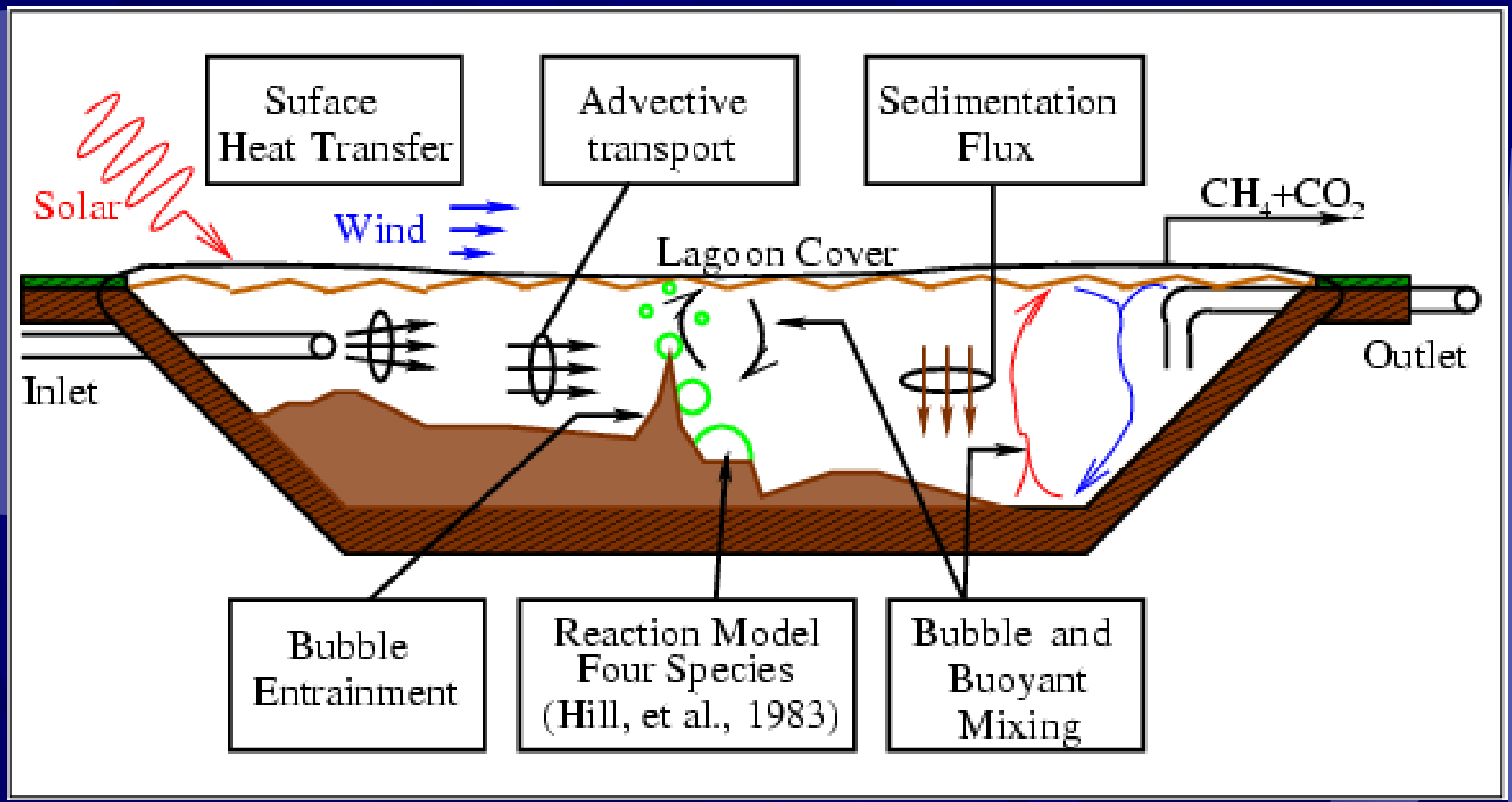
What's Missing?

- Not a new idea…
- **Expensive**
- High maintenance
- 65% of farm-based anaerobic reactor projects fail (DOE, 1995)
- Performance predictions at full scale?
- Design guidelines?

Conventional Model



Hydrodynamic Model



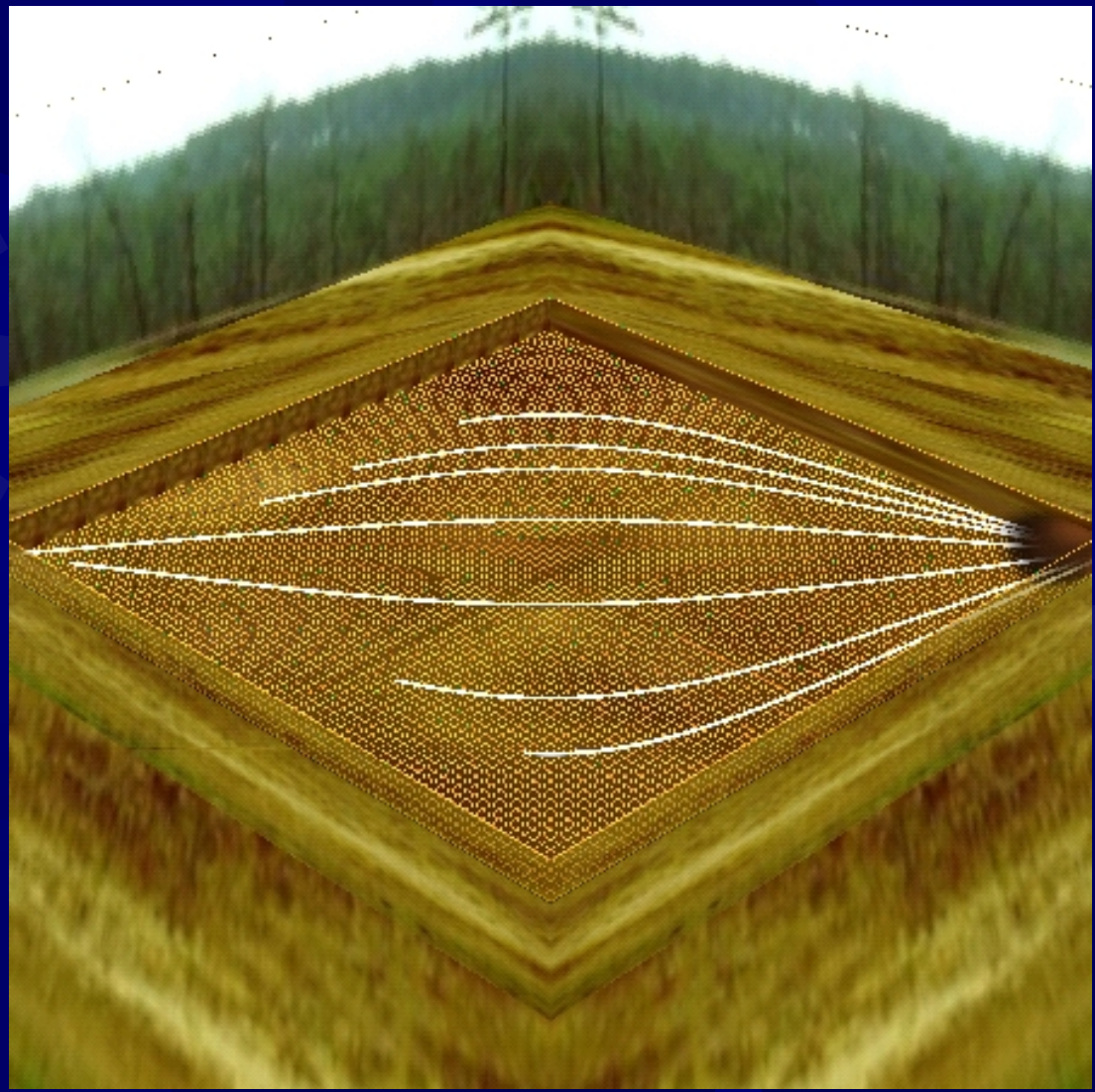
Modeling Objective

- Dynamic
- Accurate thermal and biogas performance prediction
- Use existing biological kinetic model without adjustment or calibration
- Use measured data in conjunction with model to quantify physical process parameters
- Provide a basis for high performance designs

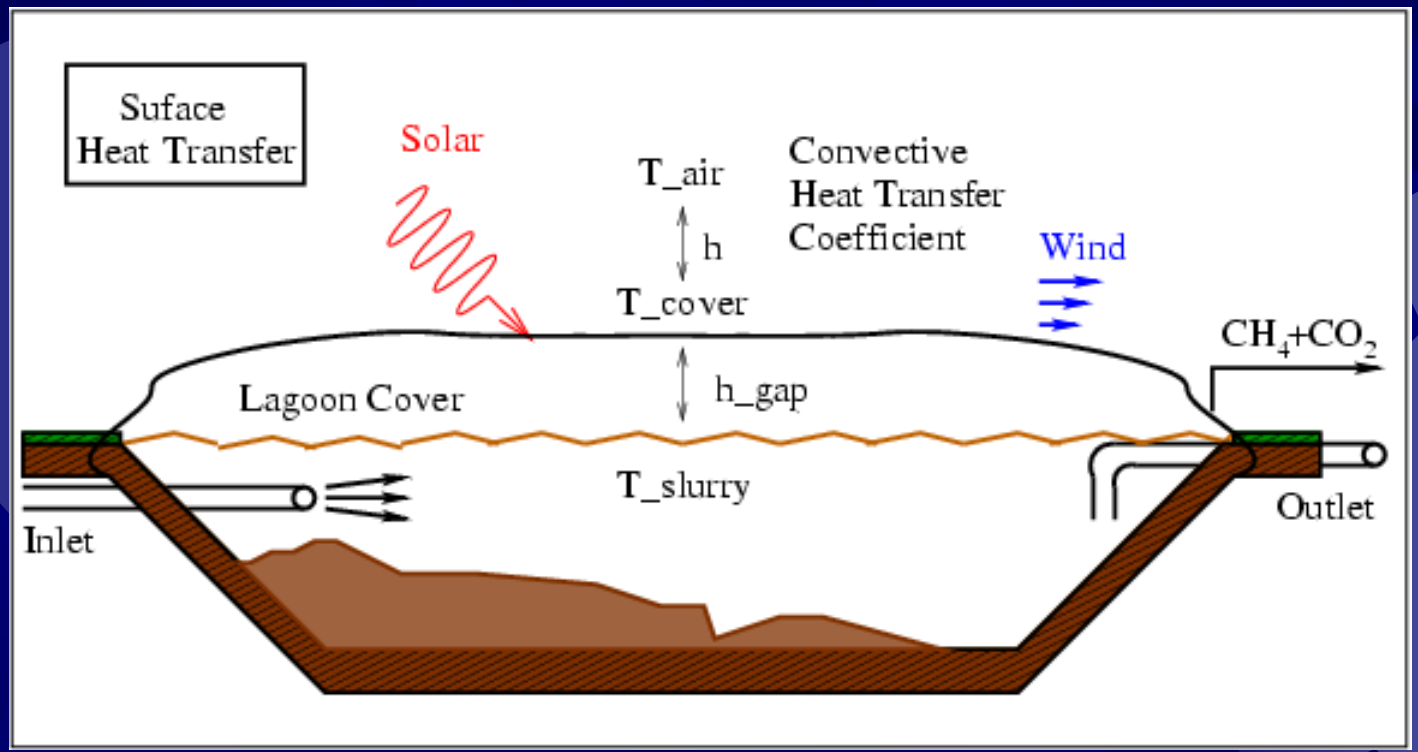
Bulk Fluid Motion

- Transport of dissolved and suspended species toward lagoon outlet
  - Patankar's SIMPLE Method for velocity
  - Navier-Stokes Equations
- Data required
  - Inlet volumetric flow rate
  - Lagoon geometry

Case Study Fluid Velocity



Cover Heat Transfer Model



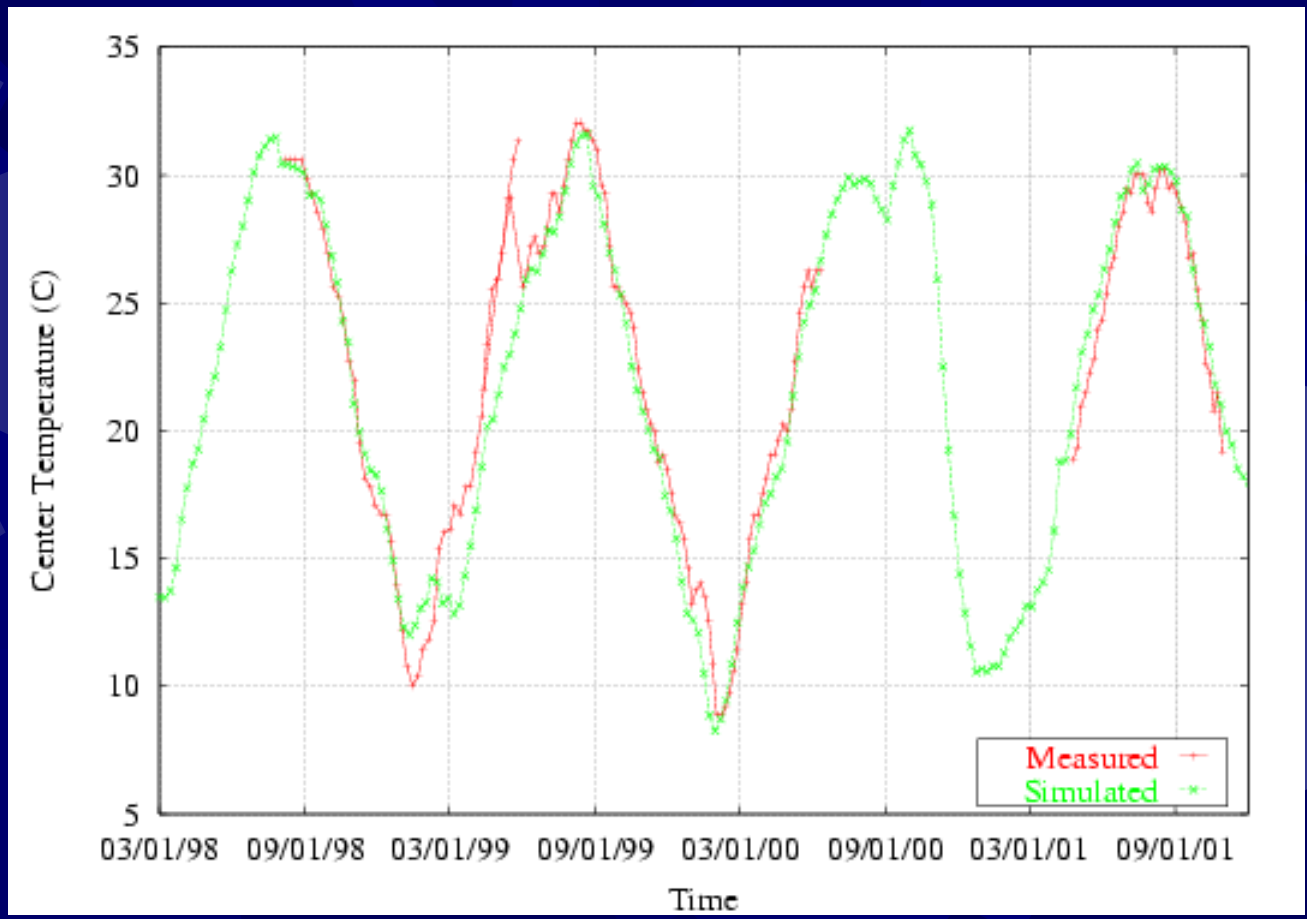
Cover Heat Transfer Equations

- Cover energy balance:
  - $q_{solar} - q_{conv} - q_{gap} = 0 \quad (1)$
  - $F_{cover} I_{solar} - h_{\infty}(T_c - T_{\infty}) - h_{gap}(T_c - T_s) = 0 \quad (2)$
- Known: I_{solar} T_{∞} T_s
- Estimated: h_{∞} and h_{gap}
- Solve for cover temperature T_c
- Plug T_c back into eqn. (1) to obtain q_{conv} and q_{gap} ; refine h_{∞} and h_{gap}

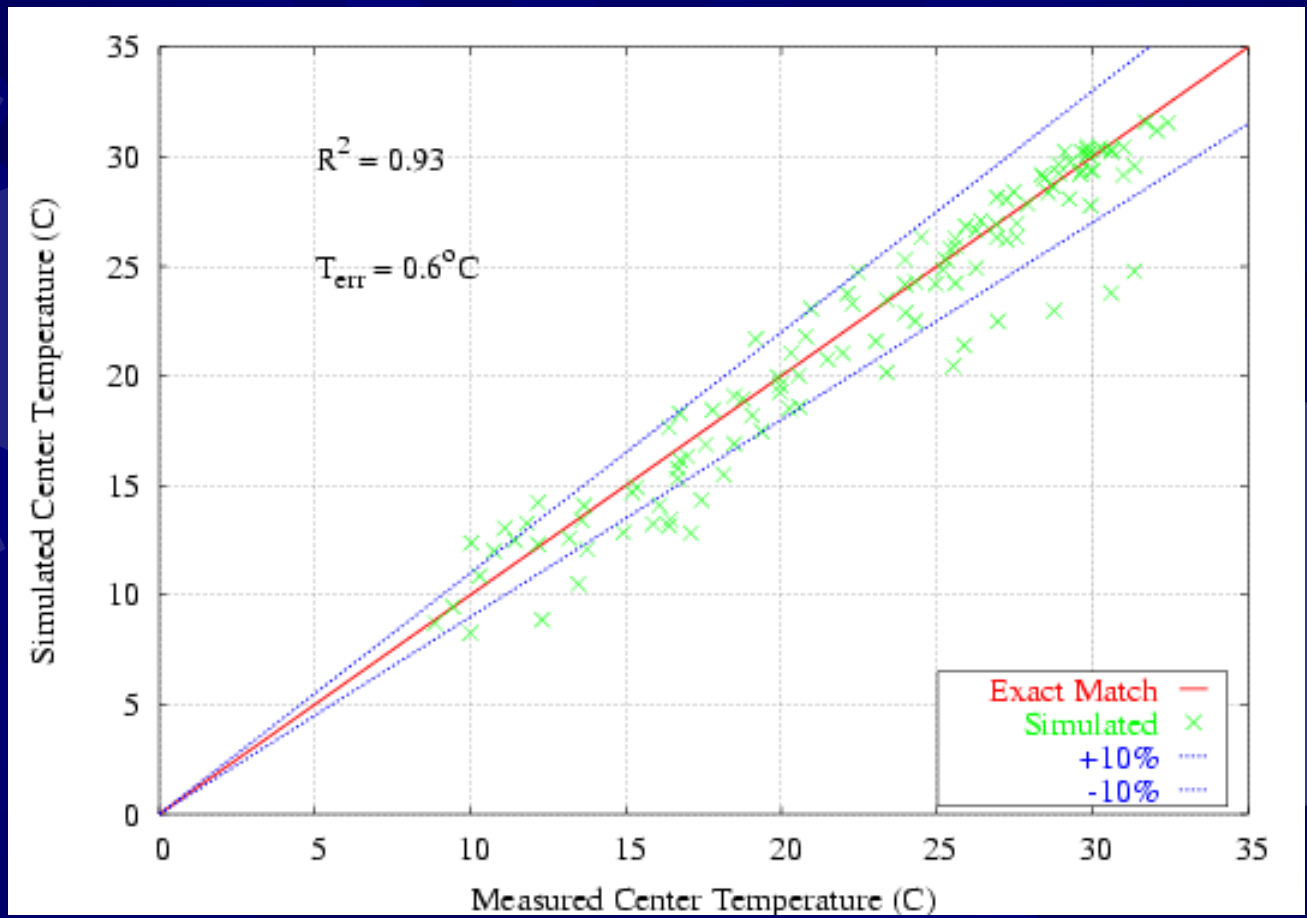
Cover Heat Transfer

- Data required:
  - air temperature
  - solar radiation
  - wind speed
  - inlet temperature
- Results
  - Average error: 0.6°C, Relative Error: 5.7%
- $\mathbf{h}_{\mathbf{gap}} = 10\ W/m^2K$; $\mathbf{h}_{\infty} = 17.5V + 6 W/m^2K$ where V = wind speed in m/s

Temperature Results



Correlation with Measured Temperature Data



Biological Reaction

- Monod kinetics, temperature dependent
- Hill (1983), unadjusted parameters

$$\frac{dS}{dt} = \frac{S_0 - S}{HRT} - \frac{\mu M}{Y}$$

$$\frac{dA}{dt} = \frac{A_0 - A}{HRT} - \frac{\mu M}{Y}(1 - Y) - \frac{\mu_c M_c}{Y_c}$$

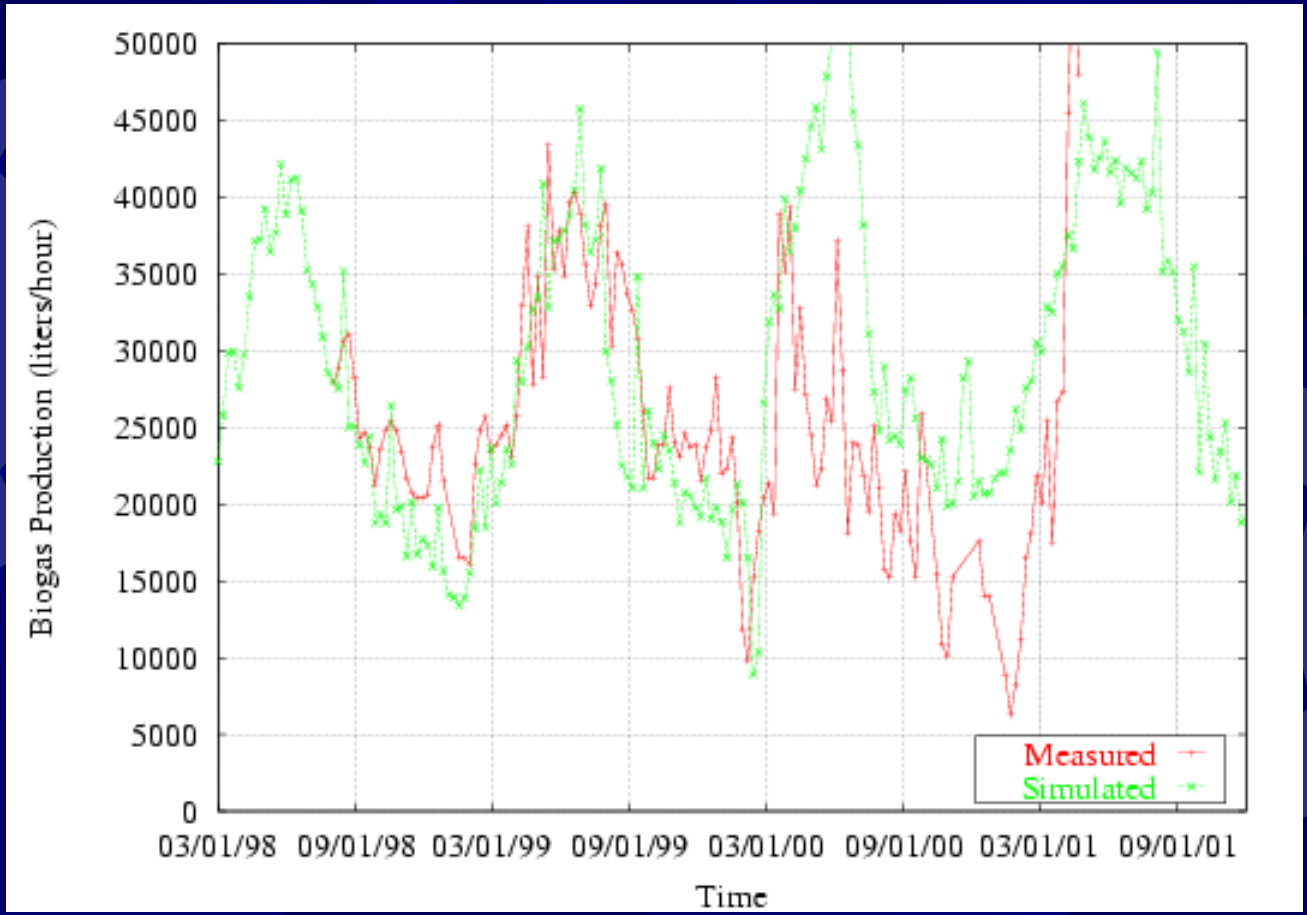
$$\frac{dM}{dt} = \left(\frac{\mu - k_d - 1}{HRT} \right) M$$

$$\frac{d\,M_c}{dt} = \left(\frac{\mu_c - k_{dc} - 1}{HRT} \right) M_c$$

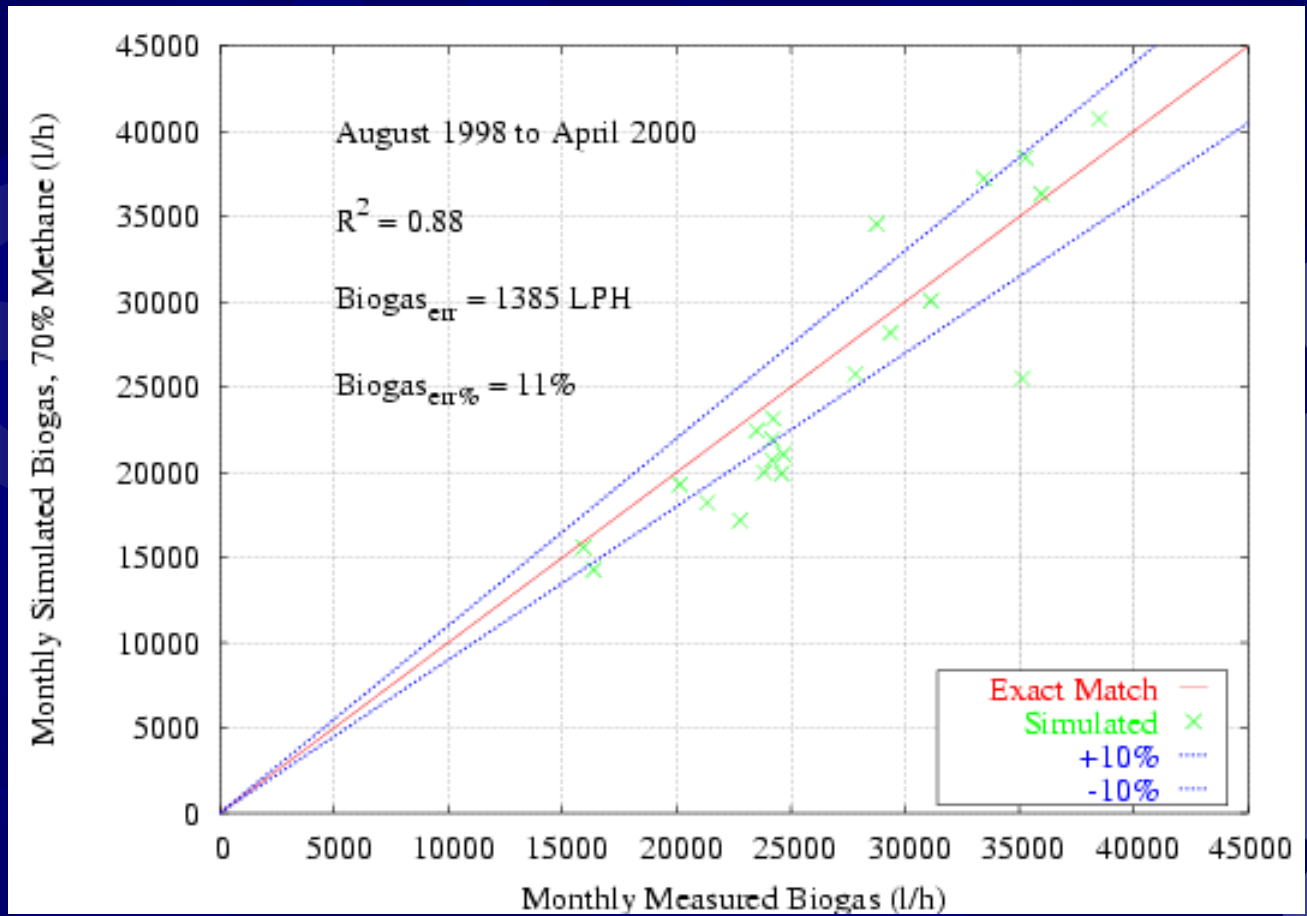
Mixing Mass Transfer Model

- Mixing mass transfer based on mixing heat transfer:
  - $D_{total} = D_{mix} + D$
- Assumed bubbles mix heat and mass equally well
- $\Rightarrow D_{mix} = \alpha_{mix}$; no new unknown parameters
- Sherwood number for sludge entrainment
- Sh_{ent} analogous to Nu, therefore $Sh_{ent}=1.0$

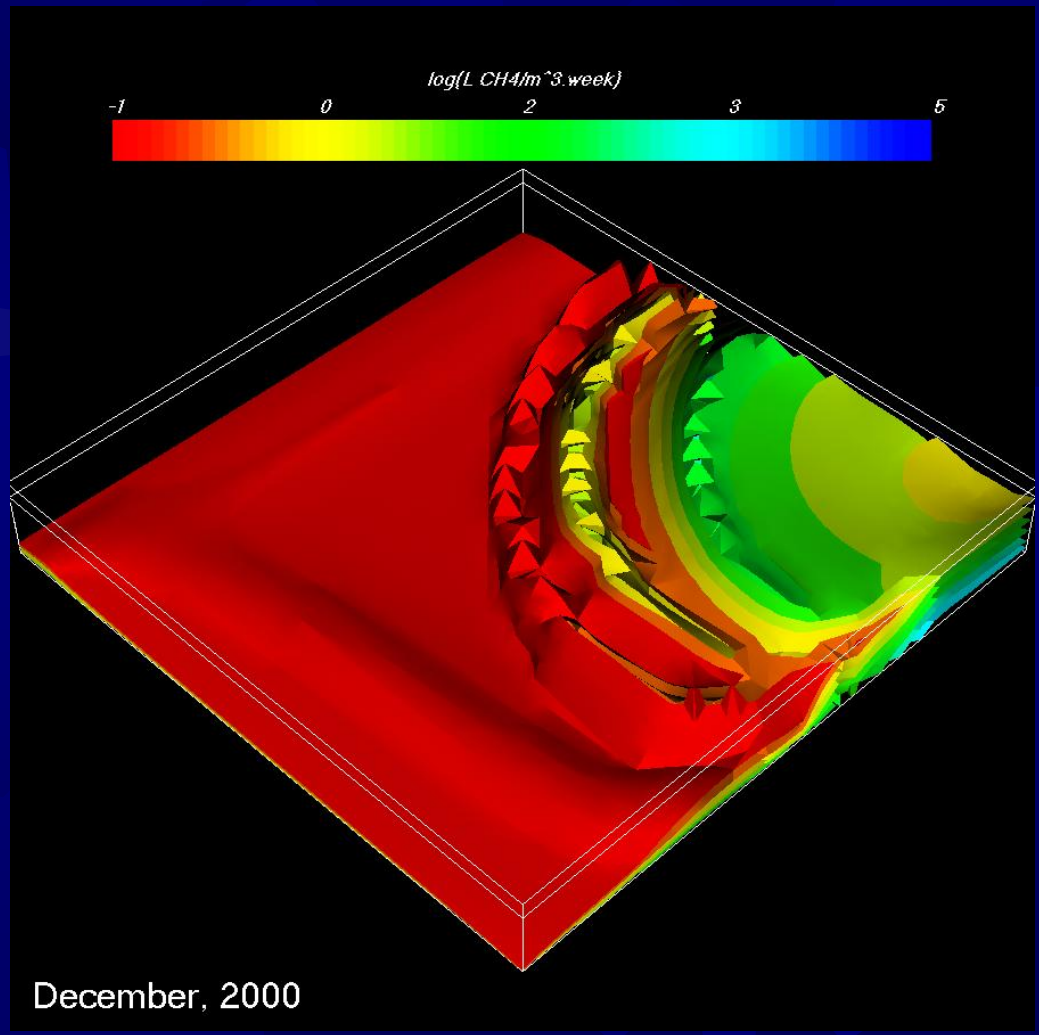
Biogas Results



Correlation with Measured Gas Data



Biogas Results



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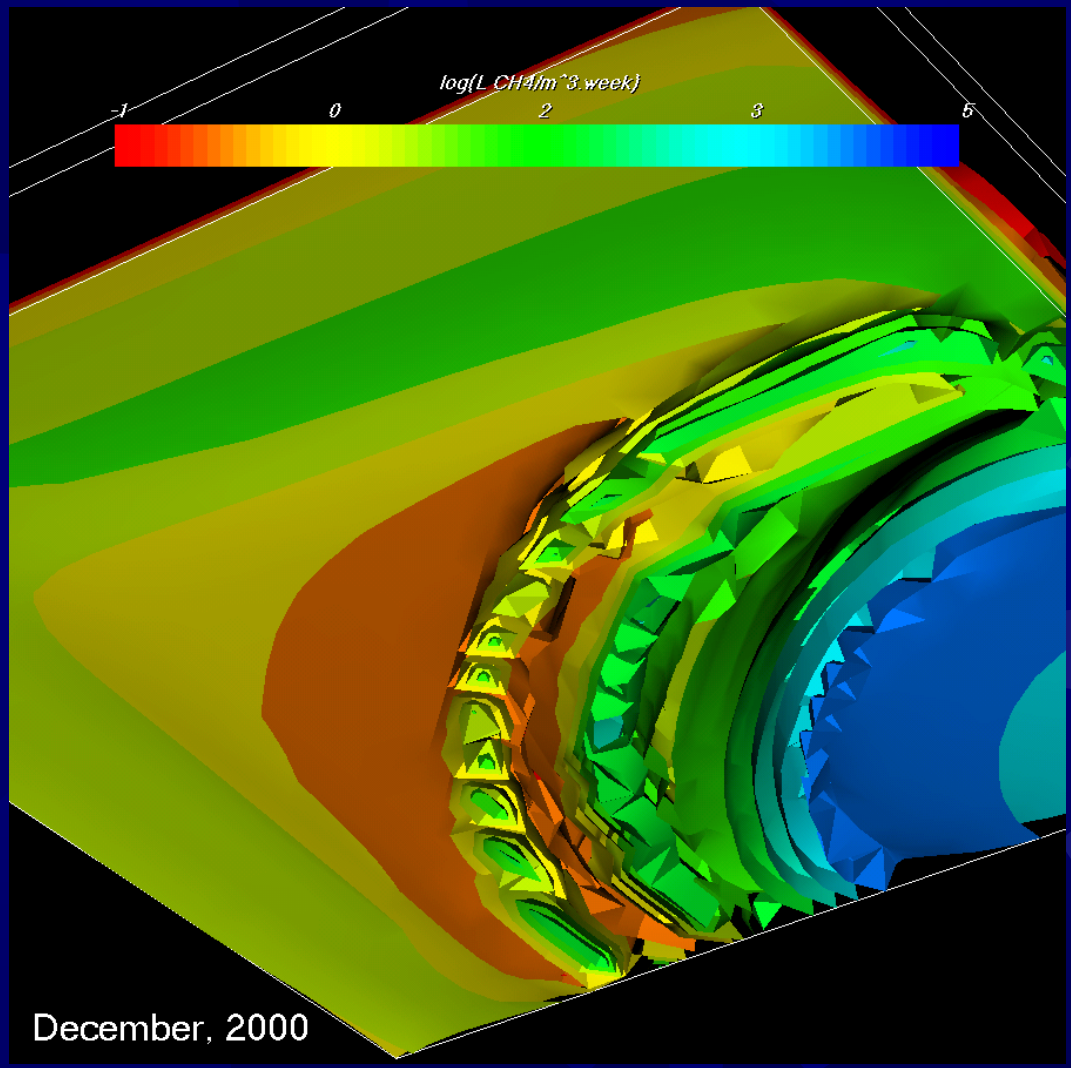
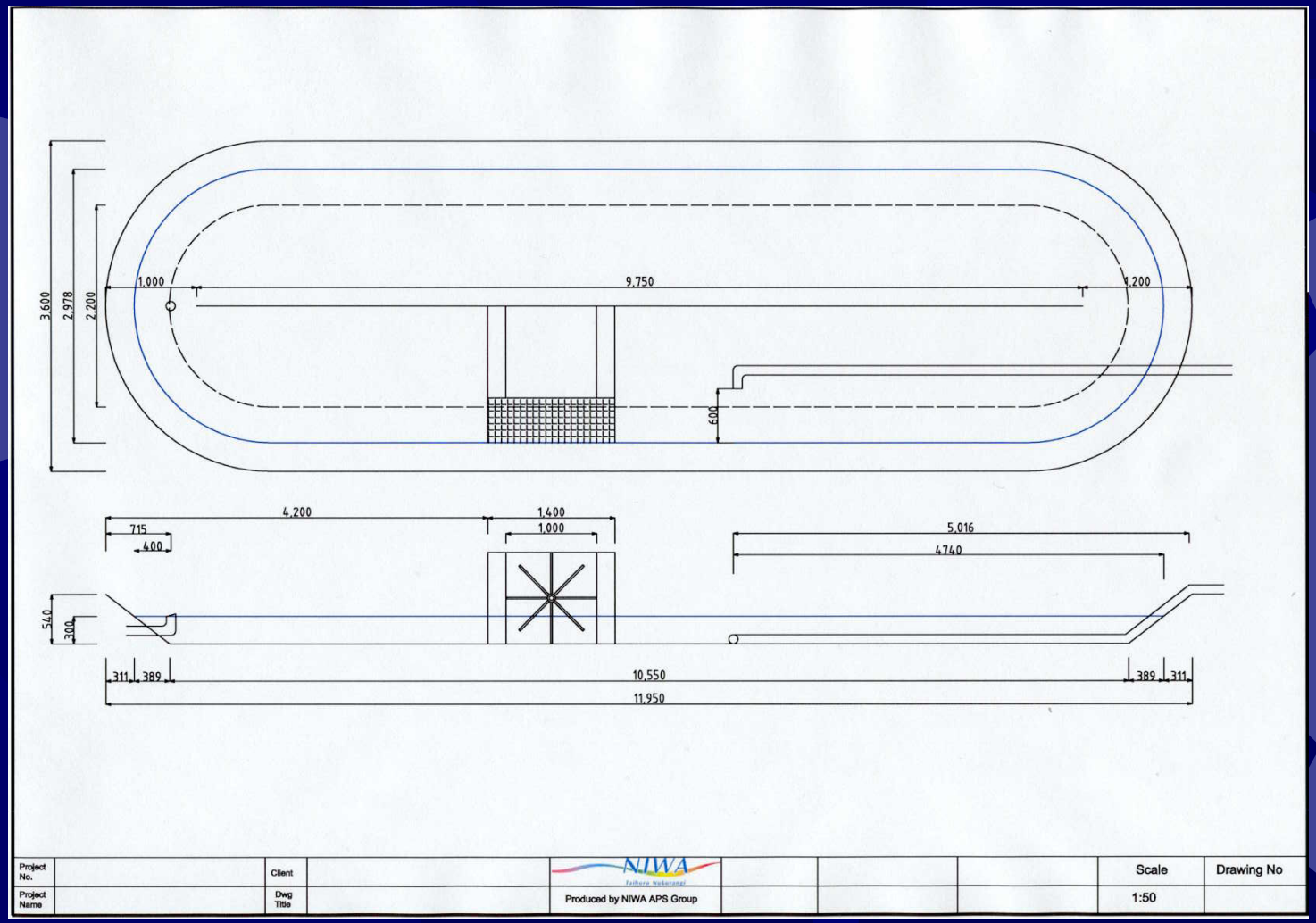


Overall Results

- Predicted temperature of case study system within 6%
- Predicted performance of case study system within 11%
- **NIWA** is currently extending the model for other anaerobic configurations
- Future research efforts underway to investigate biogas scrubbing

Experimental High Rate Pond



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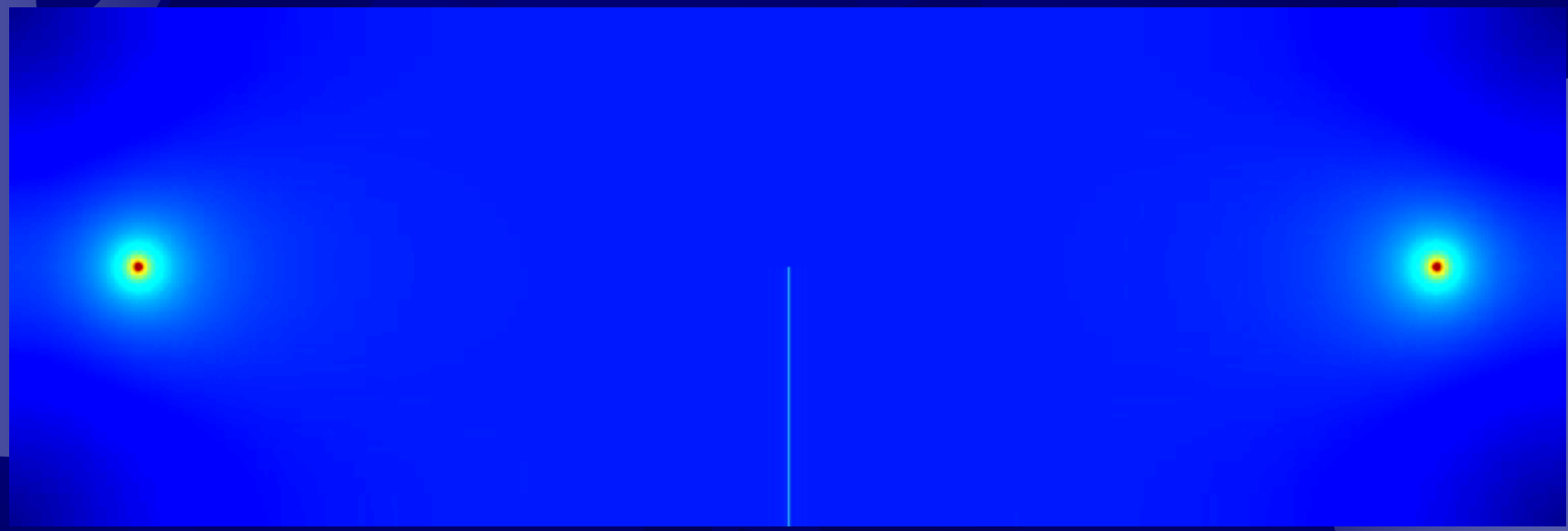

Full Scale High Rate Pond

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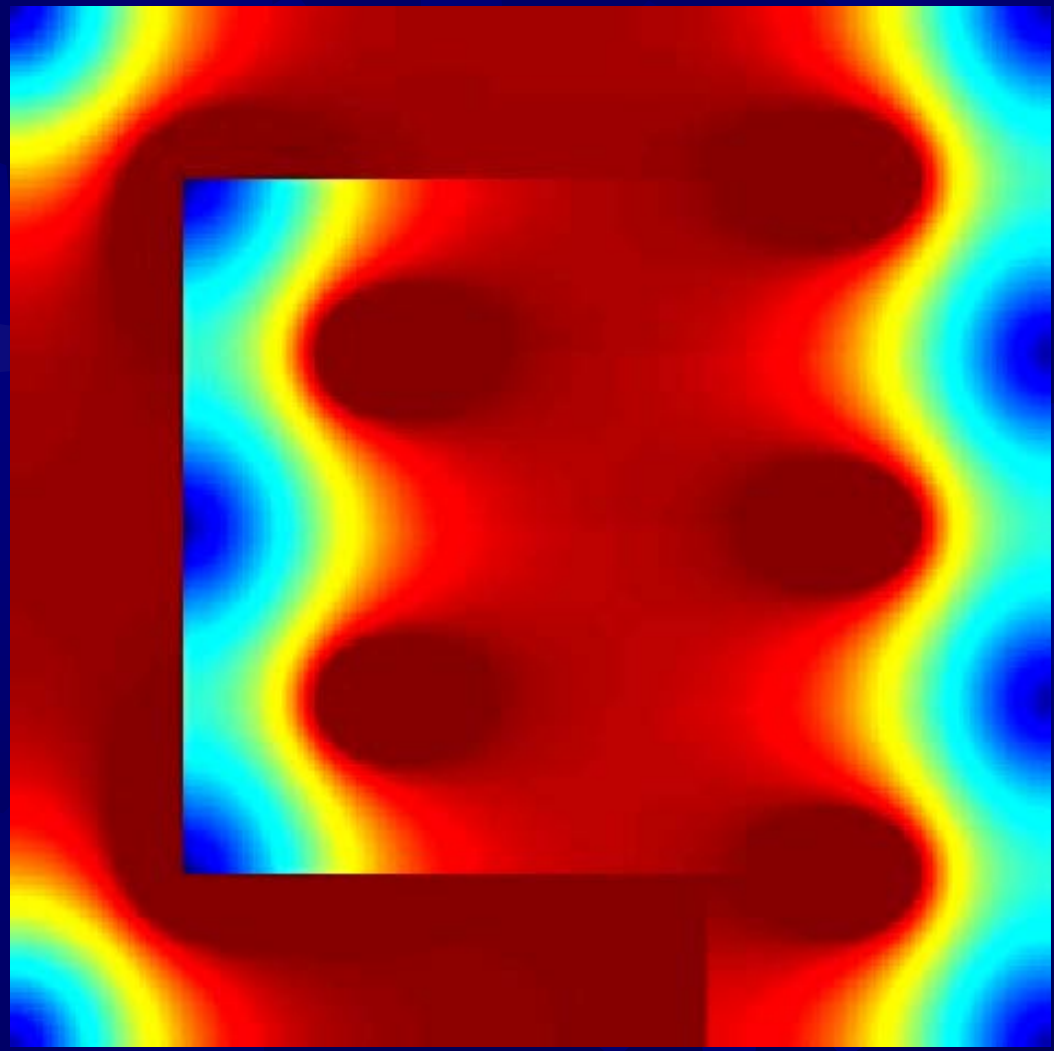

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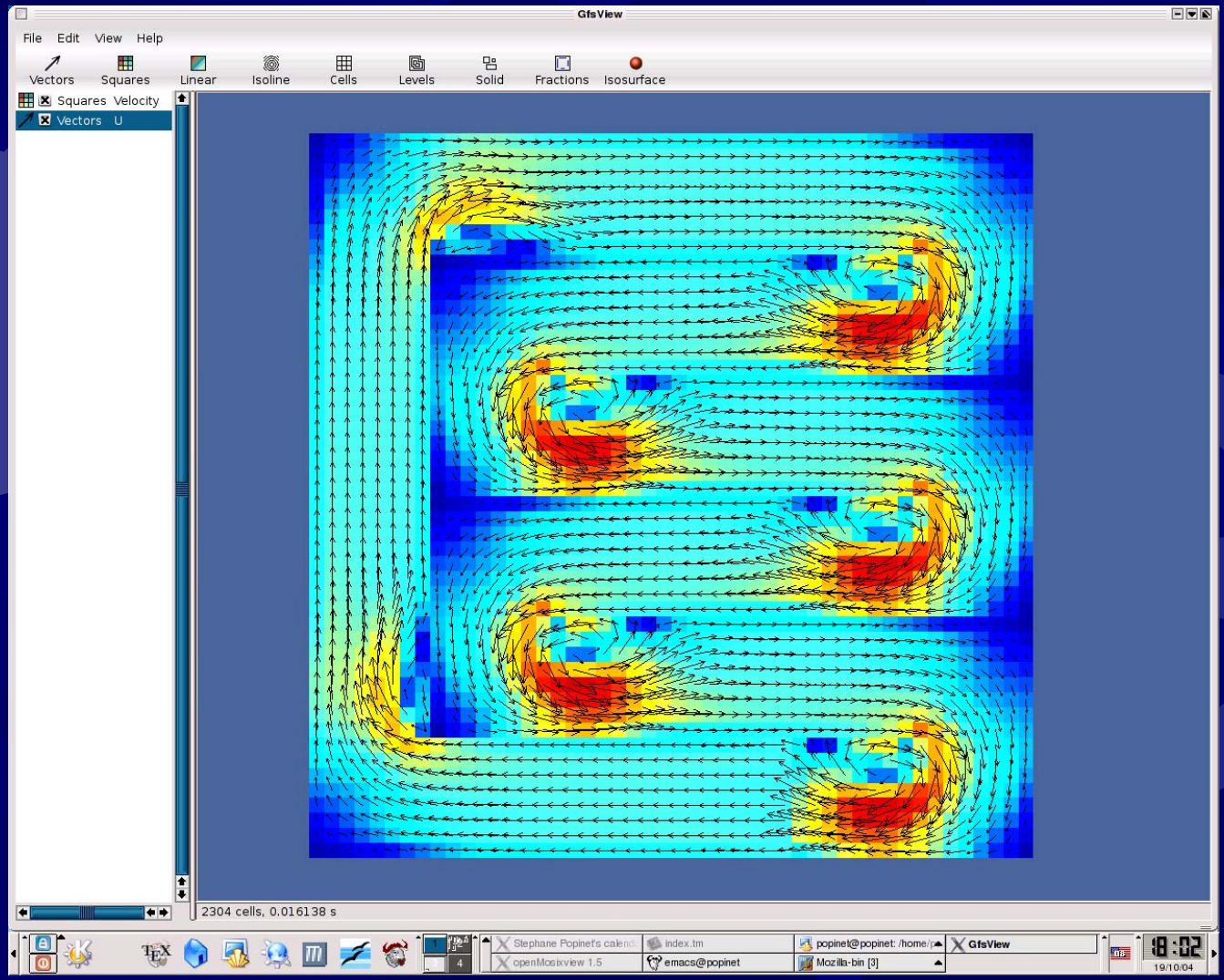

Conclusions

- Covered anaerobic pond model was successfully developed using CFD
- Extensions are being made for alternative configurations
- Hydraulic models also under development for biogas scrubbing