Effects of Mixing Energy and Hydrodynamics on Chemical Dispersion of Crude Oil in Bench-Scale Tests

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Advantages of Bench-Scale Testing

- Useful for empirical testing of dispersant effectiveness
  - screen dispersant-oil combinations
  - evaluate effects of oil weathering and environmental factors
- Simple, inexpensive replication
  - evaluate statistical significance of results
  - accurately reproduce experimental conditions in different labs and at different times
- Check data quality using mass balances

Disadvantages of Bench-Scale Testing

- Bench-scale tests cannot predict effectiveness at sea
  - ➢ method for scaling results to predict at-sea performance is not clear
  - ➢ energy dissipation rate has been suggested as fundamental scaling parameter
- Relatively poor correlation between effectiveness in different bench-scale tests
  - ➢ energy dissipation rates have not been determined for many bench-scale effectiveness procedures at typical operating conditions
  - ➢ differences in droplet-formation mechanisms may be responsible for variability among procedures

Objectives

- Measure dispersion effectiveness in two well-characterized experimental systems over wide range of energy dissipation rates
- Evaluate effects of mixing energy and hydrodynamics on droplet-size distributions of dispersed oil

Experimental Conditions

- Crude oil:
  - weathered Mars (Gulf of Mexico; initial API gravity ≈ 30)
  - evaporative mass loss = 18% (final API gravity ≈ 22)
  - oil-water ratio = 1:1200
- Dispersants:
  - sorbitan monooleate (Span 80; HLB = 4.3) and ethoxylated sorbitan monooleate (Tween 80; HLB = 15) in dodecane
  - HLB = 10 and HLB = 12
  - dispersant-oil ratio = 1:25 (pre-mixed)
- Mixing systems:
  - baffled flask and baffled paddle jar
  - mixing energy: 0.00017 to 0.16 J/kg-s
  - mix for 15 minutes; settle for 10 minutes

Baffled Flask

Paddle Jar

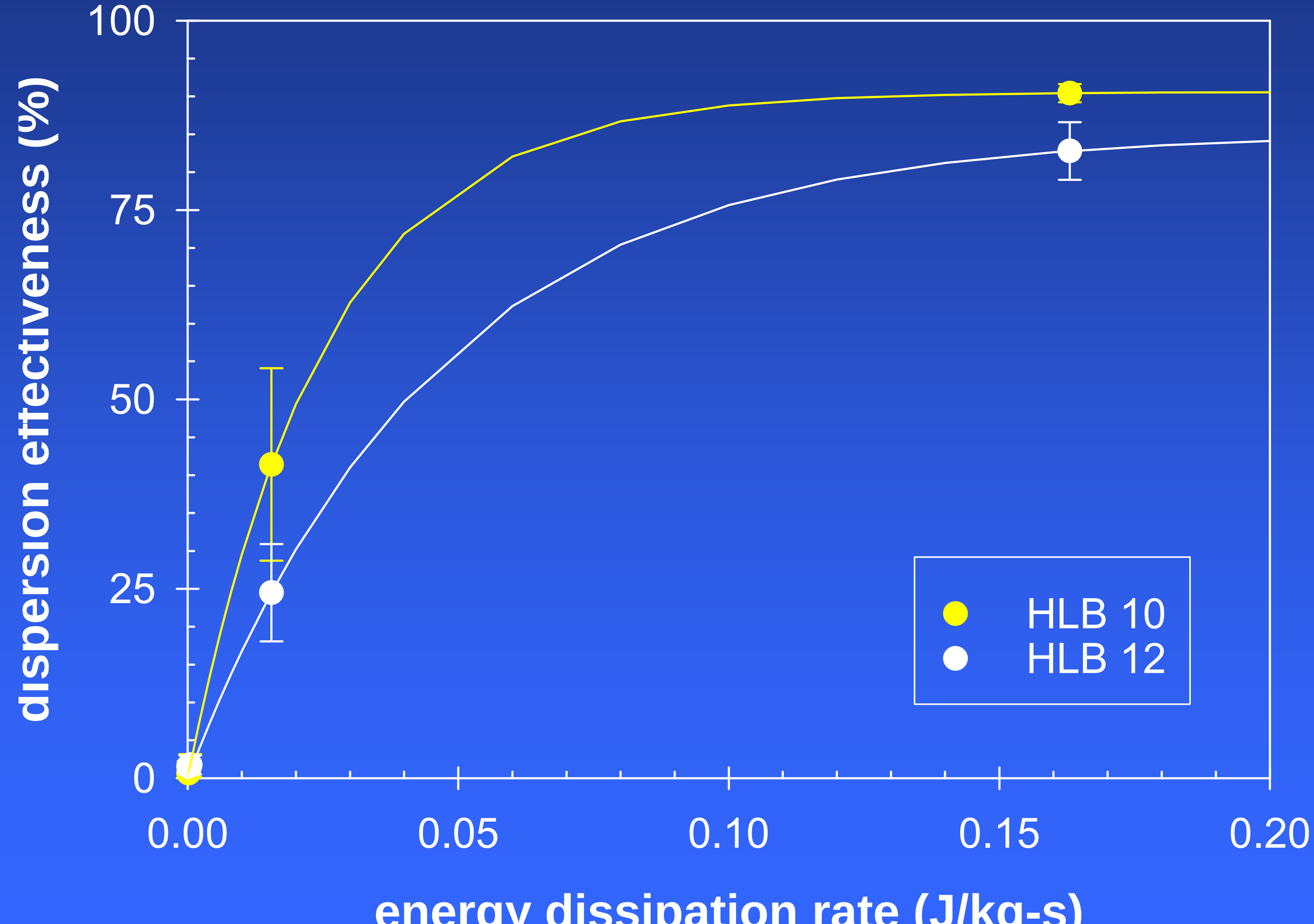
Analytical Methods

- Dispersion effectiveness (η):
  - extract dispersed oil into dichloromethane
  - measure oil concentration by integrated absorbance (340 to 400 nm)

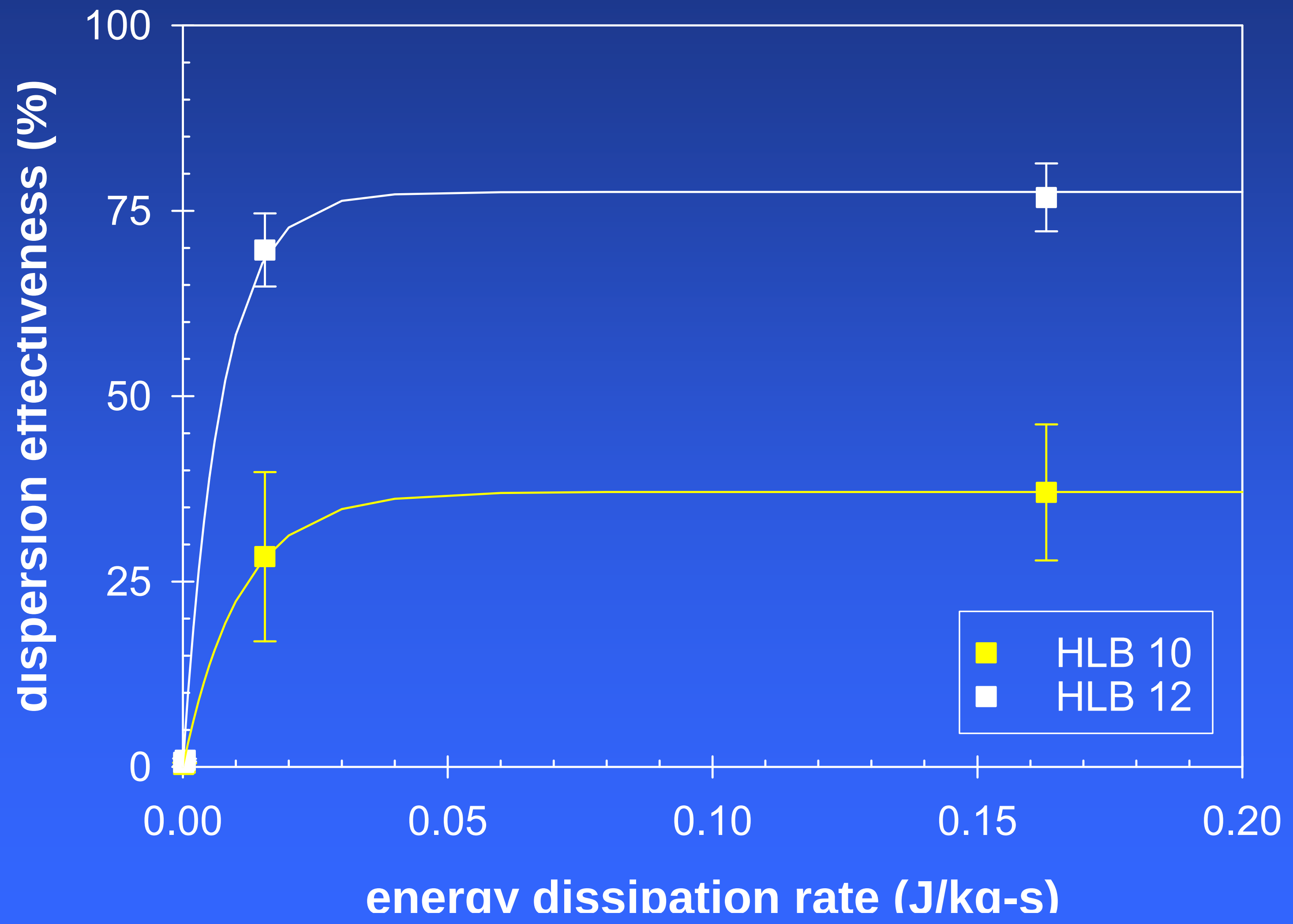
$$\eta = \frac{M_{oil,extracted}}{M_{oil,added}}$$

- Droplet-size distribution:
  - dispersed oil droplets measured and counted (number distribution) using optical particle counter (OPC)
  - compute volume distribution and dispersed oil volume
- Quality assurance/quality control:
  - mass balances on $\geq$5% of experimental units
  - effectiveness based on dispersed oil volume (OPC) not significantly different from effectiveness based on extraction

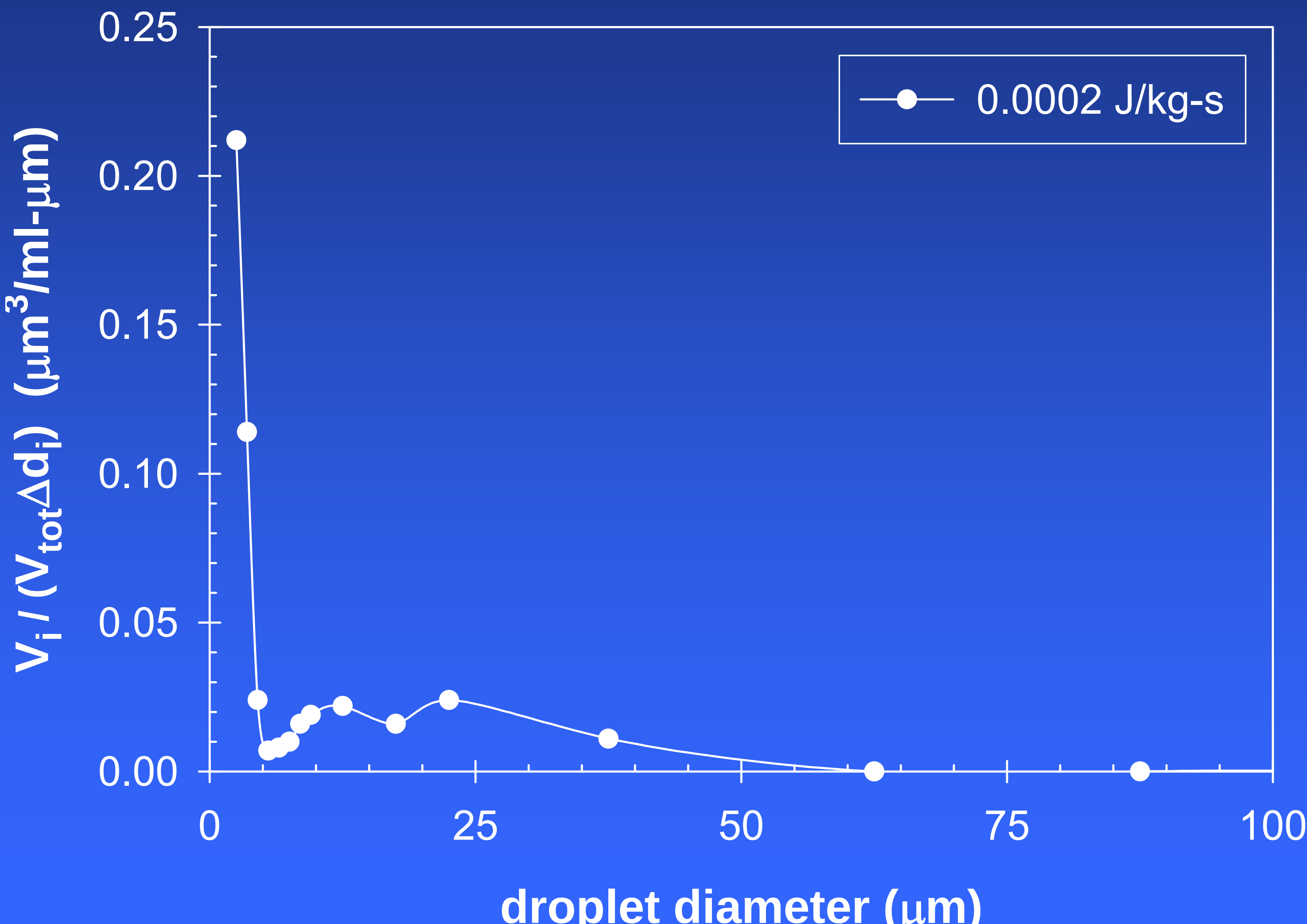
Effect of Mixing Energy on Dispersion Effectiveness: Baffled Flask



Effect of Mixing Energy on Dispersion Effectiveness: Paddle Jar



Effect of Mixing Energy on Droplet-Size Distributions: Baffled Flask (HLB = 12)



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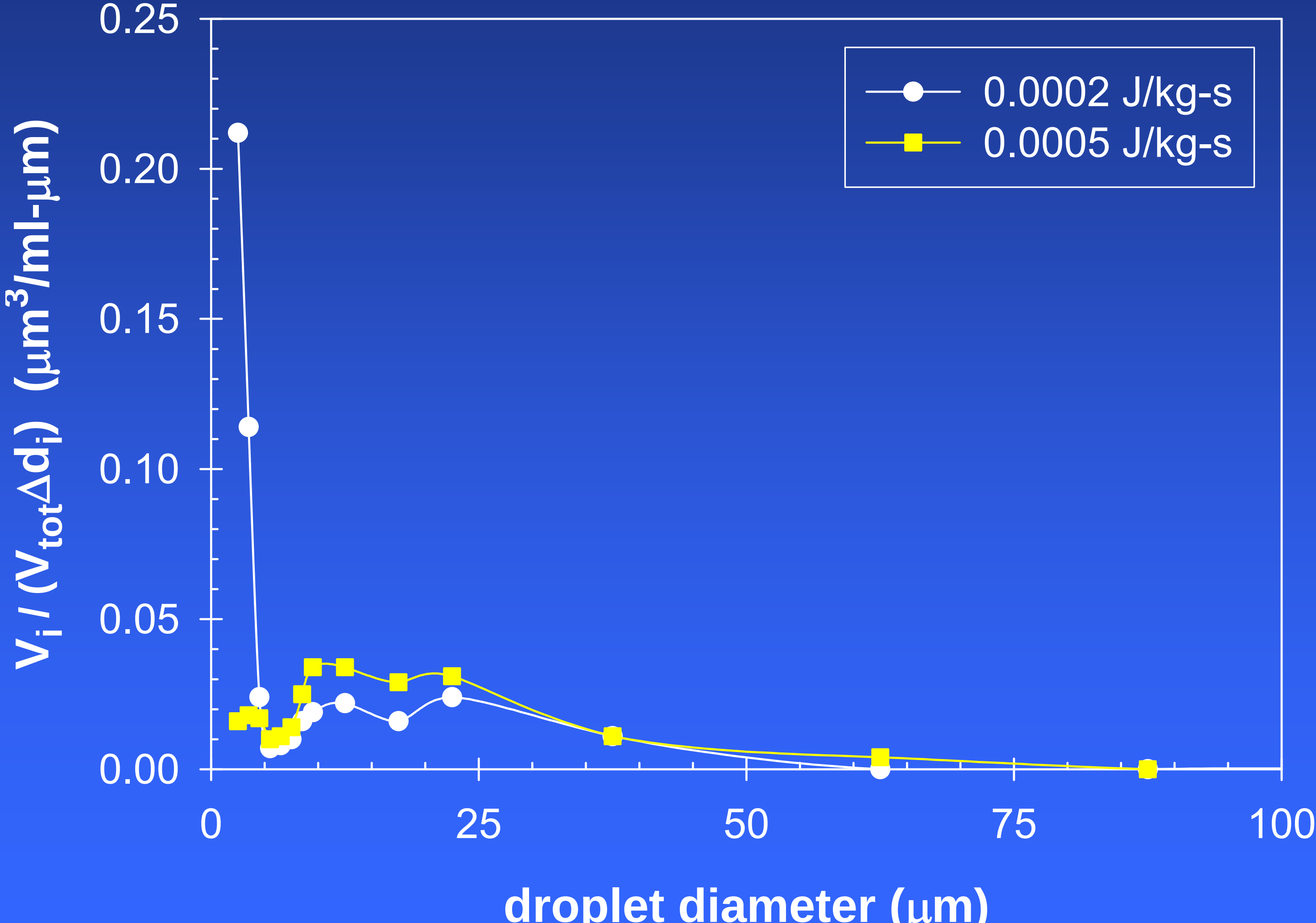

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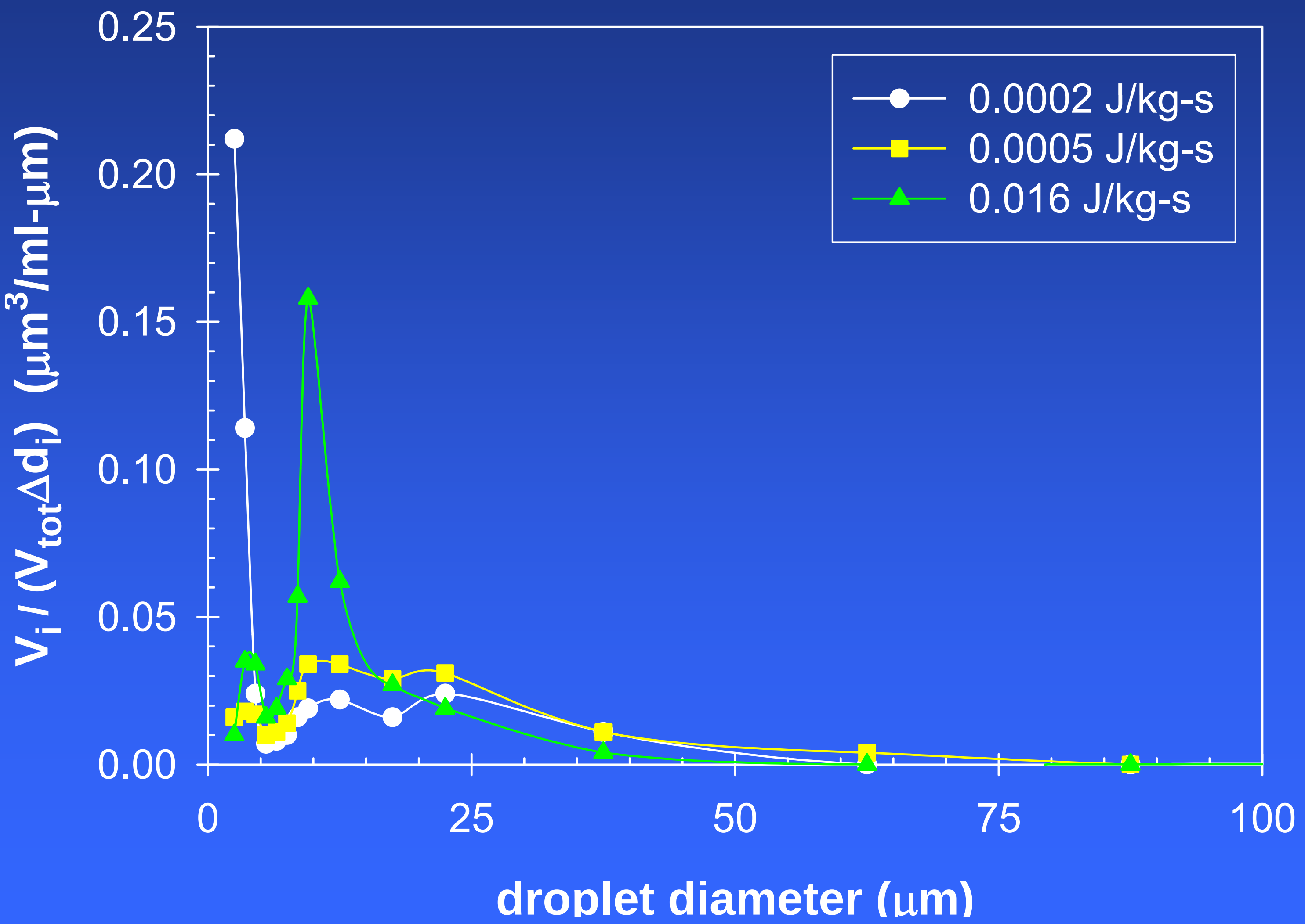

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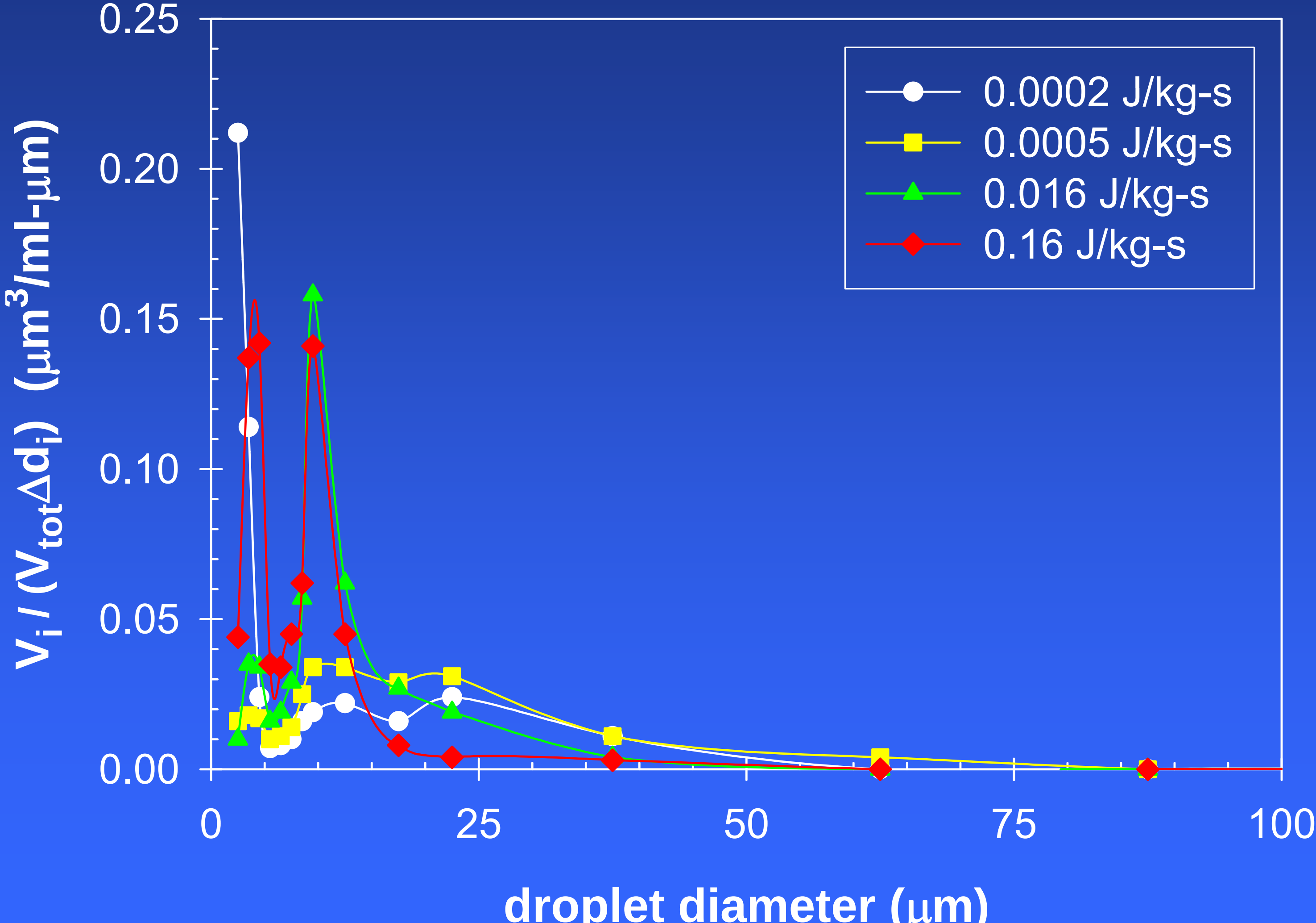
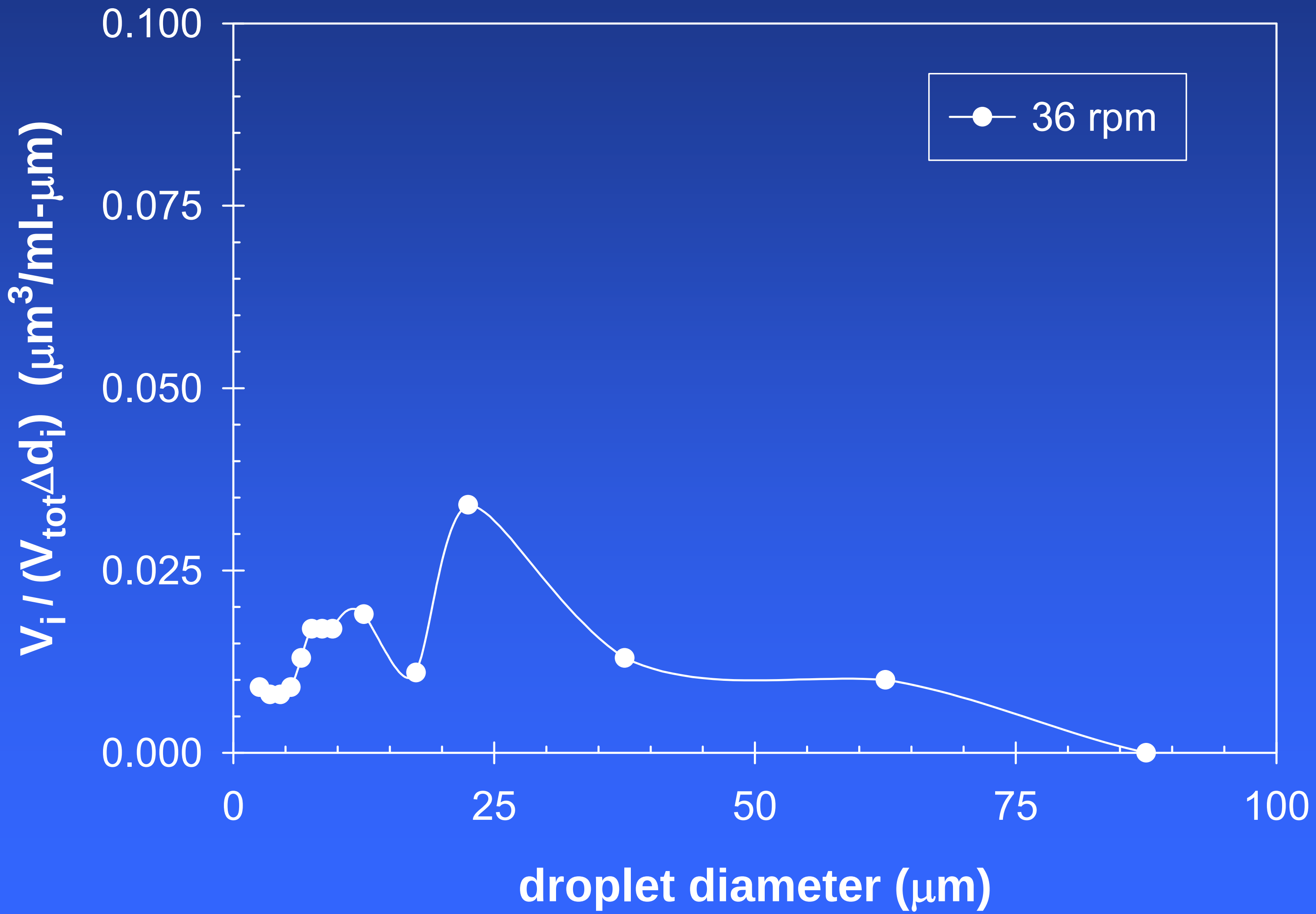


Effect of Mixing Energy on Droplet-Size Distributions: Swirling Flask (HLB = 12)



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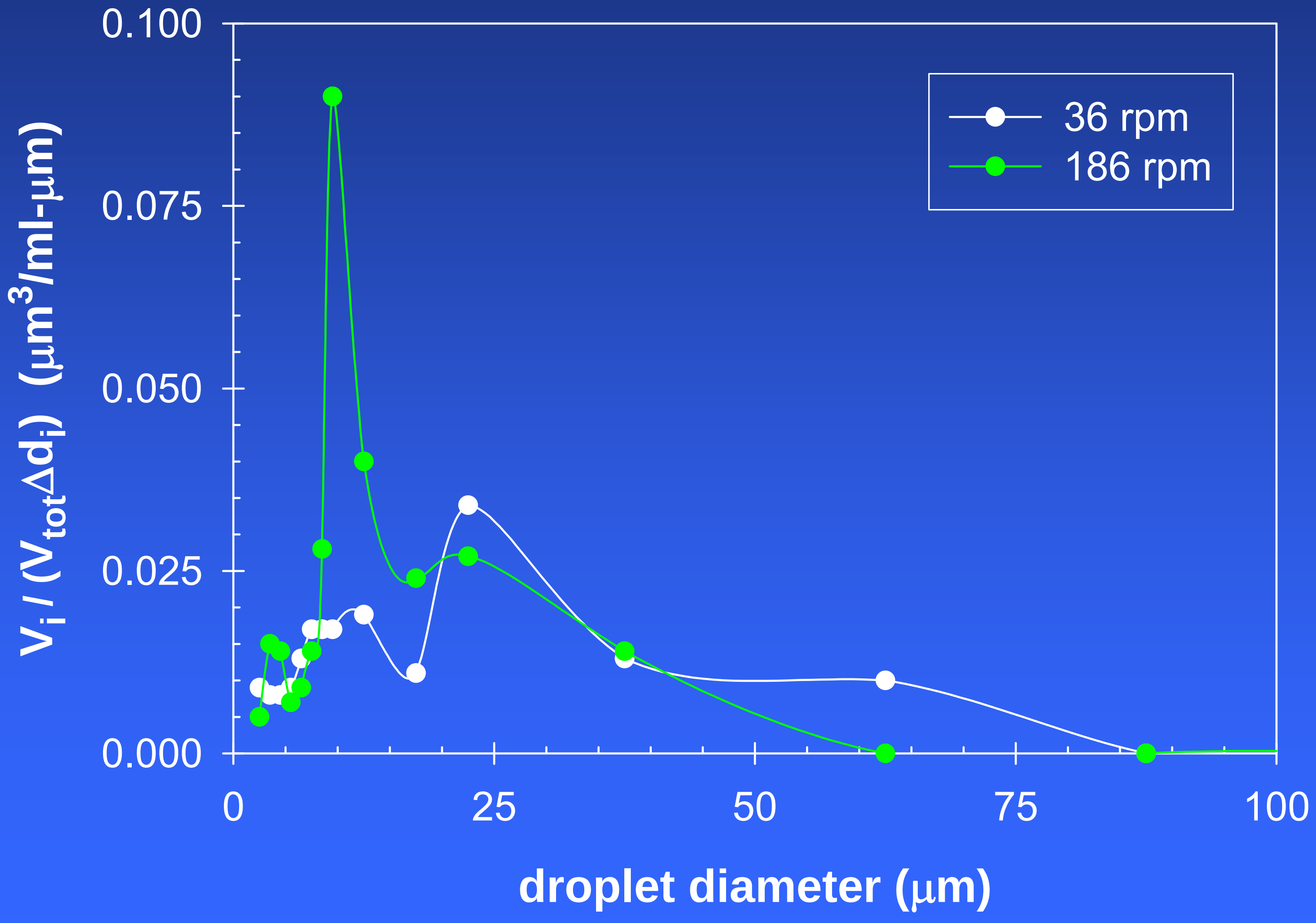
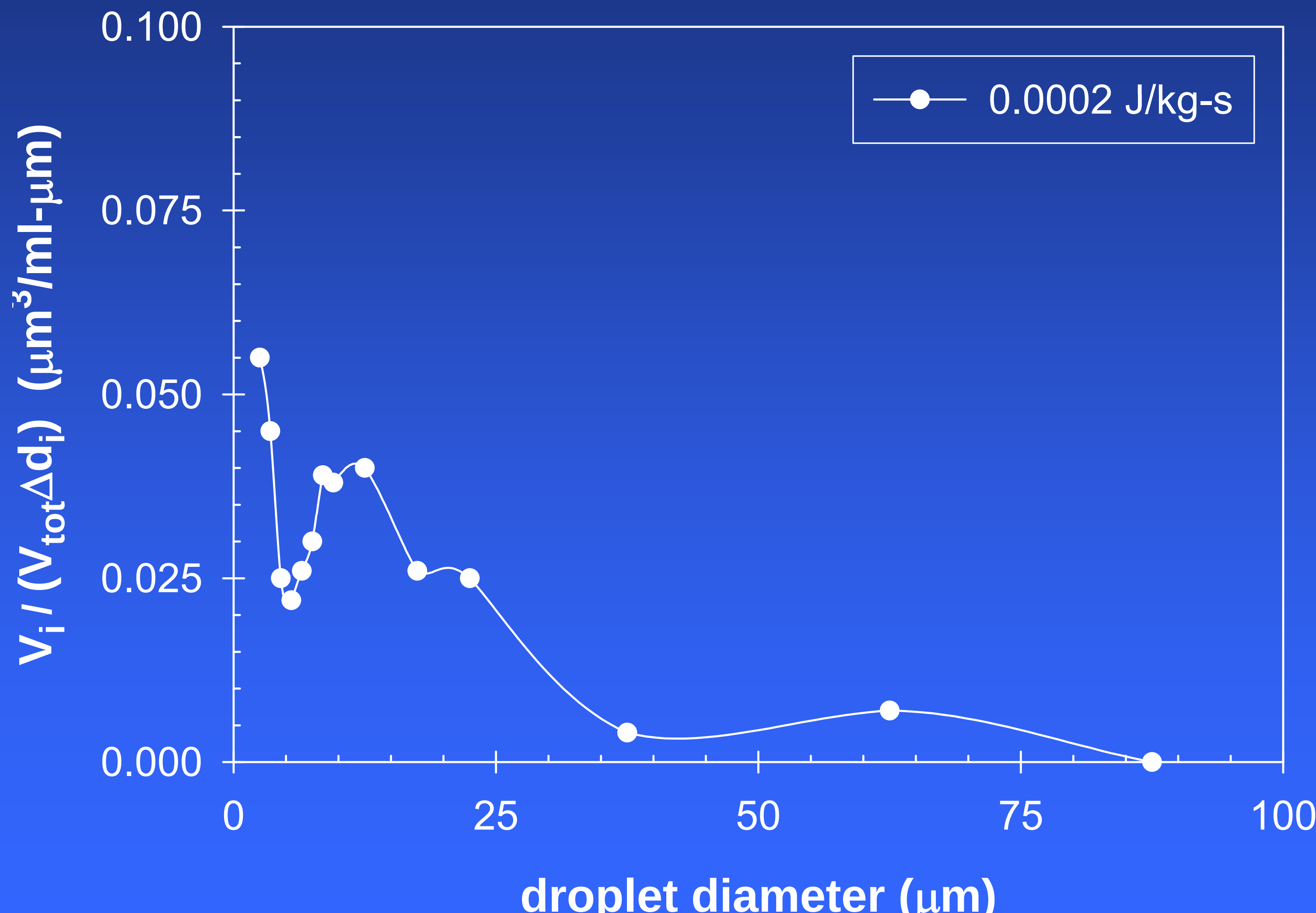


Effect of Mixing Energy on Droplet-Size Distributions: Paddle Jar (HLB = 12)



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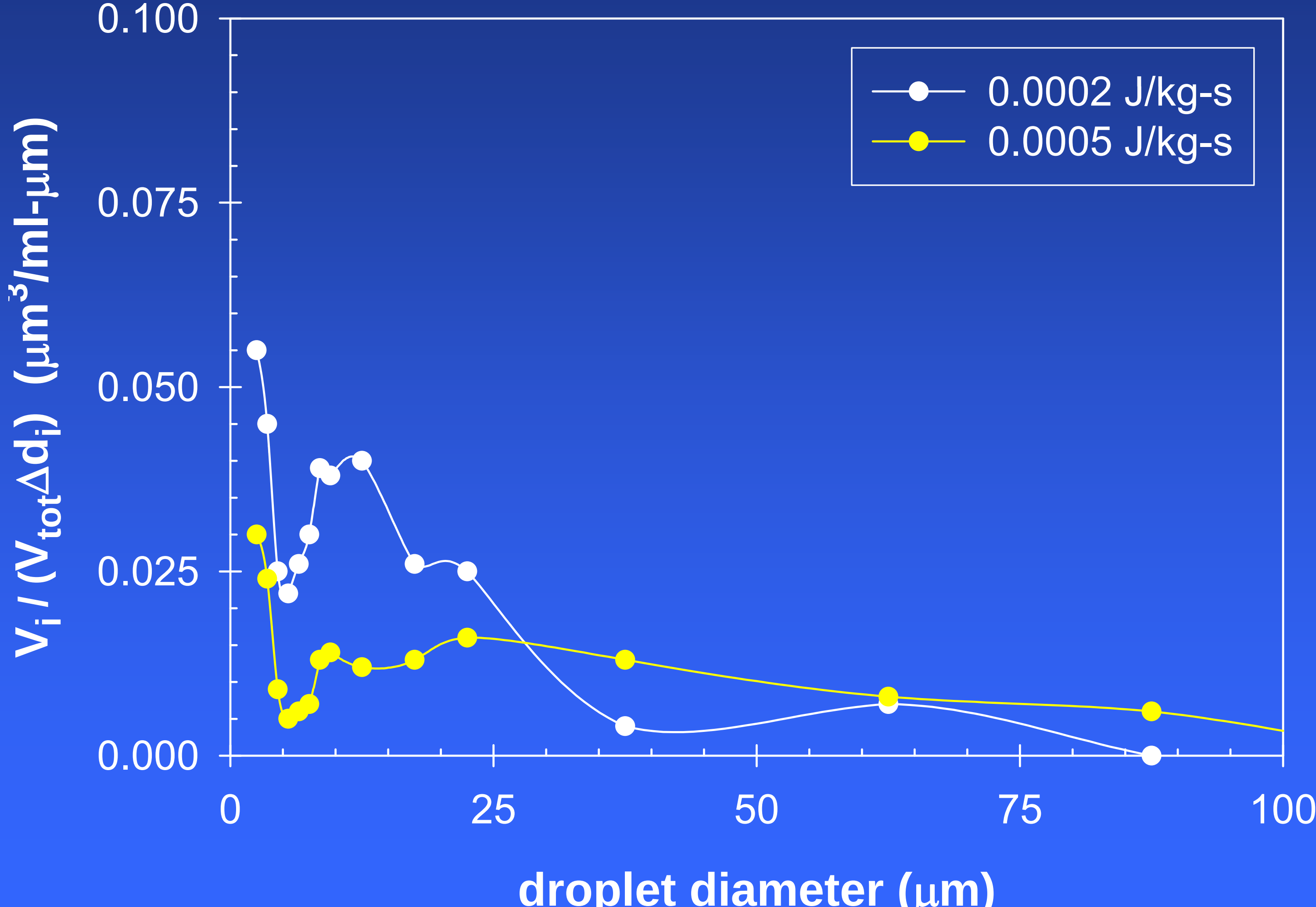

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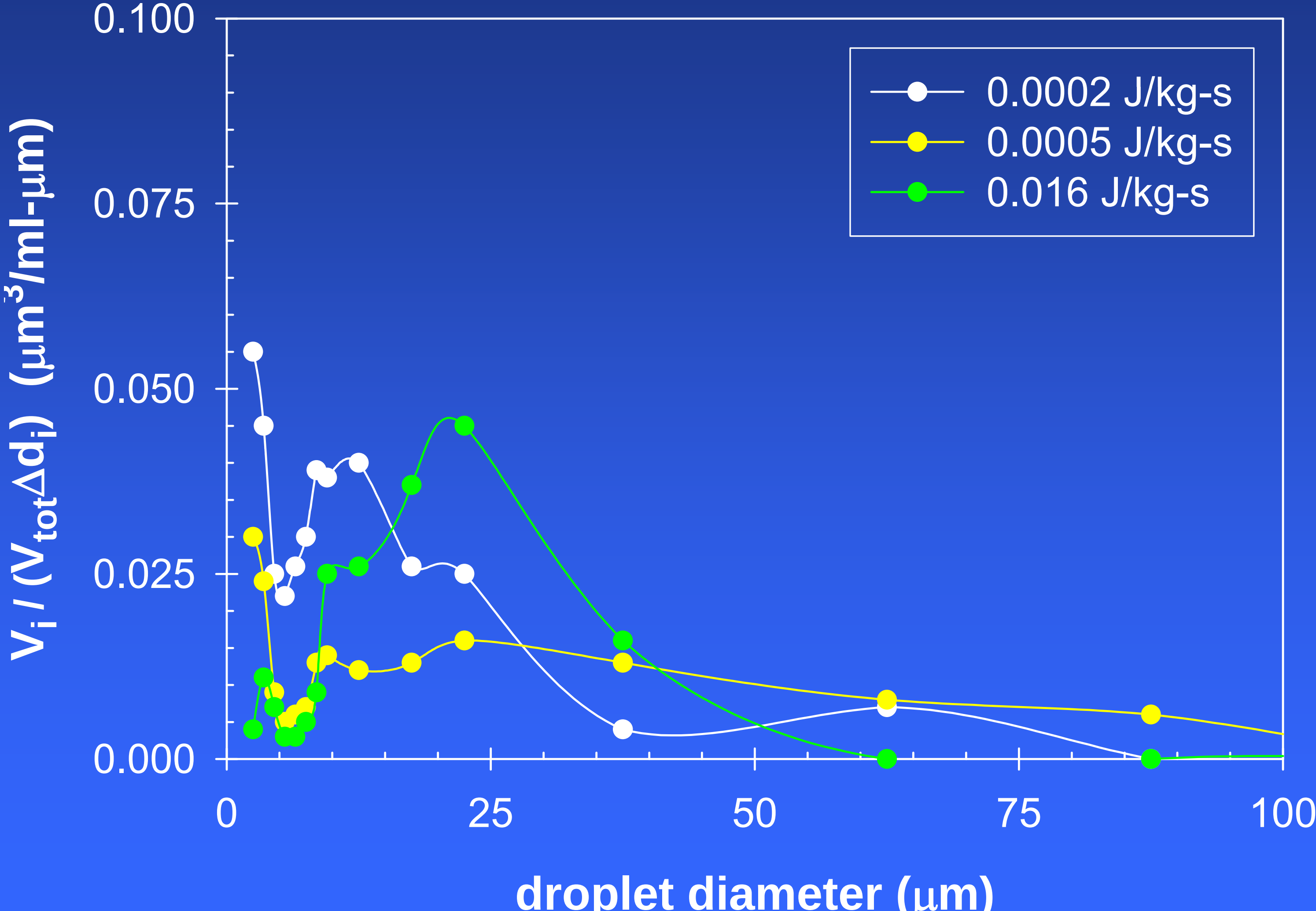

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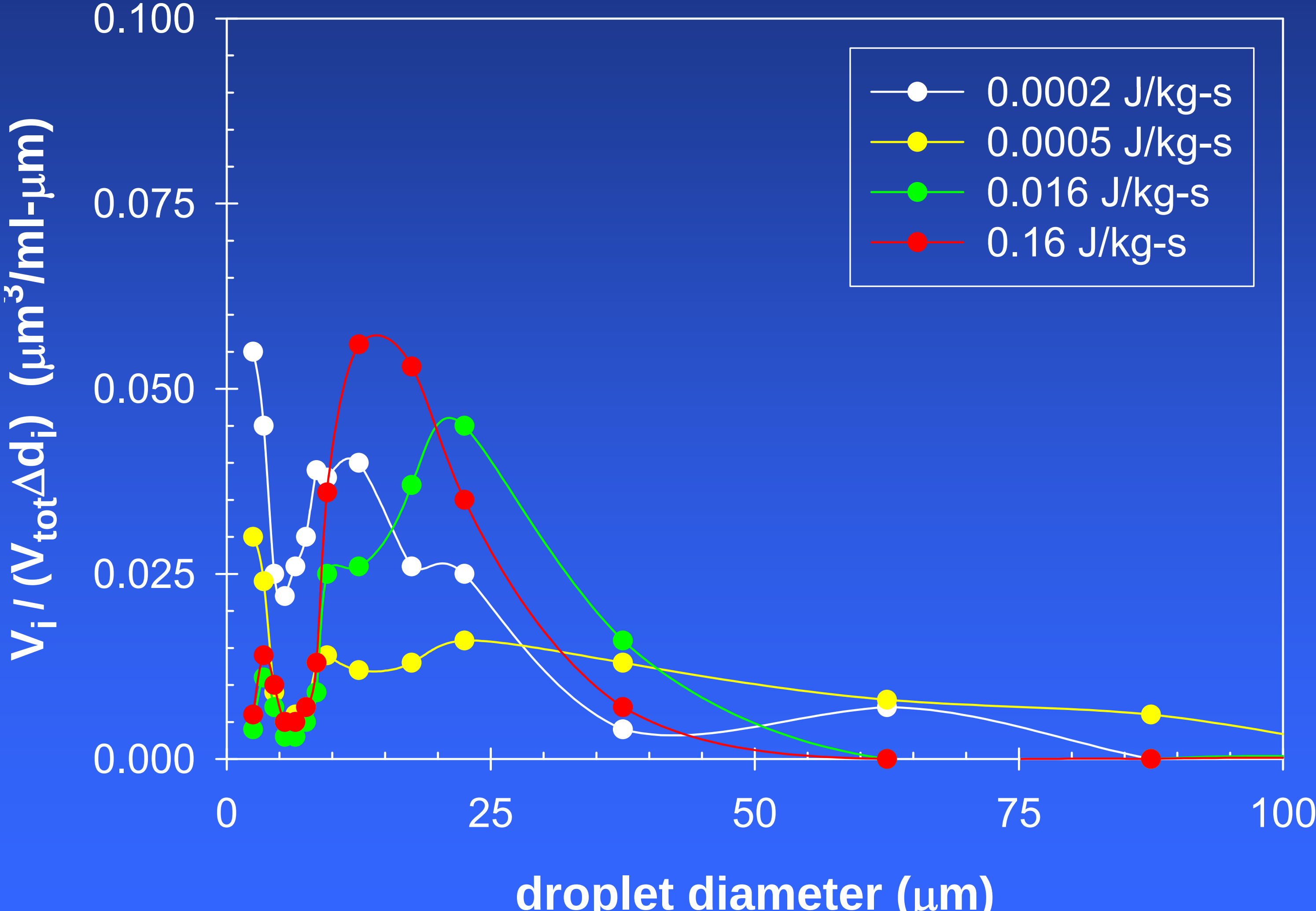
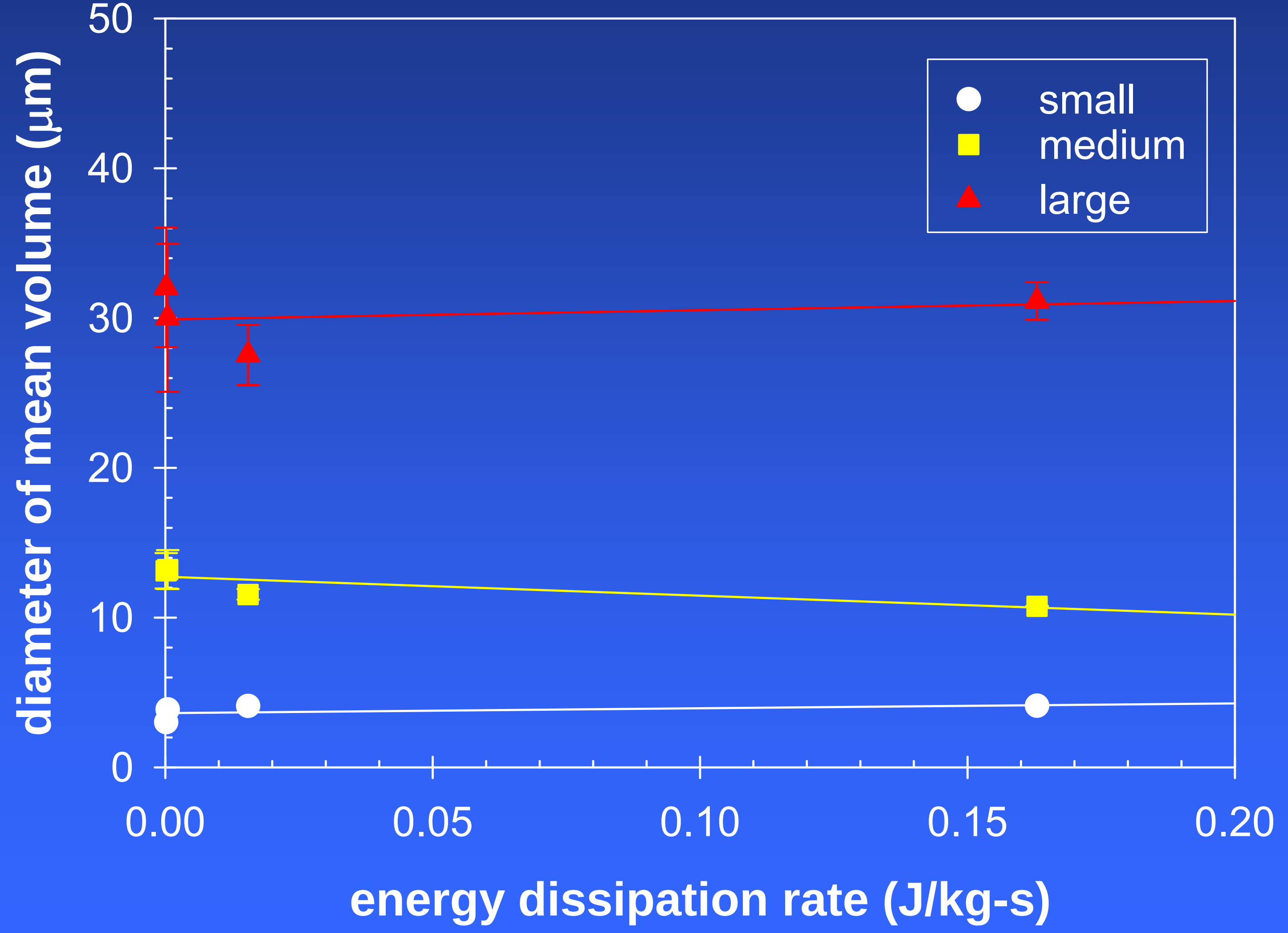


Effect of Mixing Energy on Droplet Size Modes: Baffled Flask (HLB = 12)



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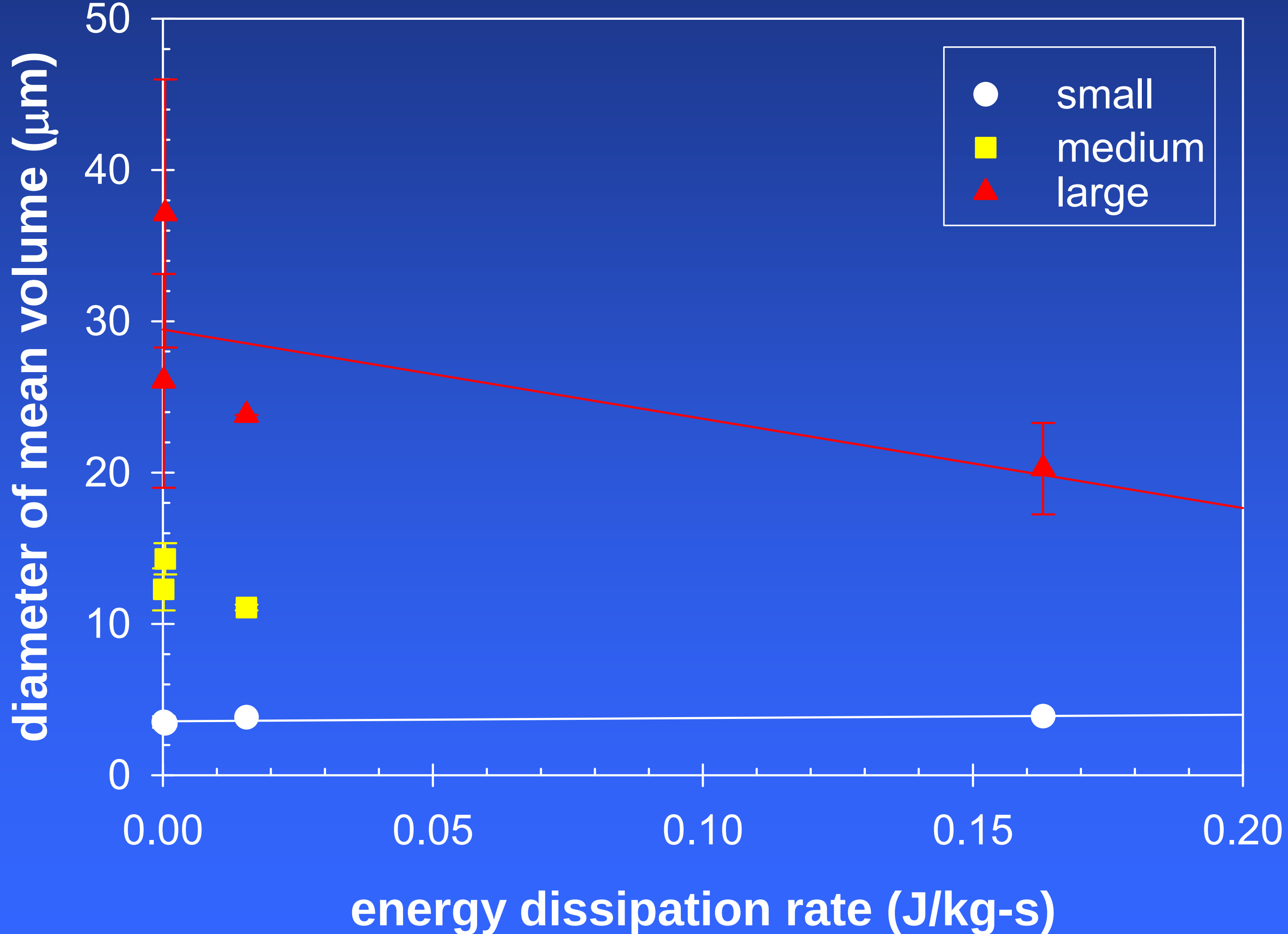
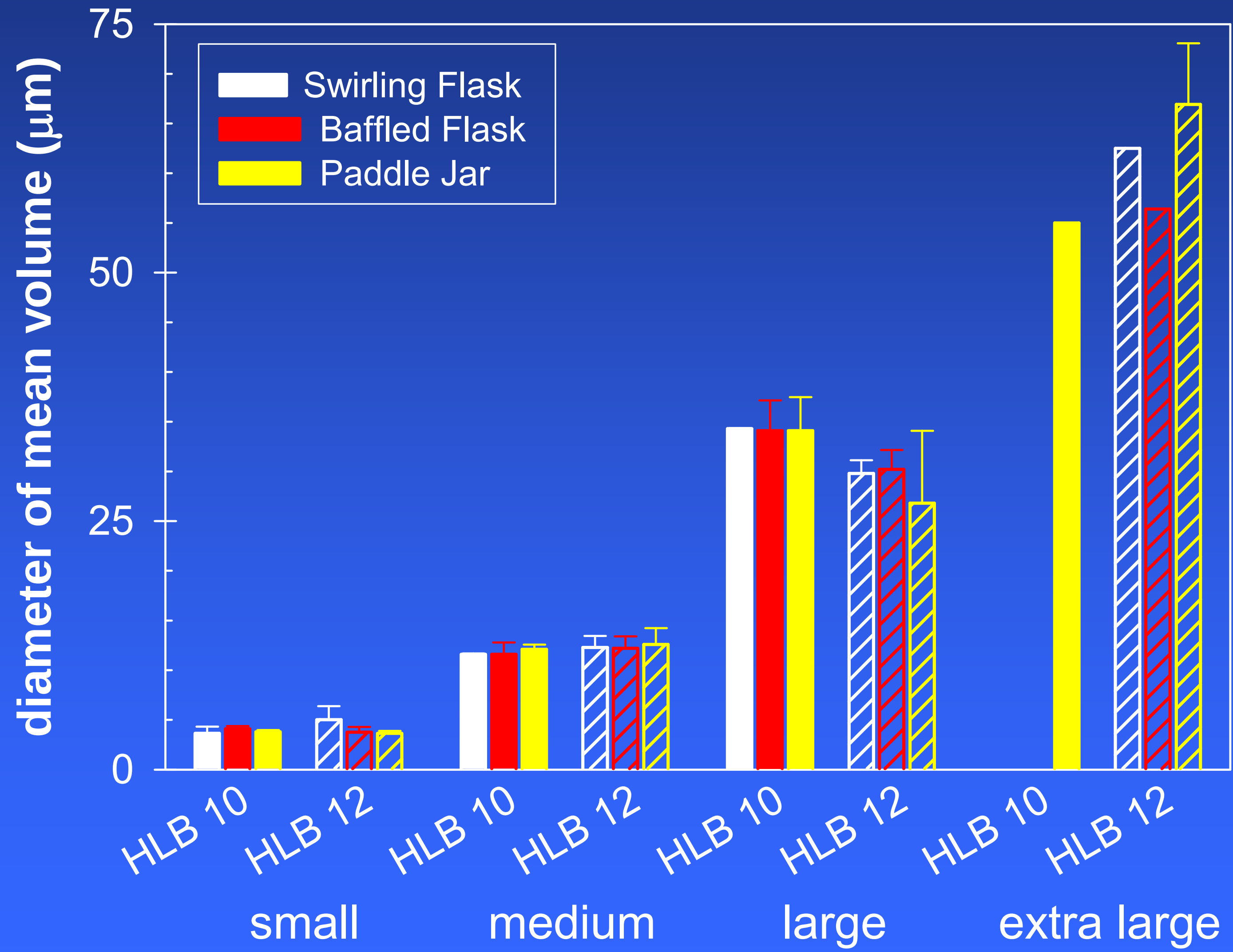
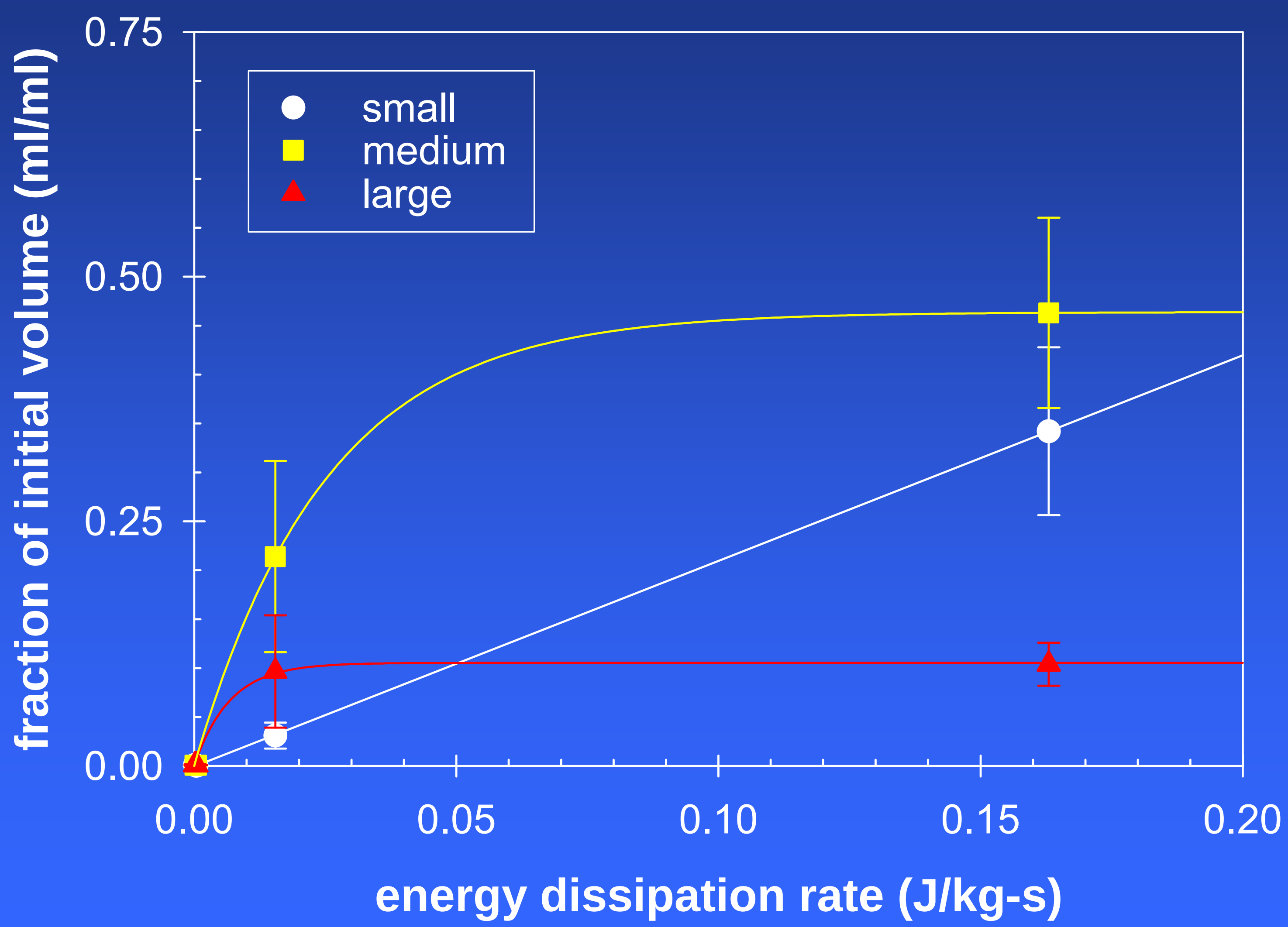


Effects of Mixing System and Dispersant HLB on Droplet Size Modes



Effect of Mixing Energy on Distribution of Oil Among Size Modes: Baffled Flask (HLB = 12)



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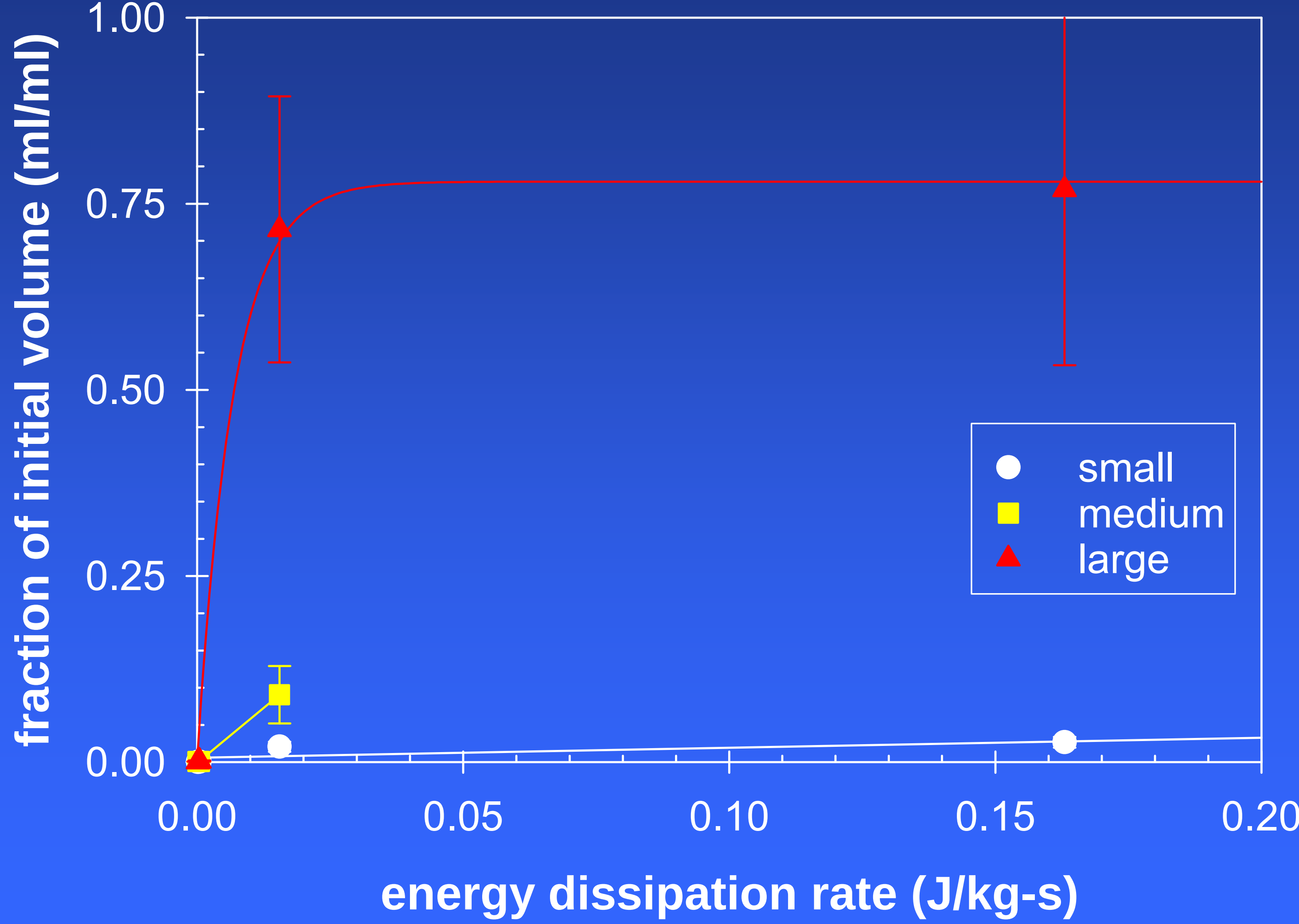
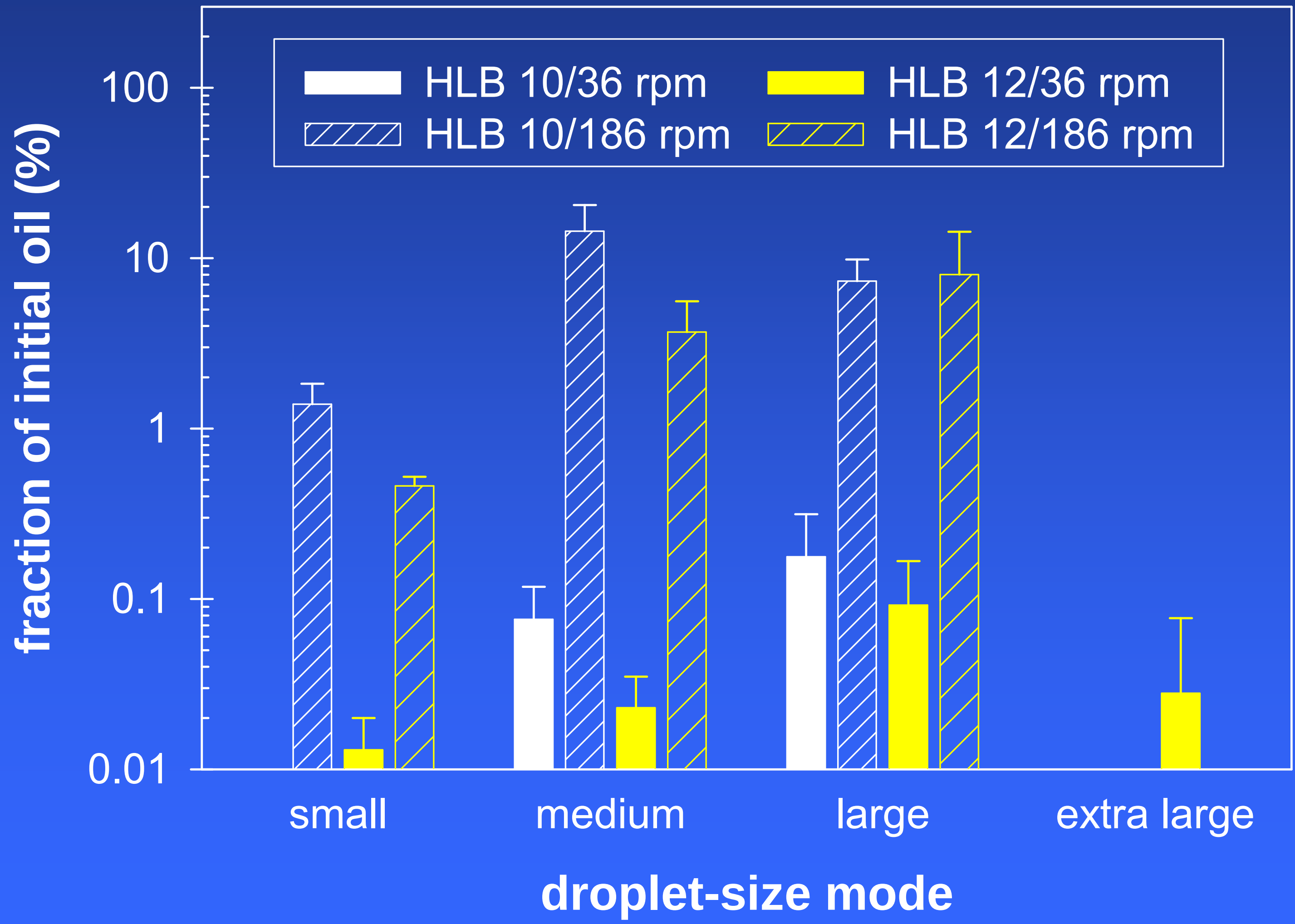


Effect of Mixing Energy on Distribution of Oil Among Size Modes: Swirling Flask



Conclusions

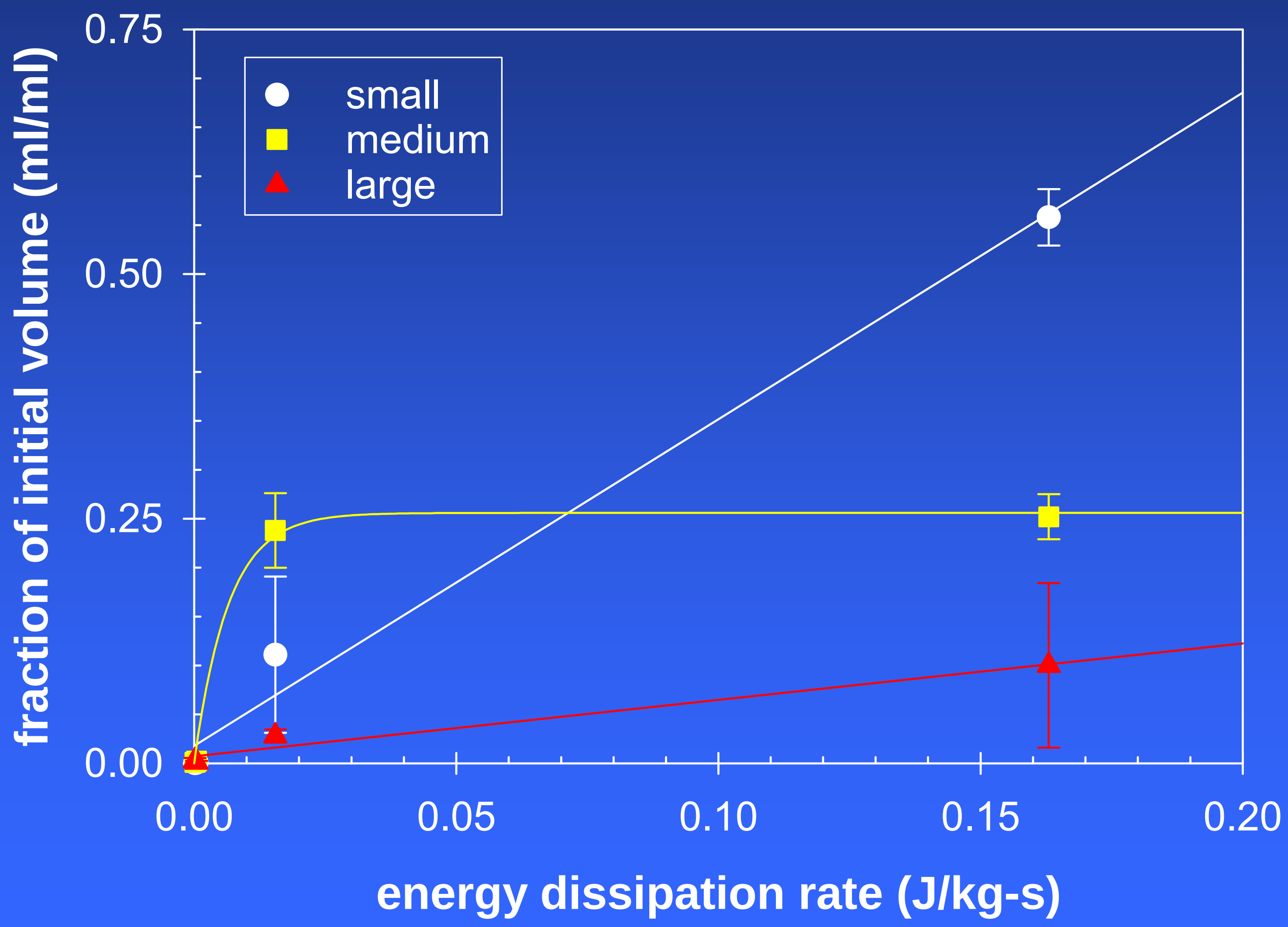
- Dispersion effectiveness increased with mixing energy but did not necessarily approach 100%
- Energy dissipation rate alone was not sufficient as scaling parameter
  - hydrodynamic differences between baffled flasks and paddle jars resulted in different relationships between mixing energy and dispersion effectiveness
  - small differences in dispersant formulation affected performance; relative effectiveness was not consistent across all mixing systems
- Droplet size distributions were (largely) tri-modal; the means of the major modes were unaffected by mixing energy and mixing system
  - the distribution of oil among modes was affected mixing energy and mixing system

Acknowledgements

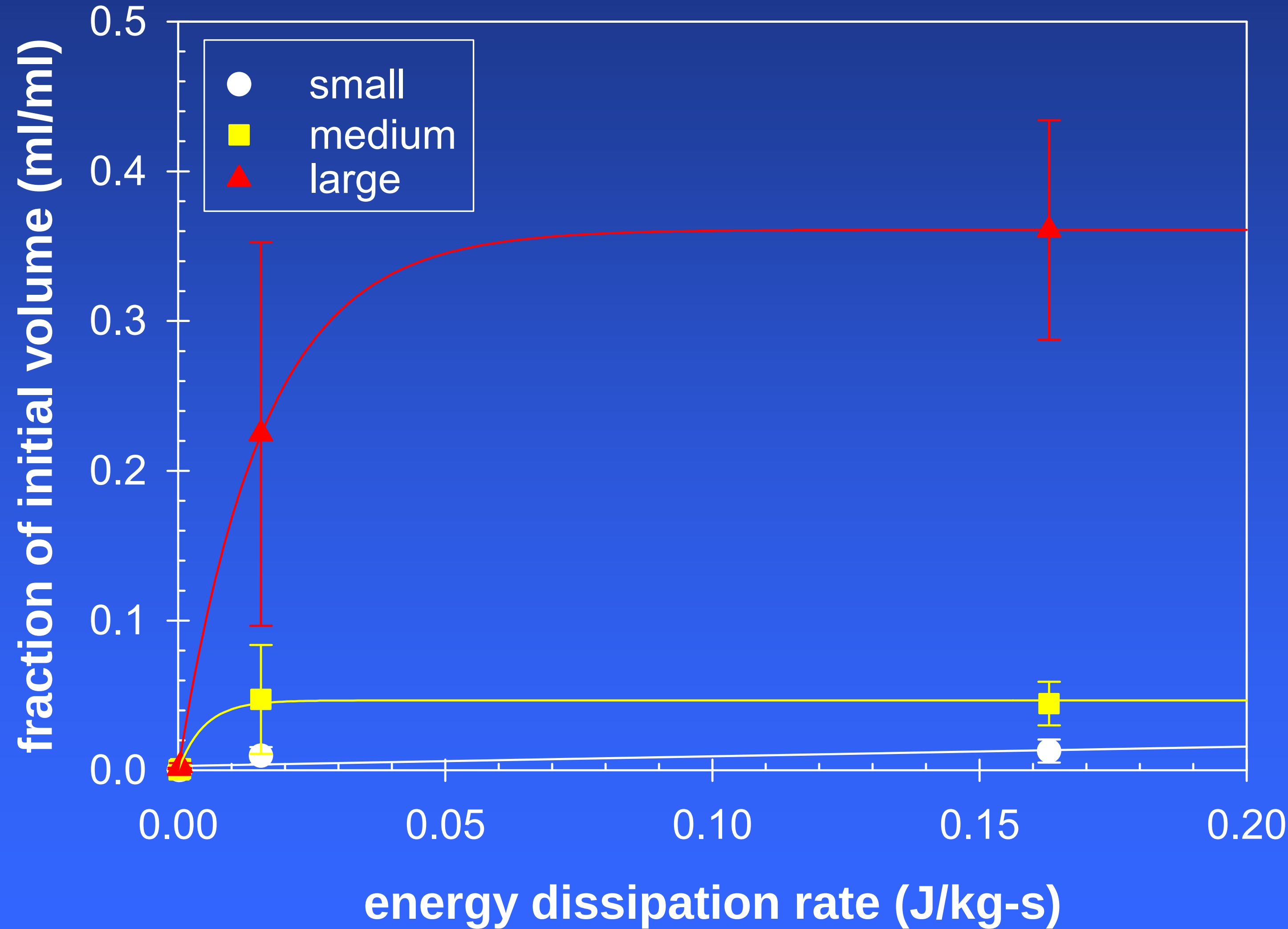
- ConocoPhillips
- Pratim Biswas
- Amanda Virkus and Alyssa Smith

Questions?

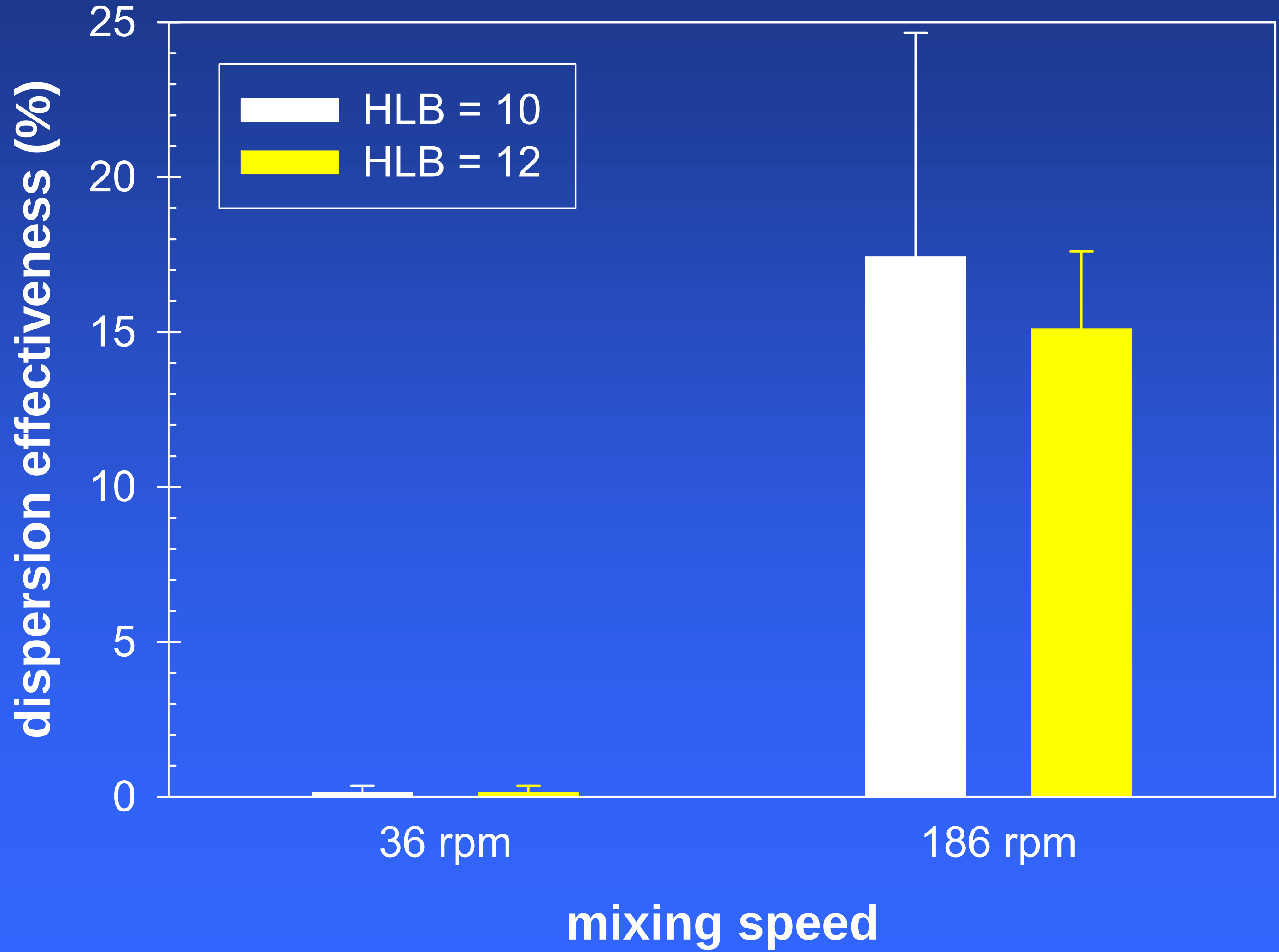
Effect of Mixing Energy on Distribution of Oil Among Size Modes: Baffled Flask (HLB = 10)



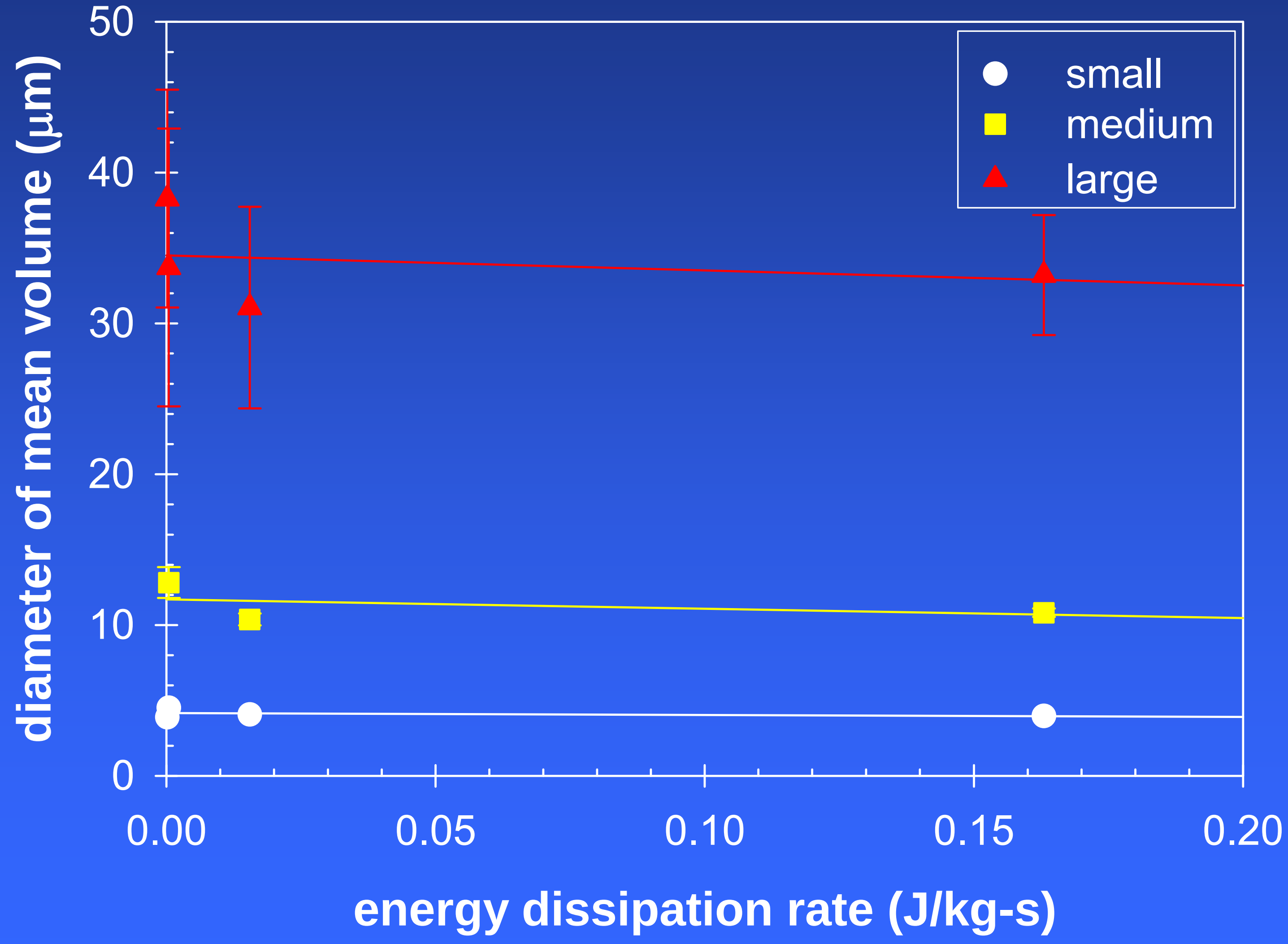
Effect of Mixing Energy on Distribution of Oil Among Size Modes: Paddle Jar (HLB = 10)



Effect of Mixing Speed on Dispersion Effectiveness: Swirling Flask



Effect of Mixing Energy on Droplet Size Modes: Baffled Flask (HLB = 10)



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