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The Role of Degradation on Foaming of Various Amine Solvents in Model Columns

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Overview

Foam: the problem in amine based post-combustion carbon capture

- Background on foam formation

Experimental methodology and modification to ASTM standard

Initial investigations on oxidative degradation (MEA, MDEA, AEP, AMP)

- Assessing the interaction of input variables on the foaming of both ‘clean’ and degraded solvents

Further investigations on thermal degradation (MEA, MDEA, AEP, AMP)

- Relating the changes in physical properties due to degradation on the resulting foaming of degraded solvents

Conclusions

Problem of Foaming

- Foaming is one of the **main operational problems** for alkanolamine based processes: Natural Gas Sweetening
  Post-Combustion Carbon Capture

- Consequence: Loss of liquid → ↓ of CO_2 absorption capacity

  - directly by: change in volume
  - indirectly by: change in solution composition
    reduction in mass transfer area
  - Financial losses

- Believed to be caused by contamination
- Ameliorated using anti-foam agents and other reactive efforts

Foam Quantification

1. Bikerman model: Foaminess = $\Sigma = \frac{H_o}{j}$ ← Foam height (numerator H_o) ← Superficial gas velocity (denominator j)

This model is said not to depend on:

- Experimental apparatus (cell size and dimensions, frit porosity, etc…)
- Gas pressure
- Solution volume (i.f.f. volume is sufficiently large)

Gas flow rate must be in a regime that is neither 'too slow' nor 'too fast'

Foam Quantification

1. Bikerman model: Foaminess(=) $\Sigma = \frac{H_o}{j}$

   ← Foam height

   ← Superficial gas velocity

2. Buckingham – Pi derived model: $\Sigma = k \frac{\mu_S}{\sqrt{\sigma_S \rho_S}}$

   ← Viscosity (dynamic)

   ← Density

   ← Surface tension

This predictive model uses a proportionality constant, k, to accommodate variability in foaming liquids.

An subsequent attempt to include bubble radius has been made, but has not been generalized in any acceptable manner

Foam Quantification

1. Bikerman model: Foaminess(=) $\Sigma = \frac{H_o}{j}$

   H_o ← Foam height

   j ← Superficial gas velocity

2. Buckingham – Pi derived model: $\Sigma = k\,\frac{\mu_s}{\sqrt{\sigma_s \rho_s}}$

   μ_s ← Viscosity (dynamic)

   ρ_s ← Density

   σ_s ← Surface tension

3. Non-dimensional analysis: $Ca\left(\frac{H_0}{r_0}\right) = k\left(\frac{Re}{Fr}\right)^n$

   $\frac{Re}{Fr}$ ← $\frac{\text{Gravitational Forces}}{\text{Viscous Forces}}$

   r_0 ← Bubble radius

   Ca ← $\frac{\text{Viscous Forces}}{\text{Surface tension Forces}}$

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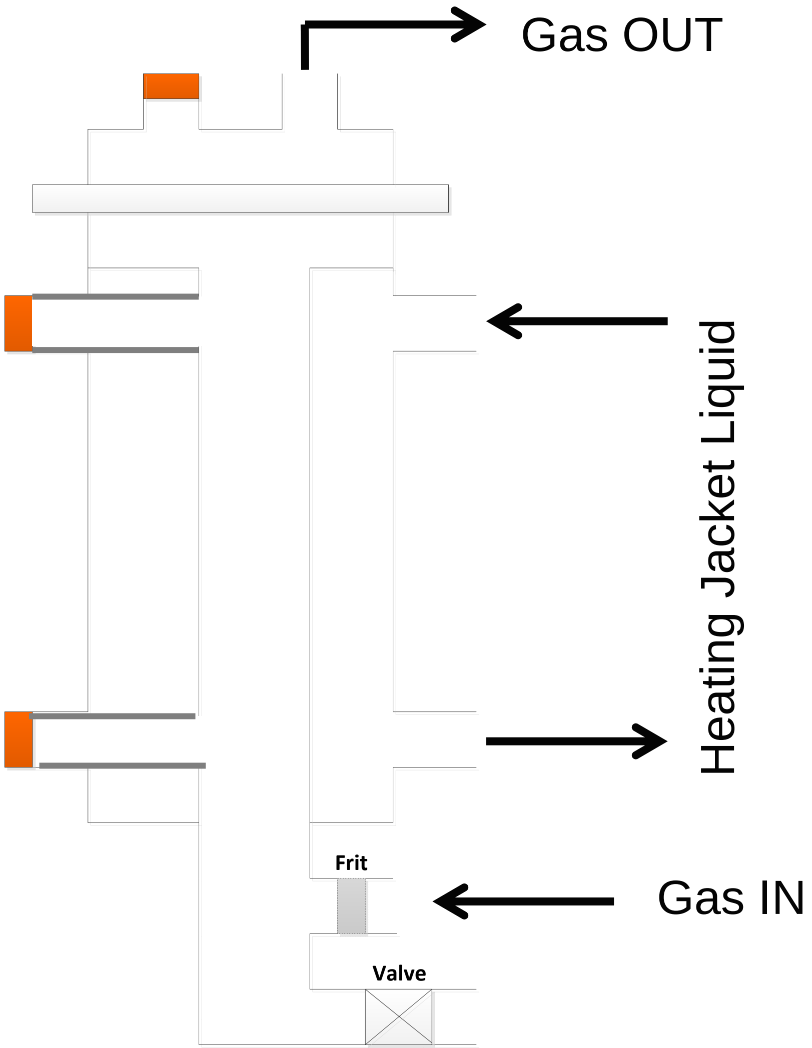
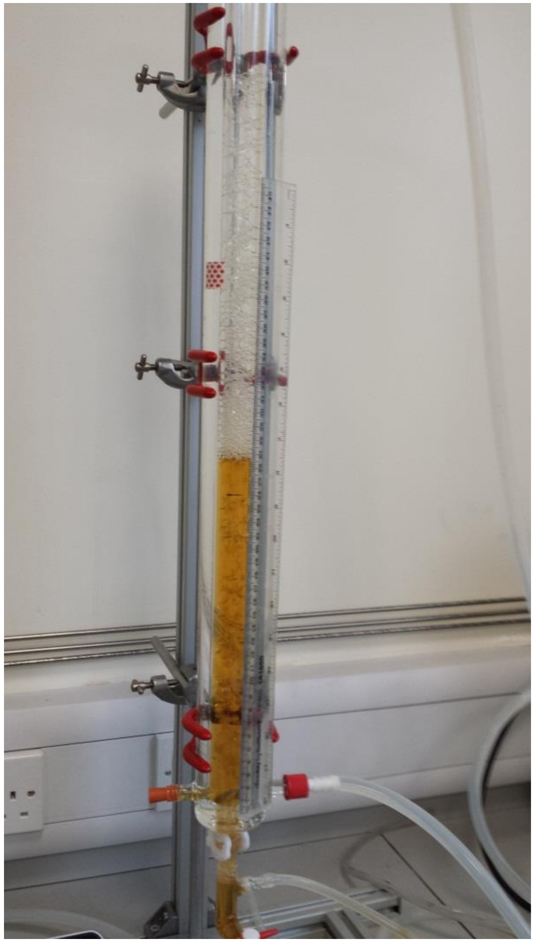
Experimental Methodology





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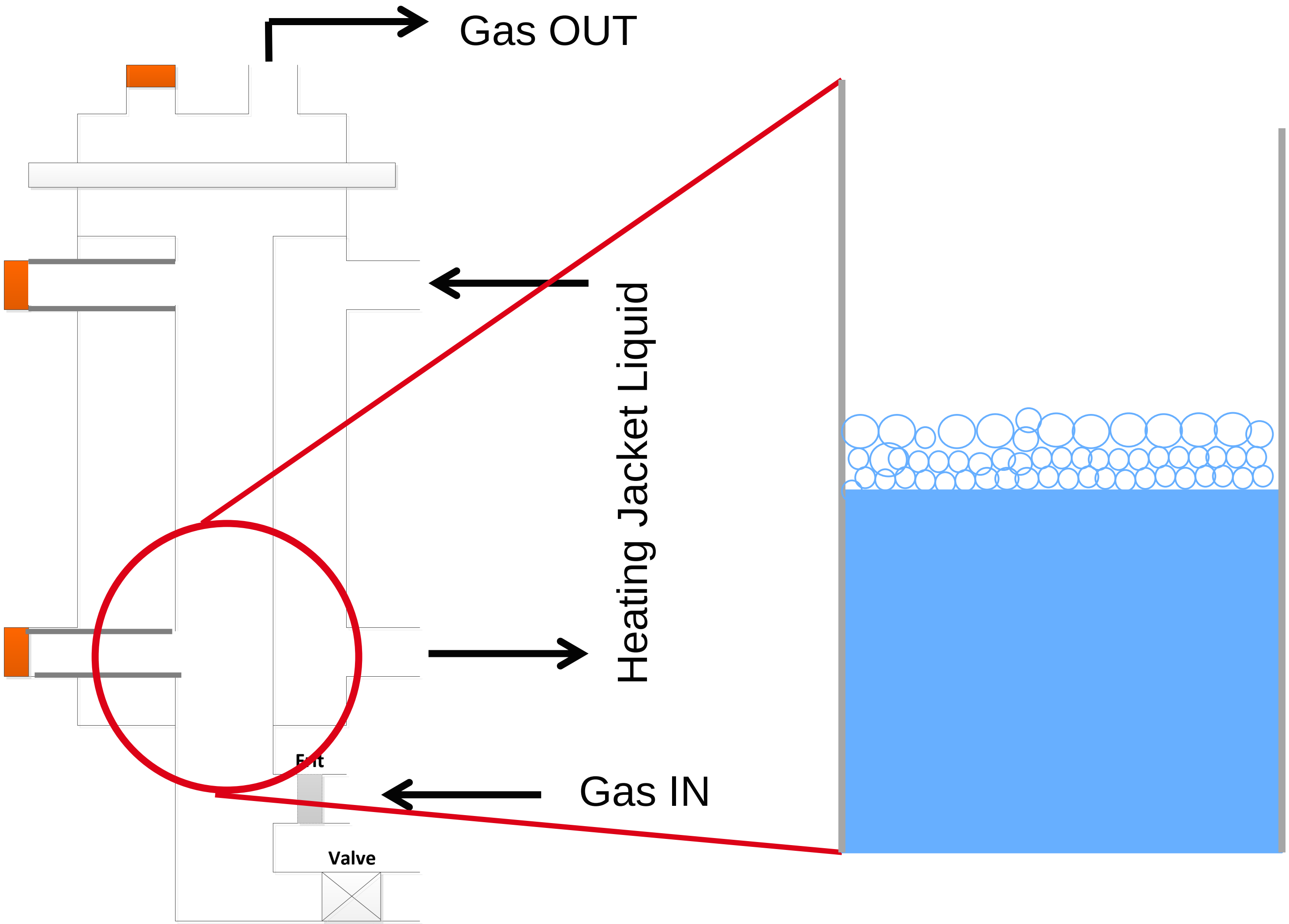
Experimental Methodology



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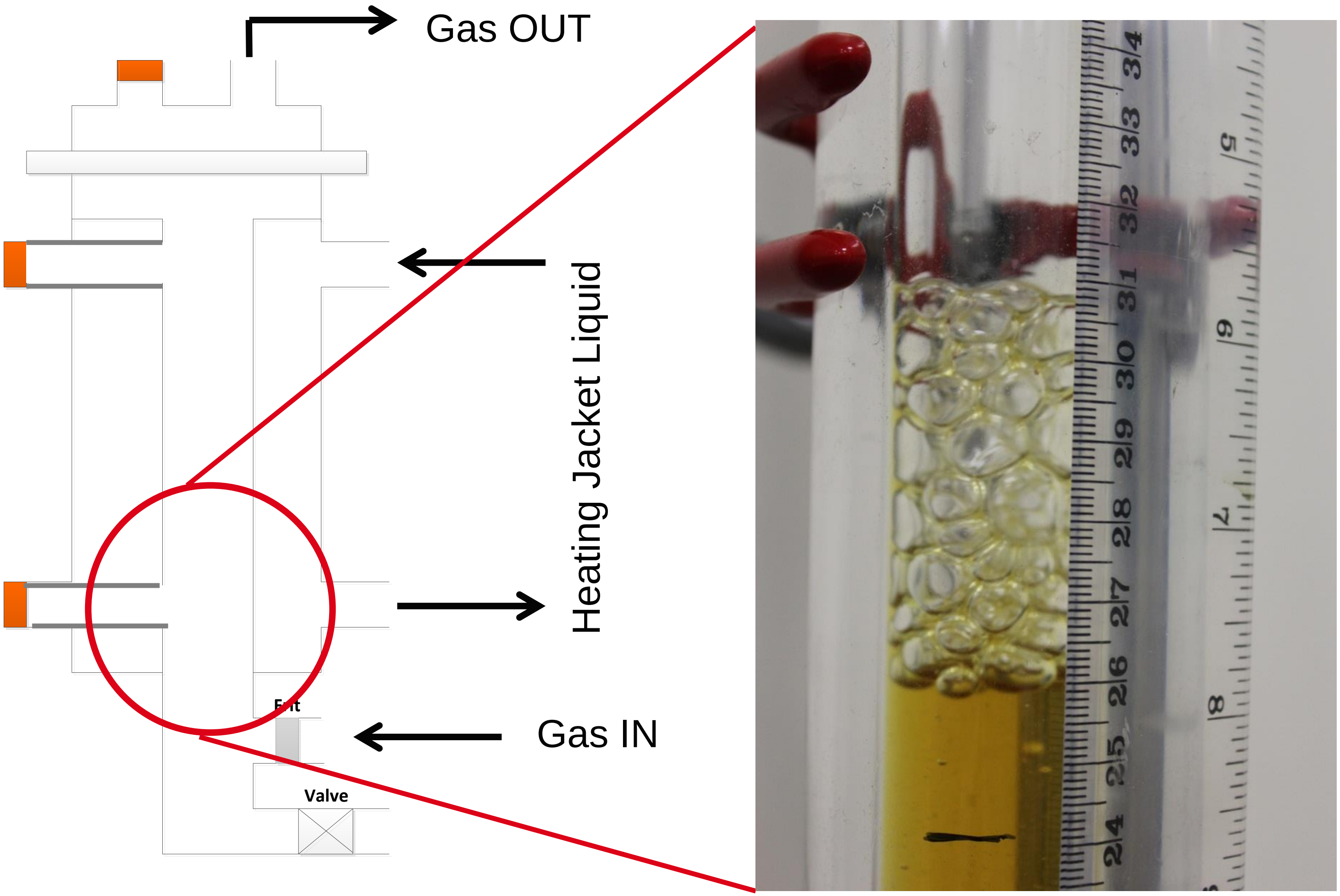
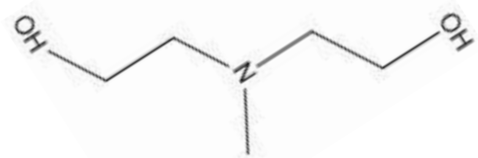
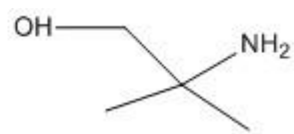
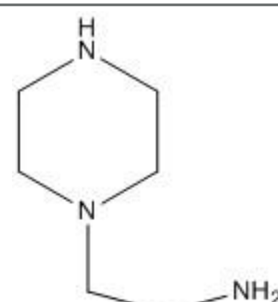
Experimental Methodology



Amine Solvents

Monoethanolamine (MEA)		#1: Primary
Methyldiethanolamine (MDEA)		#1: Tertiary
2-amino-2-methylpropanol (AMP)		#1: Primary
1-(2-aminoethyl)-piperazine (AEP)		#1: Primary #2: Secondary #3 Tertiary

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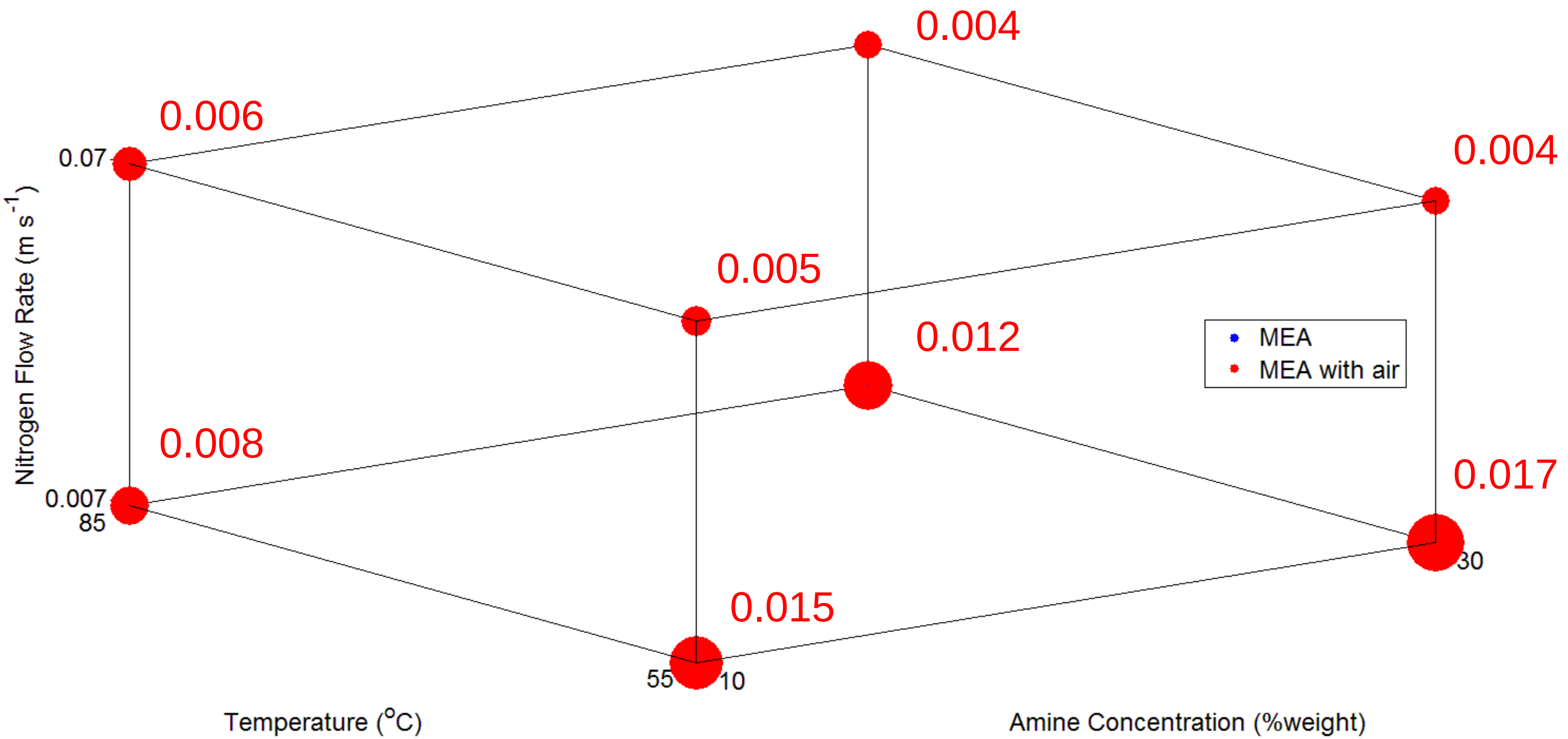
INITIAL INVESTIGATIONS (OXIDATIVE DEGRADATION)

MEA Foaminess



'Clean' MEA : No Foaminess

Oxidized MEA: Low Nitrogen Flow Rate → ↑ Foaminess

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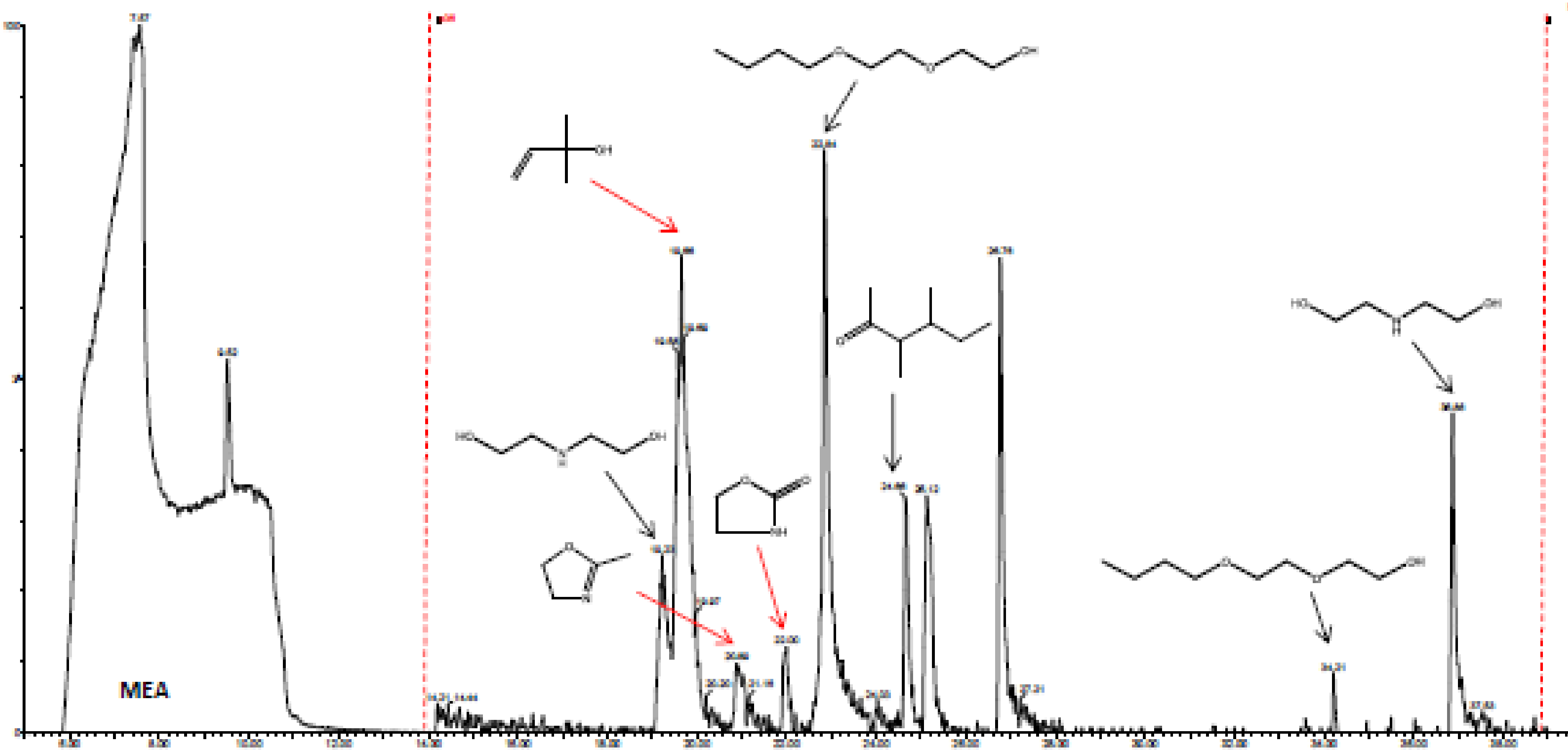
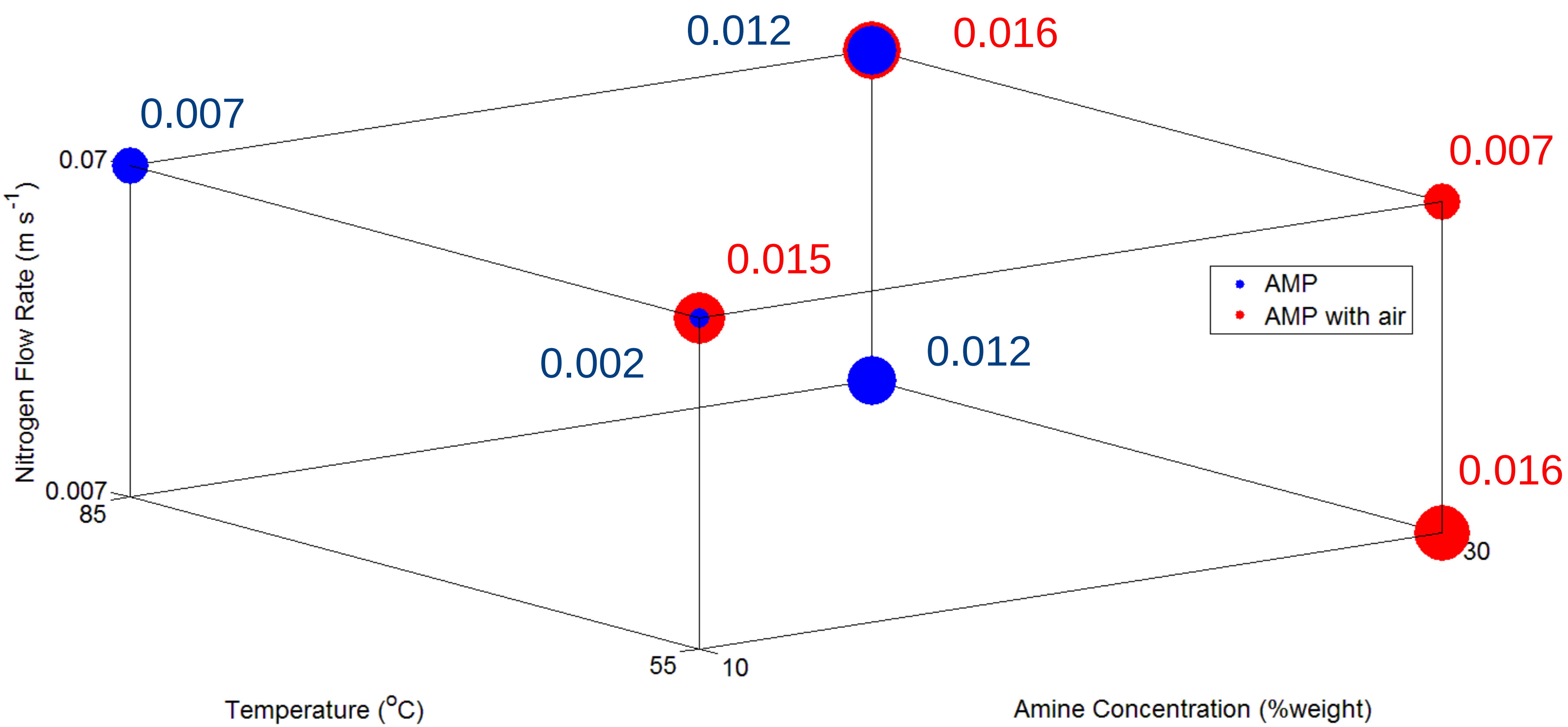
MEA Oxidative Degradation



AMP Foaminess



‘Clean’ AMP: High Temperature → Foaminess

Oxidized AMP: Low Temperature → Foaminess

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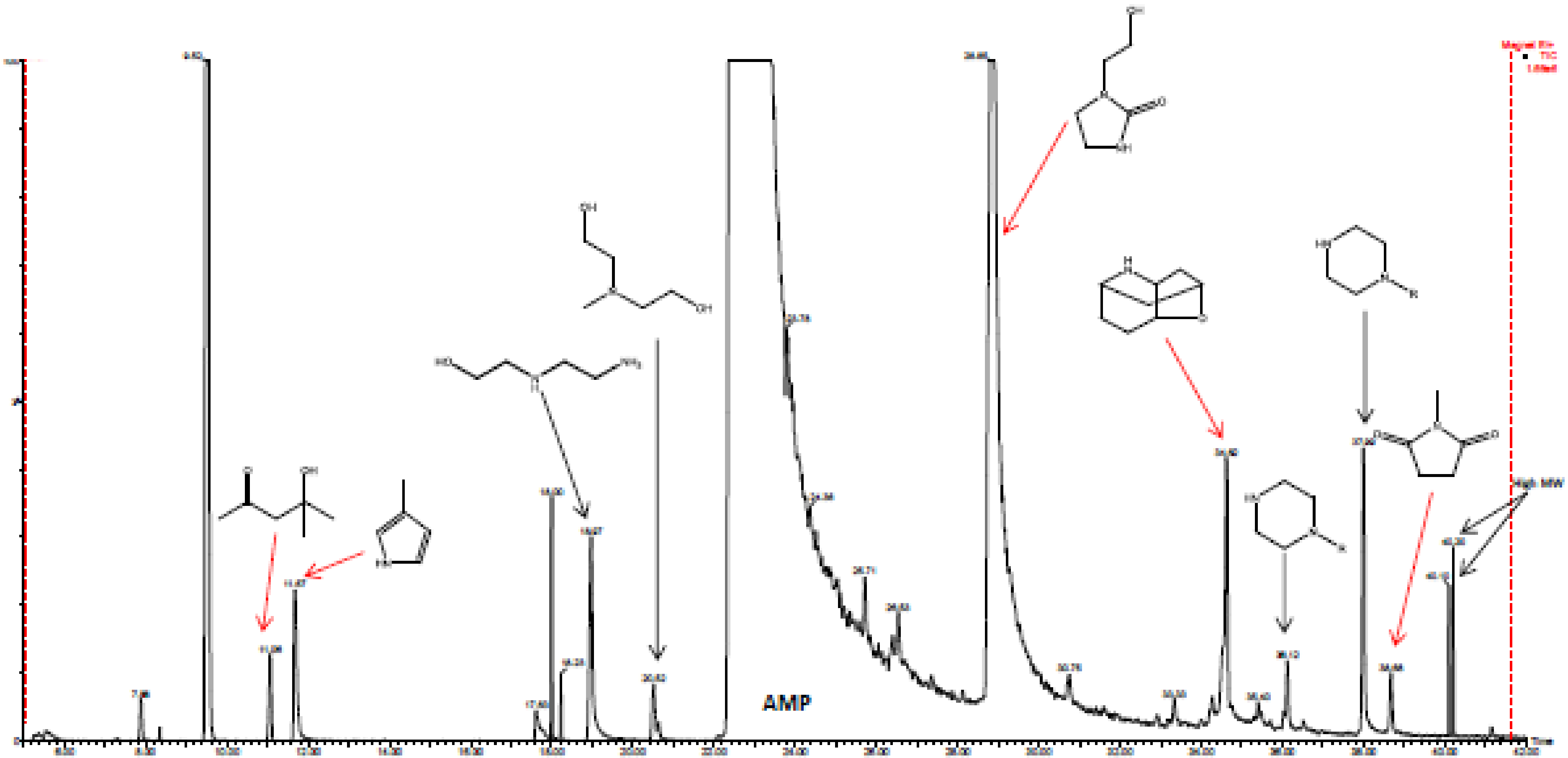
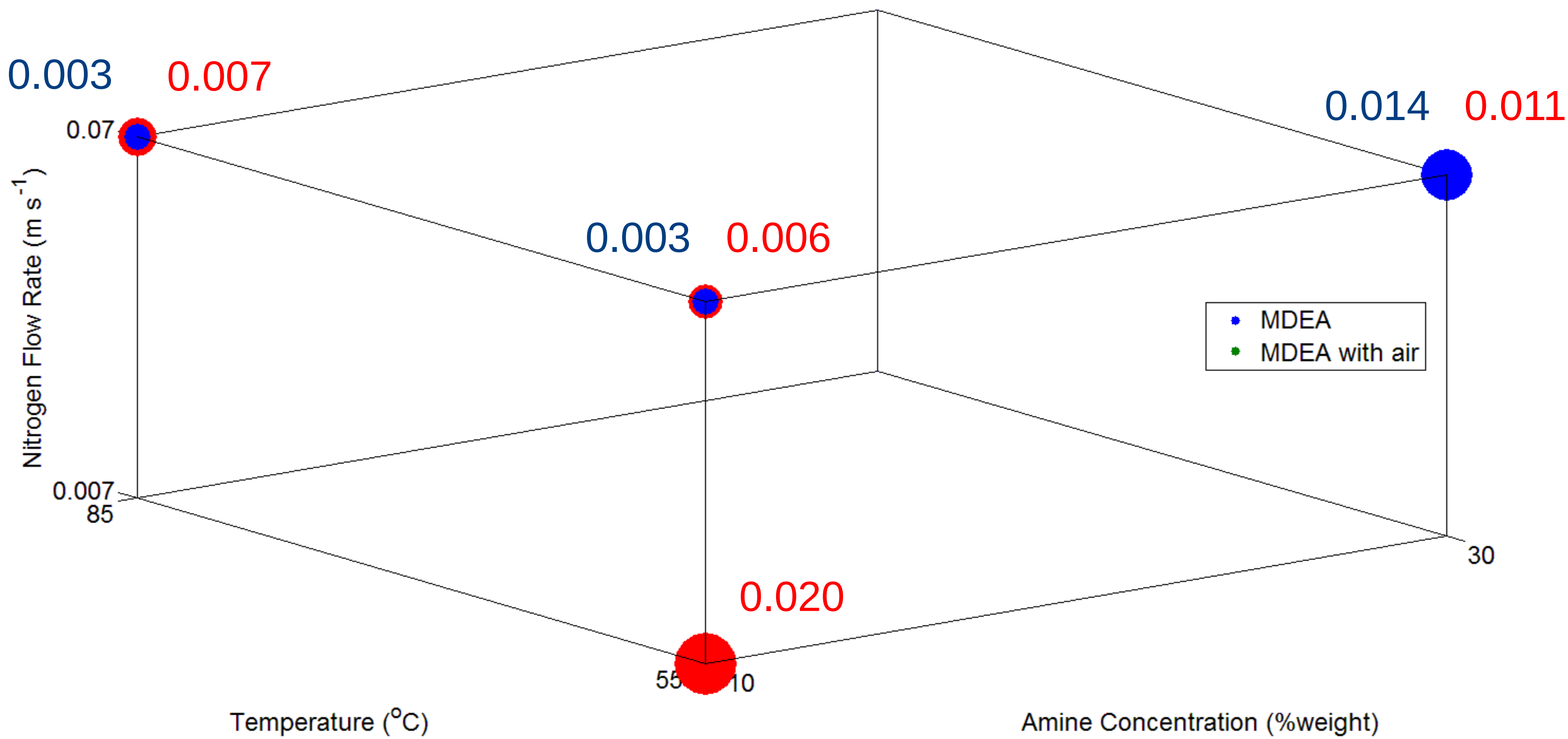
AMP Oxidative Degradation



Significant degradation products

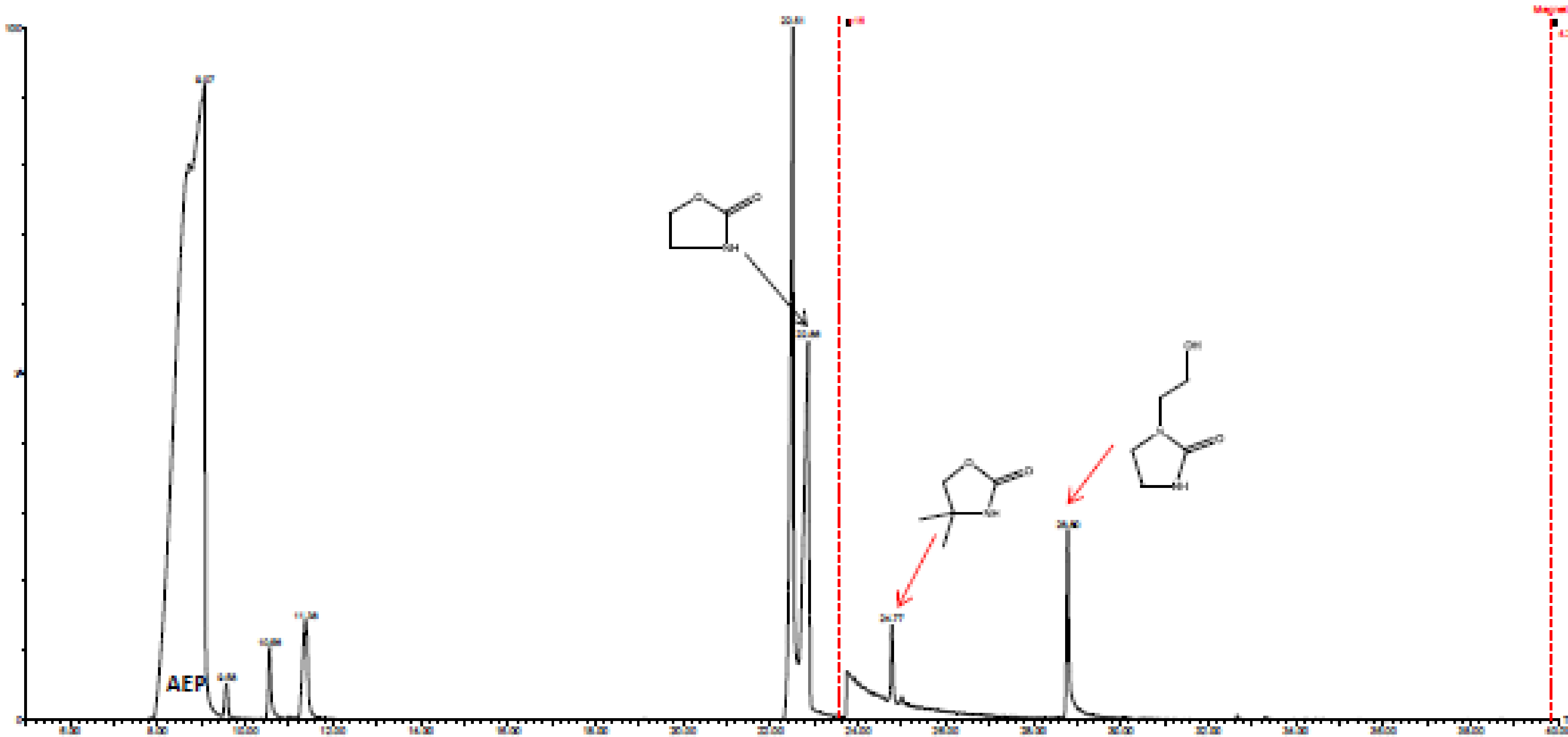
MDEA Foaminess



'Clean' MDEA : High Nitrogen Flow Rate → Foaminess

Oxidized MDEA ~ 'Clean' MDEA

AEP Oxidative Degradation



Nominal degradation products

FURTHER INVESTIGATIONS (THERMAL DEGRADATION)

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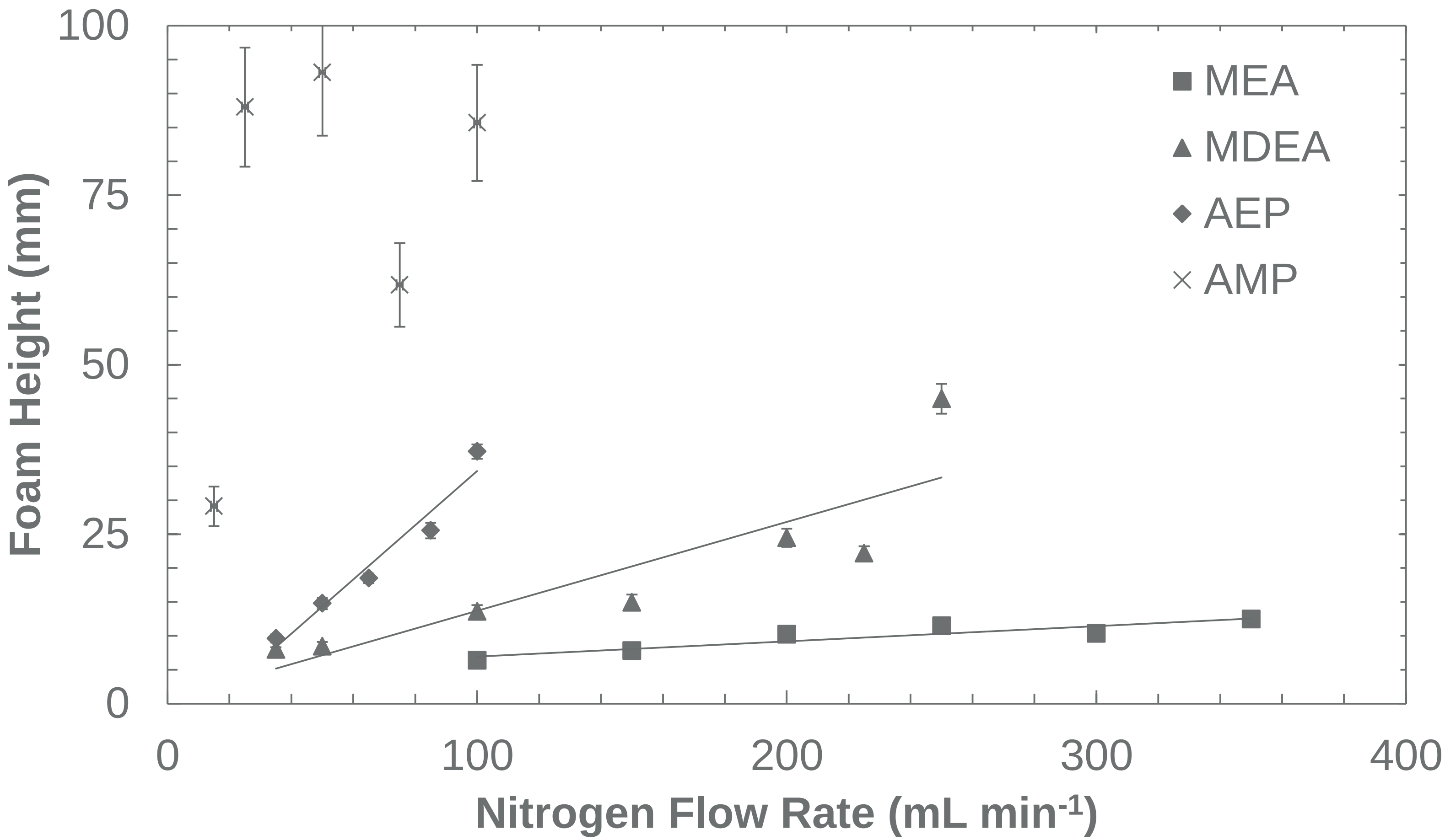
Amine Solvent Foaming – Bikerman Model



MEA, MDEA, AEP all demonstrate likely linear relationships, (as suggested by the Bikerman model)

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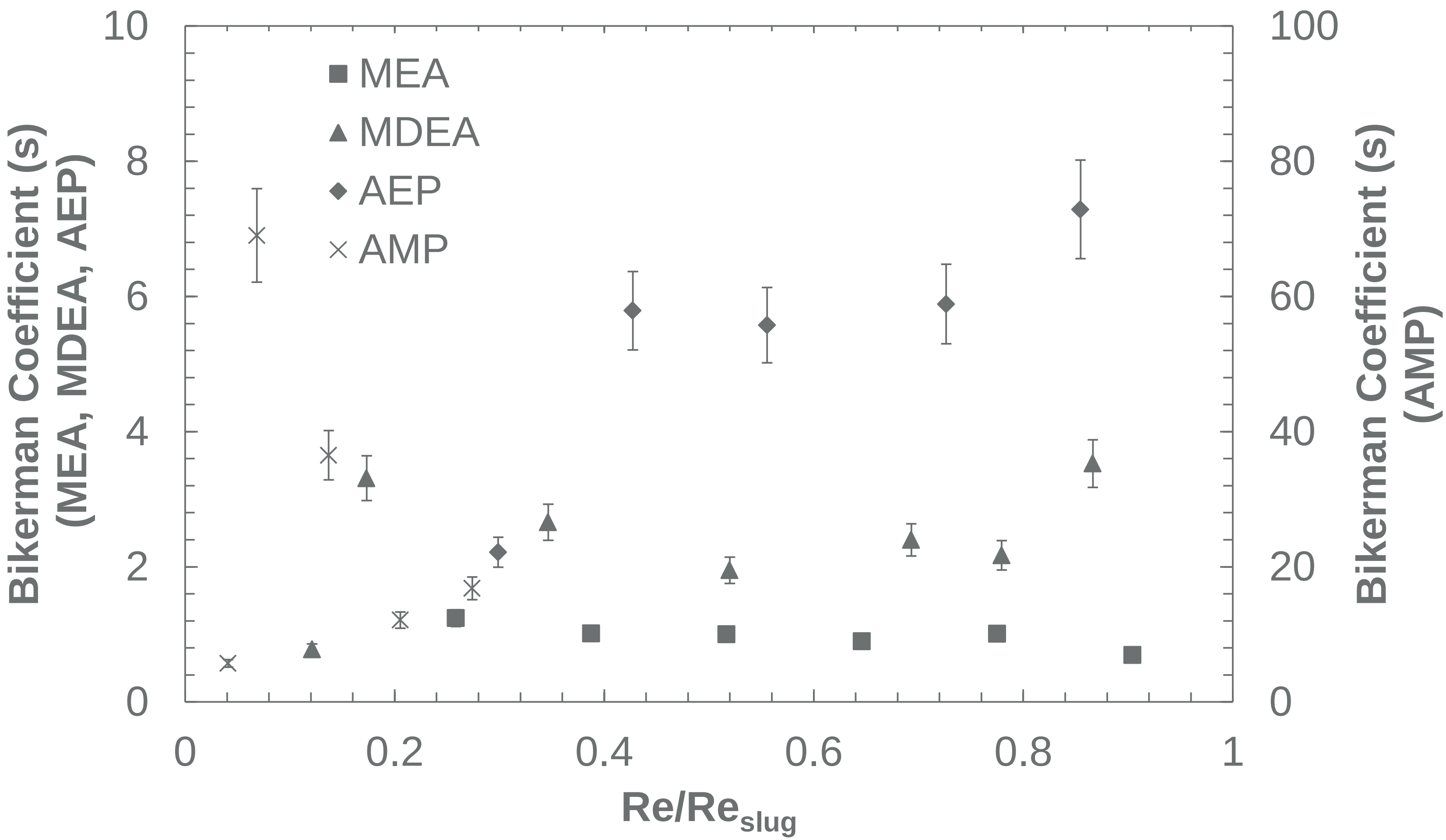
Amine Solvent Foaming – Improving Bikerman Model



MEA, MDEA, AEP now scale approximately to a constant across full foaming to slugging regime

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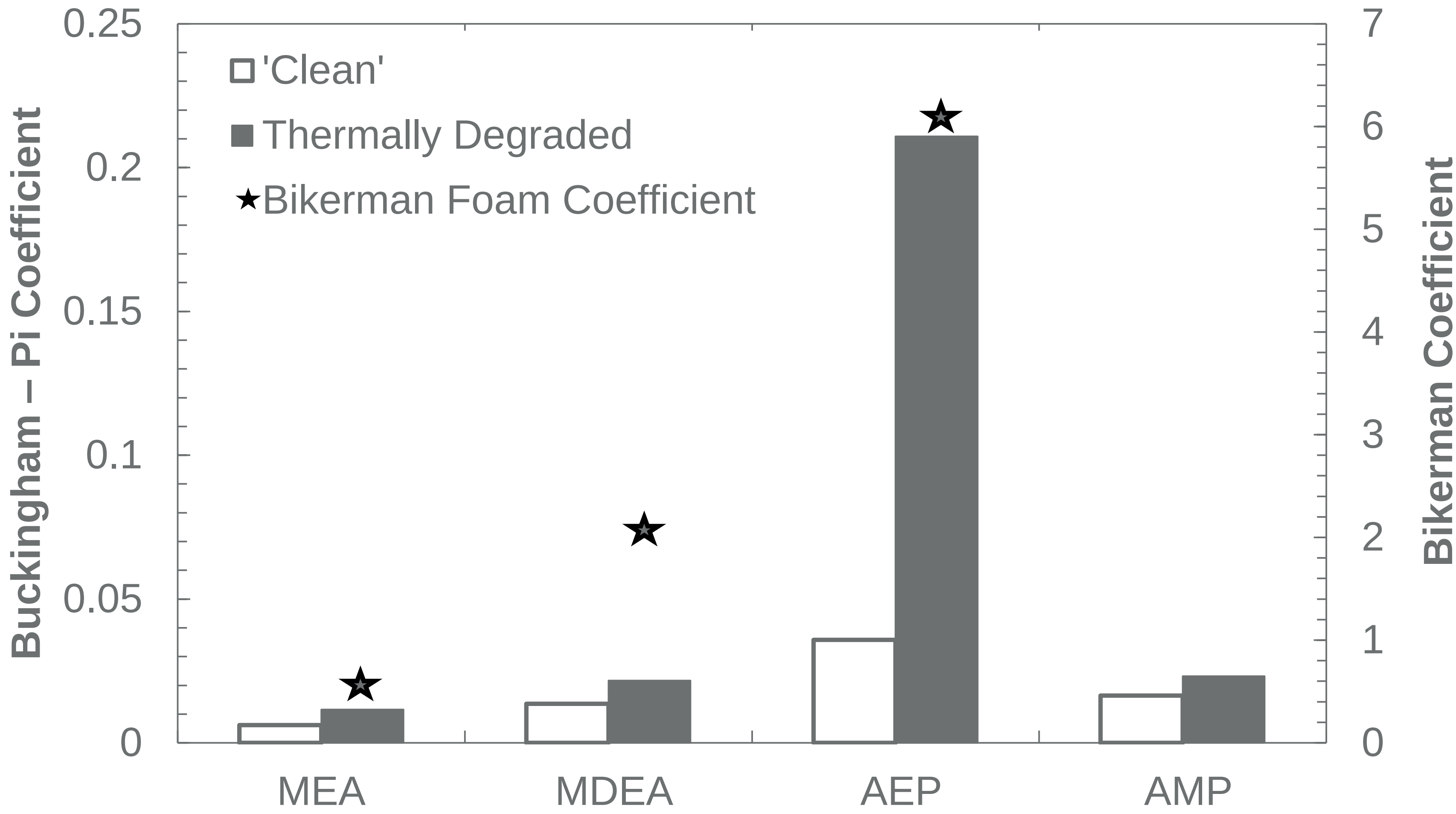
Amine Solvent Foaming – Buckingham – Pi Model



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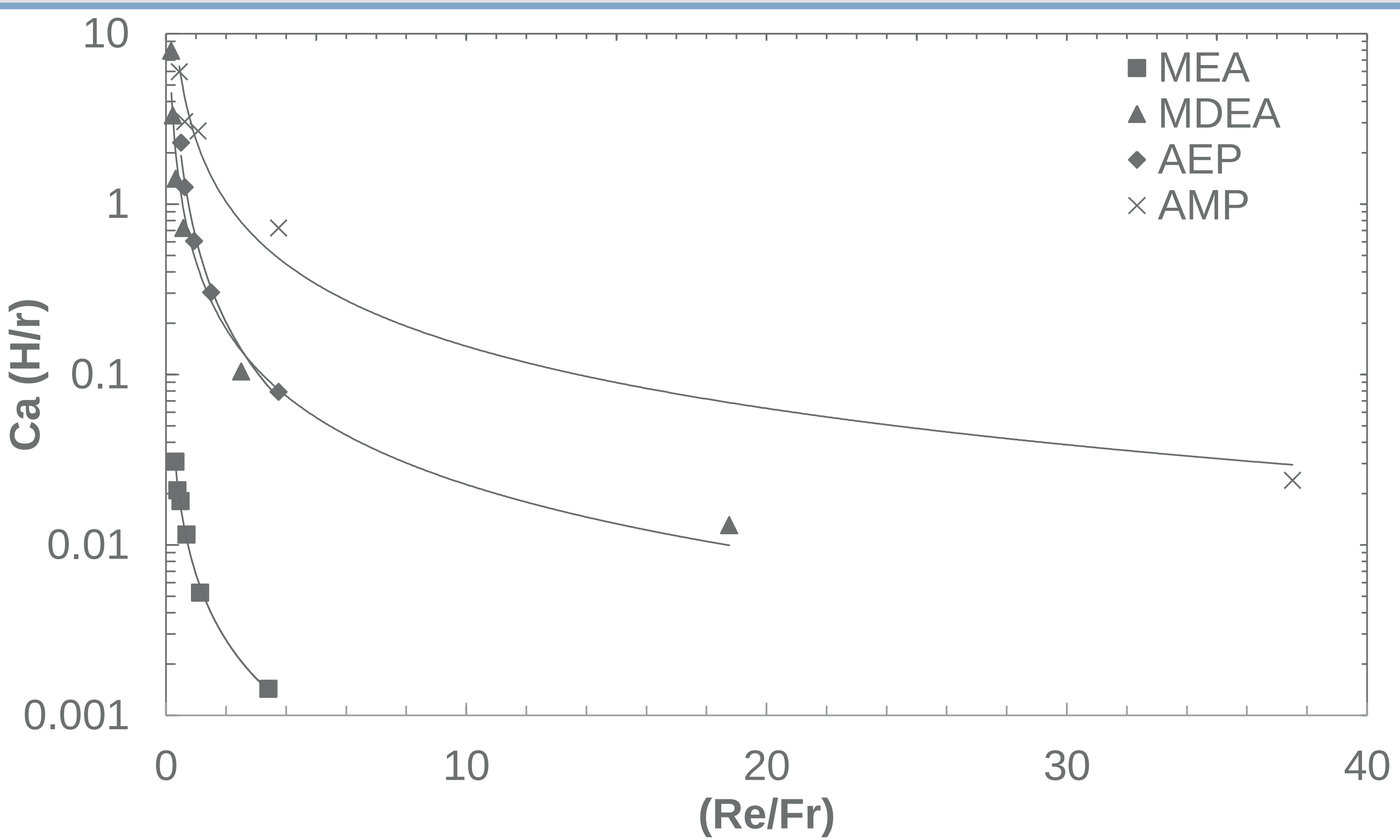
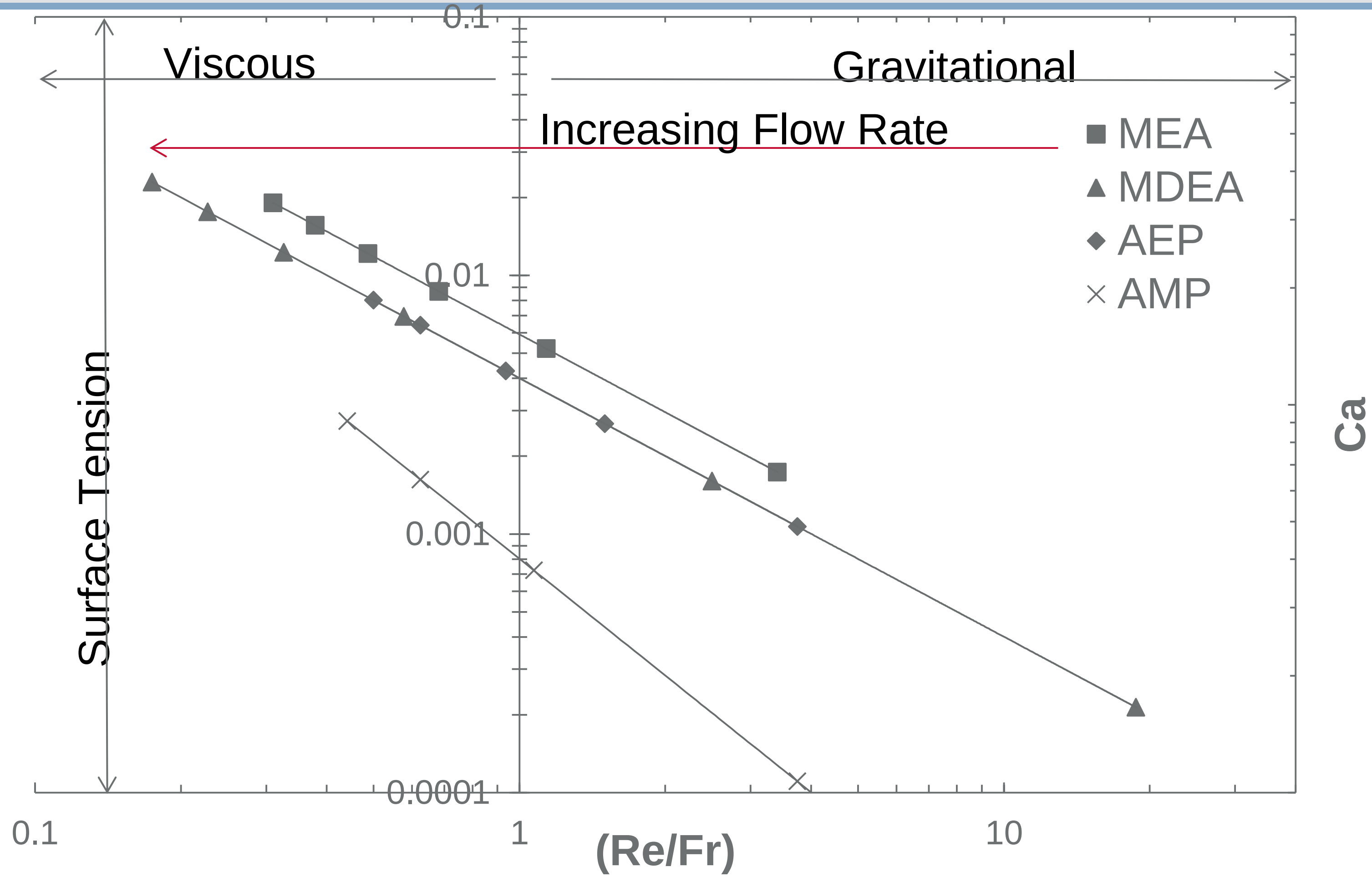
Amine Solvent Foaming – Non-Dimensional Analysis



Power law fitting indicates that the power ~ -1.4 for all four amine solvents
Pre-exponential factor varies by three order of magnitude

Amine Solvent Foaming – Non-Dimensional Analysis



Surface tension dominates strongly

Viscous forces play a role at high flow rates, gravitational at low ones

Conclusions

The foaming behavior of amine solvents are NOT consistent and must be considered individually before forming classifications

‘Clean’ MEA and AEP do not foam ; MDEA and AMP do foam

The formation of degradation products → changes solvent physical properties → changes foaming behavior

- Oxidative < Thermal Degradation induced foaming

Unstable foam: MEA, MDEA, AEP ; Stable foam: AMP

Non-dimensional method appears the best but still provides limited physical understanding of the data collected

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Acknowledgements

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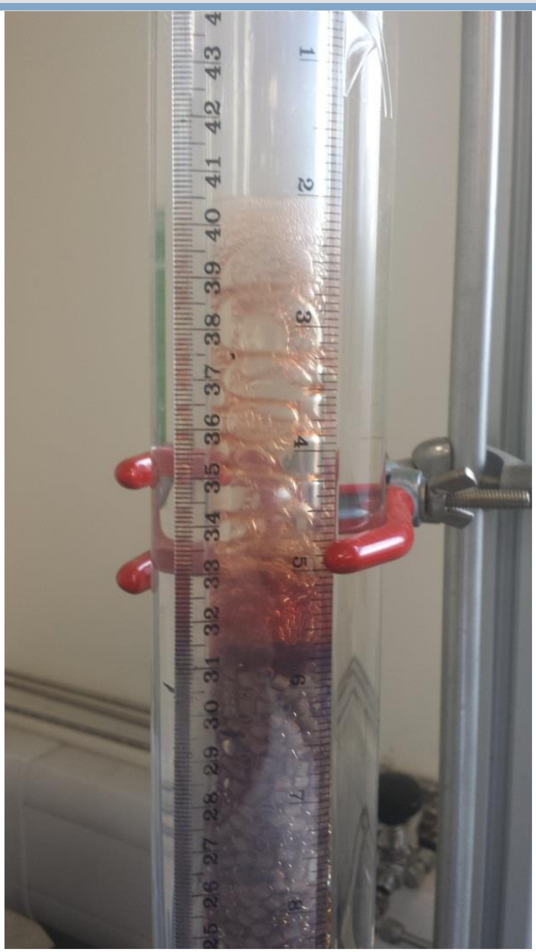

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