

Effect of Impeller Type on Drop Size of Turbulent, Non-coalescing Liquid-Liquid Dispersions

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Abstract

Drop size is one of the most important parameters in liquid-liquid dispersions as it affects mass transfer rates and physical properties of the dispersion and/or products obtained. “Low shear” narrow blade hydrofoils produce the smallest drops at a given power input compared to PBTs and RDTs. However, they all produce the same equilibrium drop size if they operate at the same maximum energy dissipation rate, which can be easily estimated using different approaches.

Introduction

Hinze-Kolmogorov equilibrium theory [1] for maximum stable drop size ($d_{\max}$) of a dispersion in turbulent flow under non-coalescing conditions is given by:

$$d_{\max} = A \left(\frac{\sigma}{\rho_c} \right)^{3/5} \varepsilon^{-2/5} \quad (1)$$

Assuming locally isotropic turbulence, the energy dissipation rate (ε) is related to the turbulent kinetic energy (k) and the flow's integral length scale (ℓ):

$$\varepsilon = 0.54 \frac{k^{3/2}}{\ell} \quad (2)$$

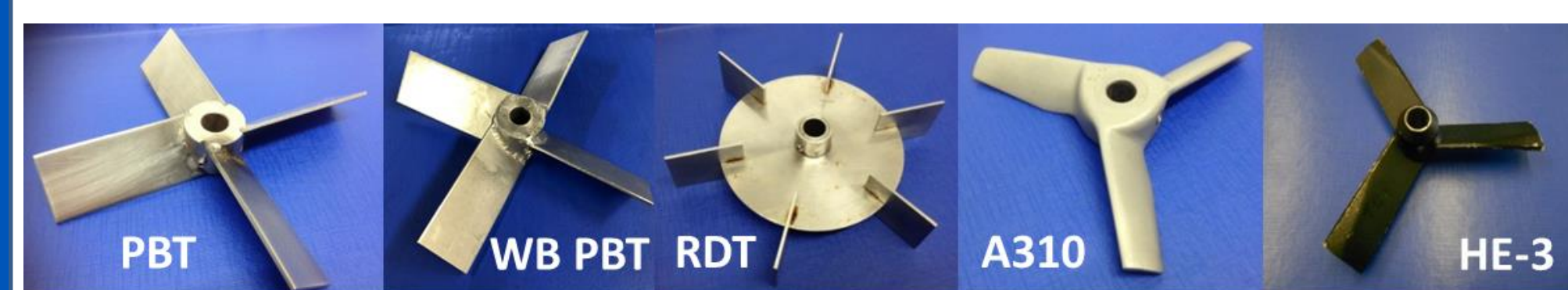
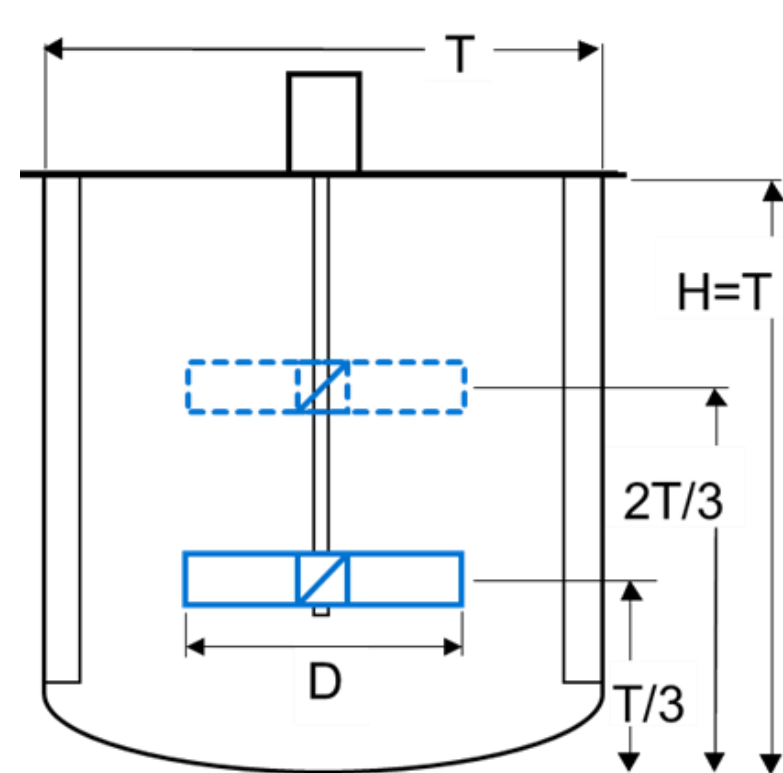
The maximum TKE produced by an impeller can be estimated based on its power number from [2]:

$$\frac{k_{\max}}{v_{\text{tip}}^2} = 0.104 Po^{1/2} \quad (3)$$

Experimental

- Dispersed phase: 5 cSt silicone oil (polydimethylsiloxane)
- Continuous phase: aqueous solution of Tergitol TMN-6
 - Non-ionic surfactant (HLB = 13)
 - Interfacial tension measured (pendant drop technique) at a range of surfactant concentrations
- Dispersed phase fraction (ϕ): 30%vol**
- Glass vessel, diameter (T) = 0.29 m, four standard baffles, liquid level equal to the tank diameter (H=T)
- Water bath, temperature constant at 25±1°C.
- Five different impellers:** pitched blade turbine (PBT), Wide Blade PBT, Rushton disk turbine (RDT), SPX A310 and Chemineer HE-3. The PBT used single and twin
- D/T = 0.49 – 0.54
- Drop size by microscopy of withdrawn samples
- Samples taken after 2 hours of agitation (equilibrium drop size)
- 500+ drops measured/sample

$$d_{32} = \sum d_i^3 / \sum d_i^2$$



Surfactant Concentration

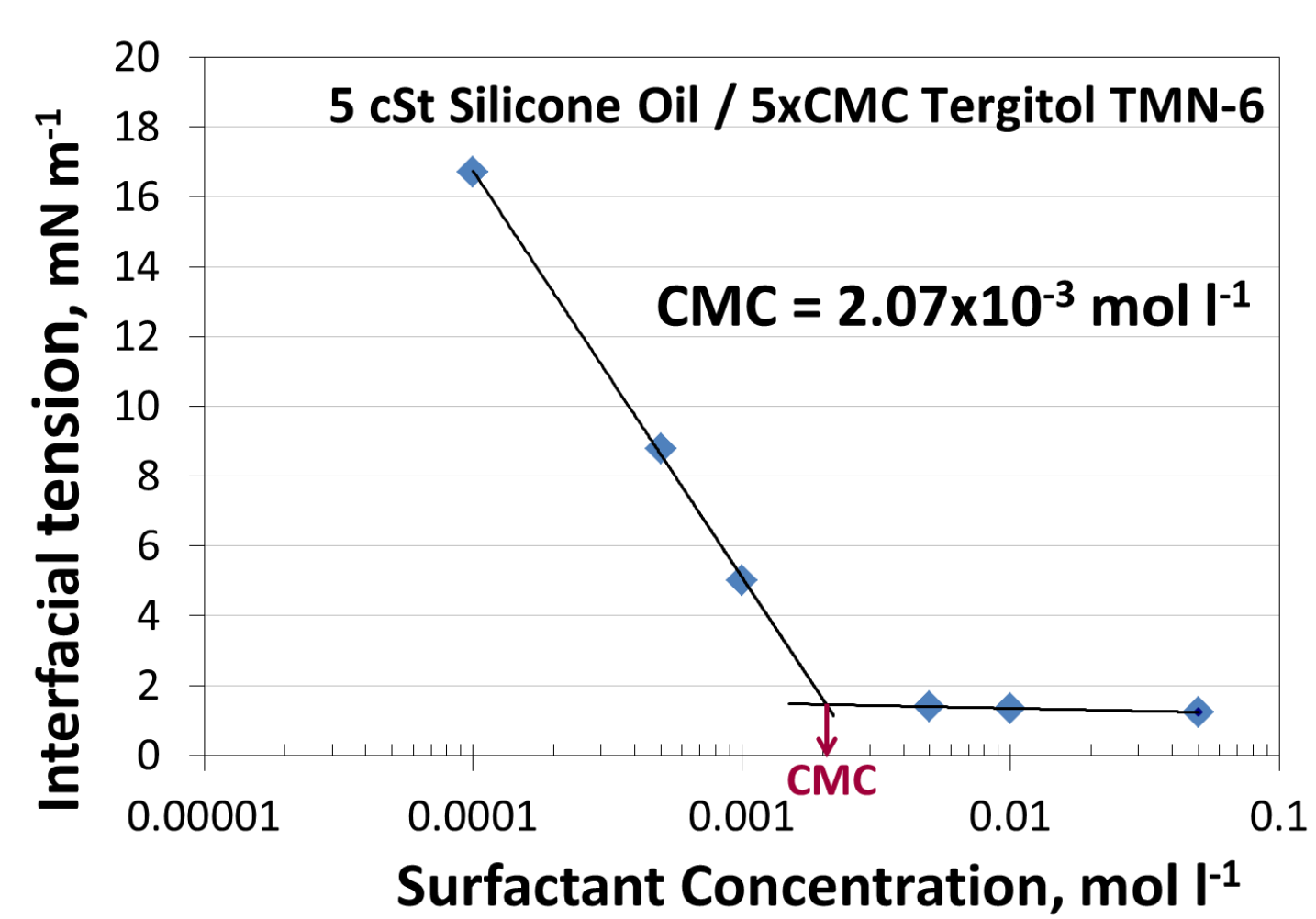
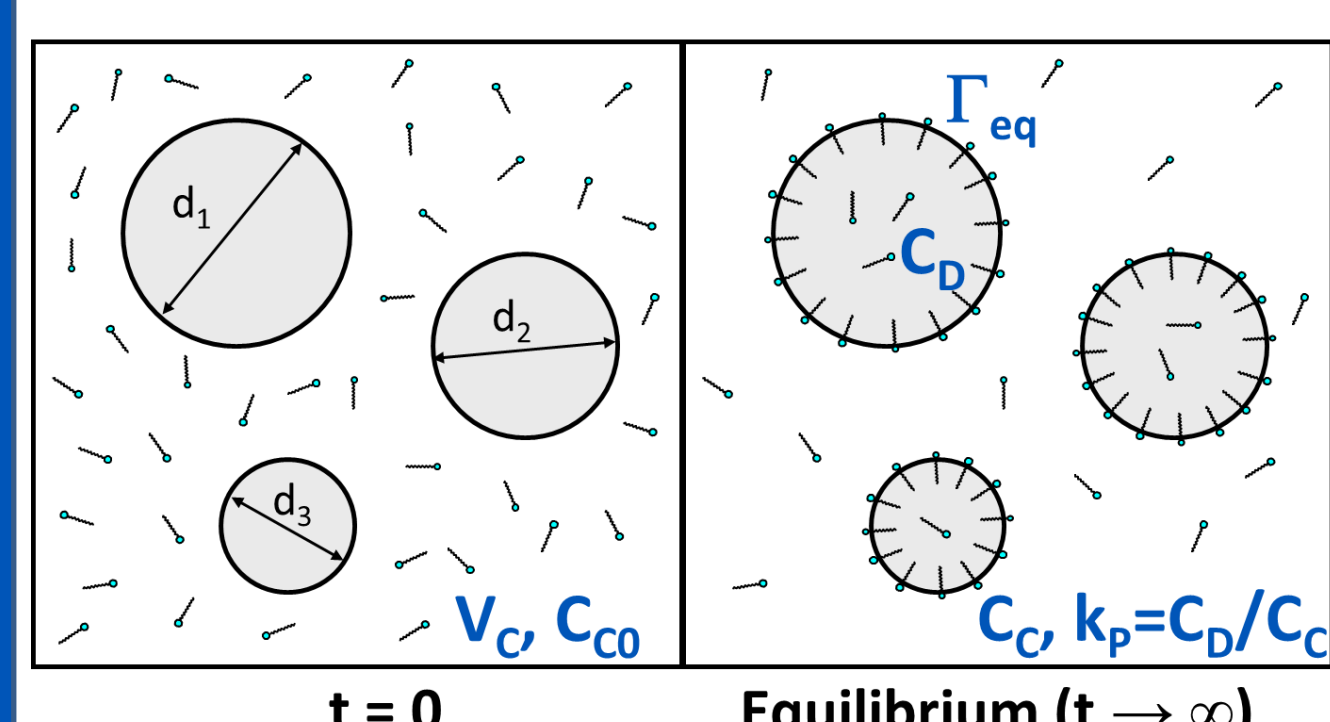


Figure 1. Interfacial tension as a function of surfactant concentration.

To ensure stability against coalescence, the surfactant concentration in the continuous phase, C_c , must be greater than the Critical Micelle Concentration [3].



Surfactant mass balance:

$$C_c = \frac{C_{c0} - \frac{6\Gamma_{eq}}{d_{32}} \frac{V_D}{V_C}}{1 + k_p \frac{V_D}{V_C}}$$

Dynamic Stability

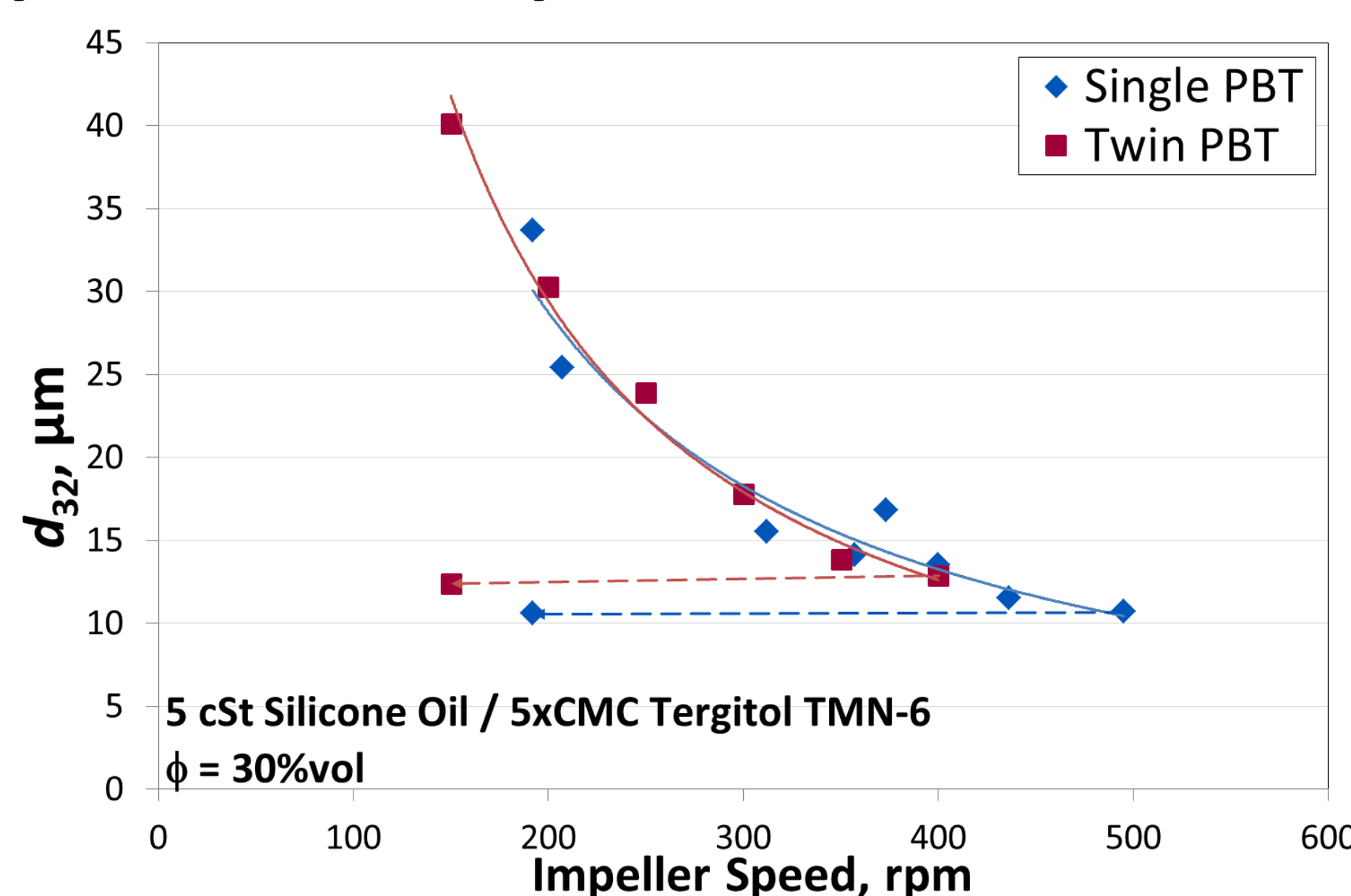


Figure 2. Equilibrium d_{32} versus impeller speed

Dispersion Kinetics

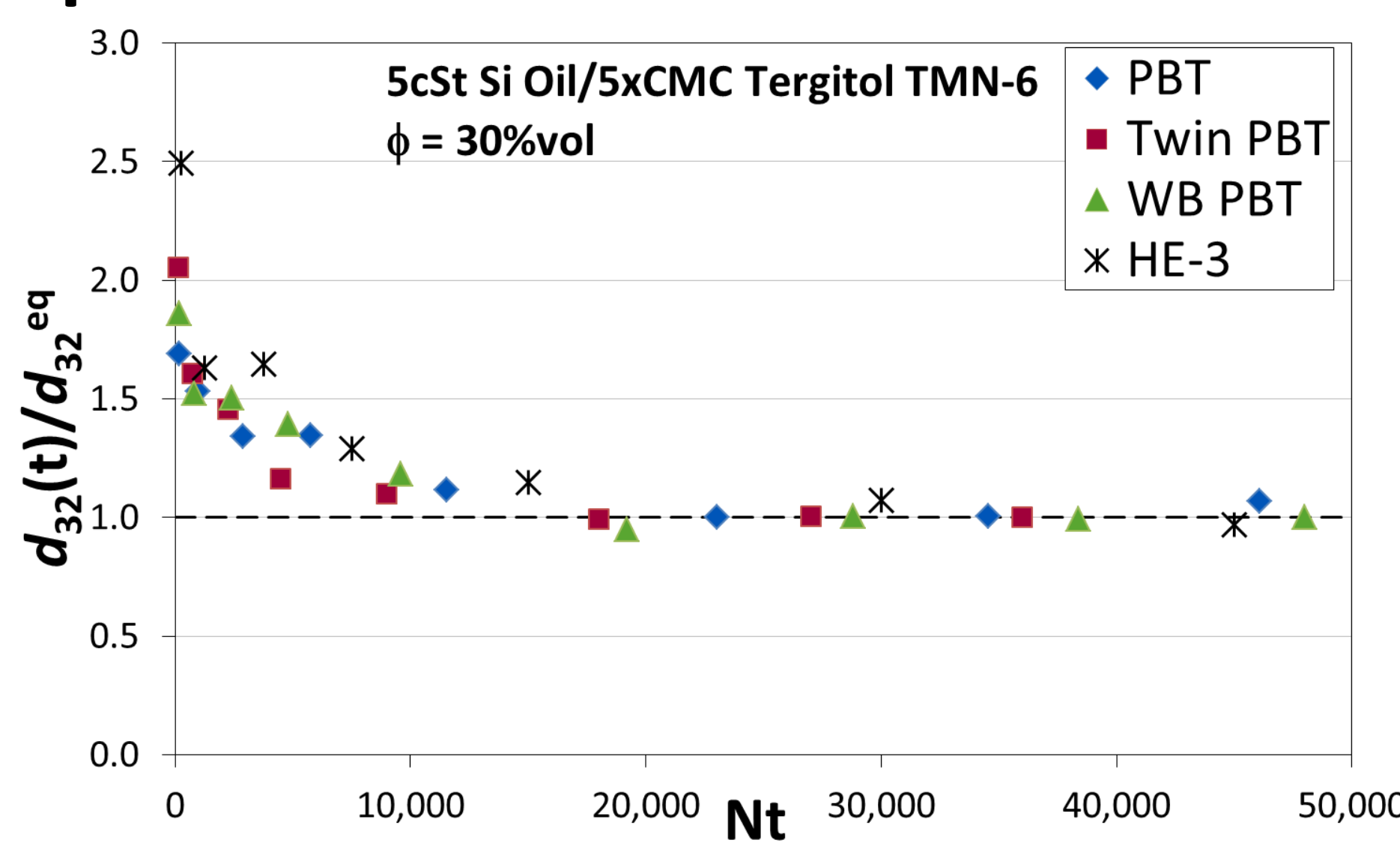


Figure 3. Normalized transient d_{32} as a function of the number of impeller revolutions (Nt)

Mean Specific Power Input

Table 1. Measured turbulent power numbers (torque)

PBT	Twin PBT	WB PBT	RDT	A310	HE-3
1.17	2.2	1.68	4.91	0.34	0.28

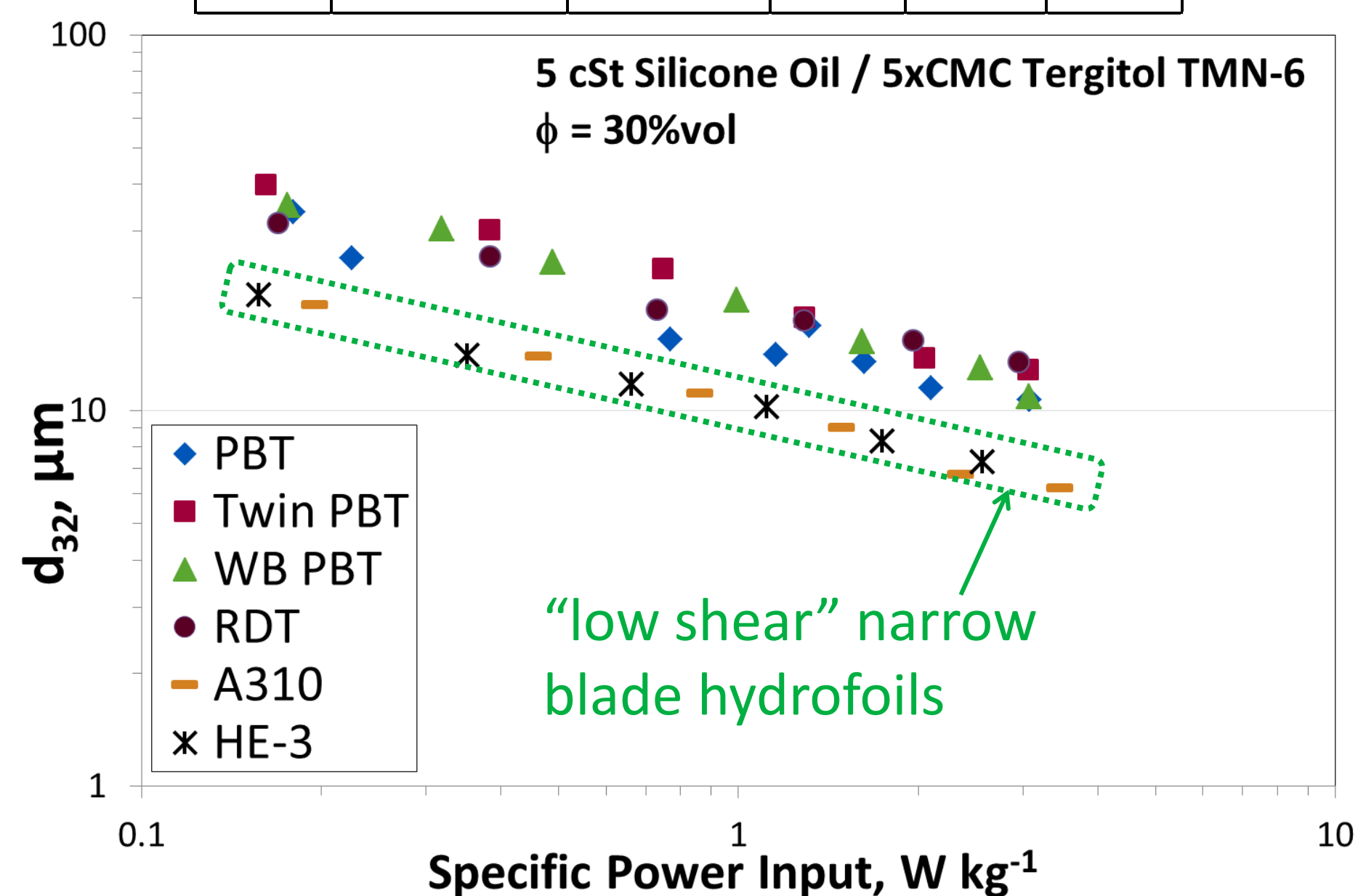


Figure 4. Equilibrium d_{32} versus mean specific power input.

Maximum Energy Dissipation Rate ($\varepsilon_{\max}$)

From LDA measurements (autocorrelation):

$$\ell = \begin{cases} W/2 & \text{for RDT} \\ W_p/2 & \text{for PBT} \\ W_p^* & \text{for Hydrofoils} \end{cases}$$

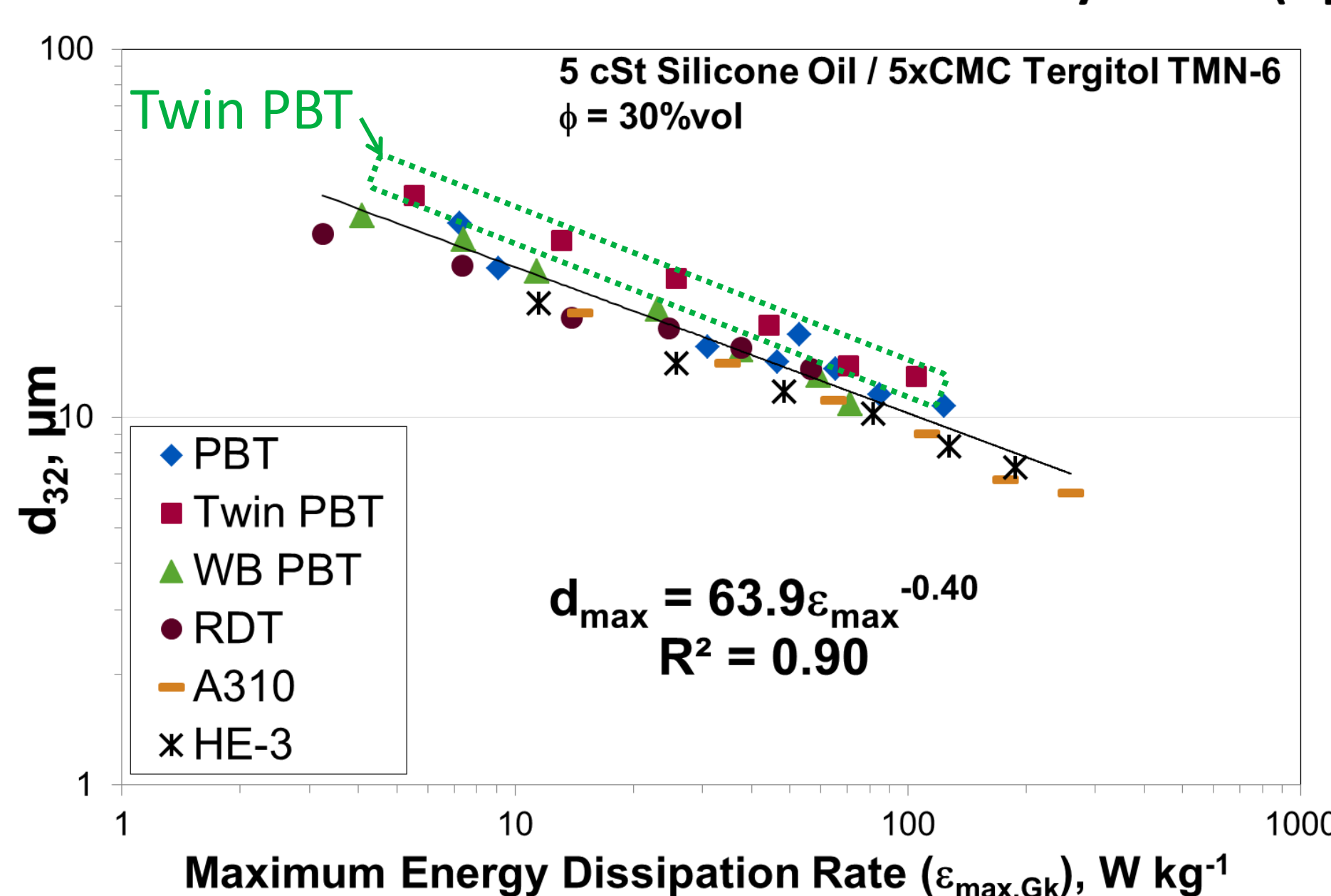
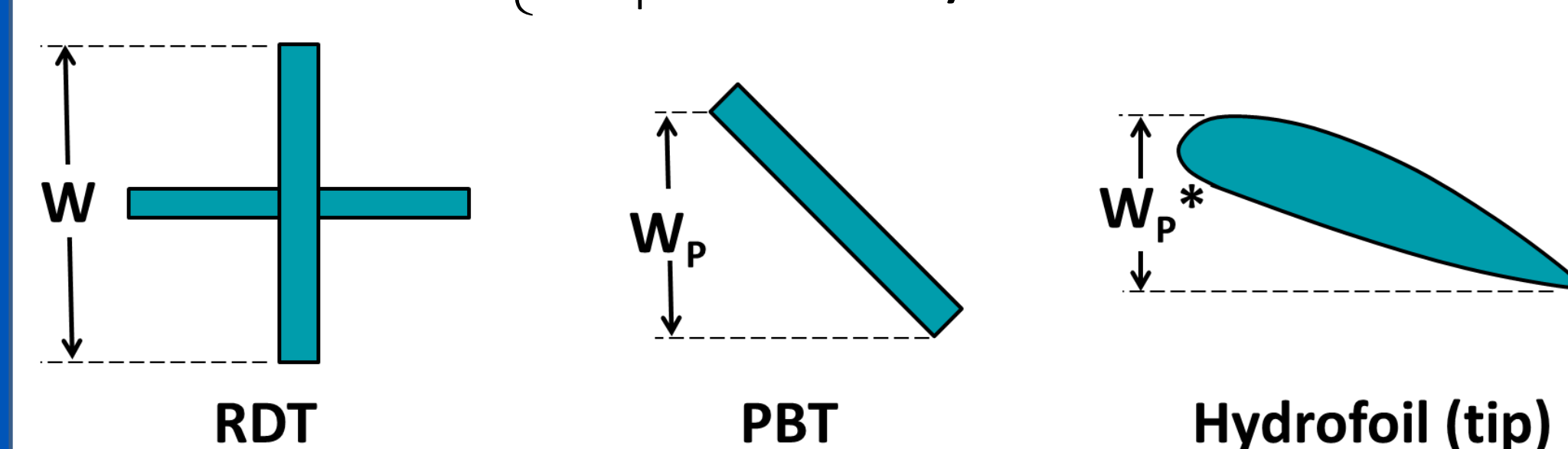


Figure 5. Equilibrium d_{32} vs $\varepsilon_{\max}$ estimated using Eq. (2), (3) & ℓ

Eq. (3) was developed using single impeller data. If $\varepsilon_{\max}$ of the twin system is recalculated using the Po of the single impeller:

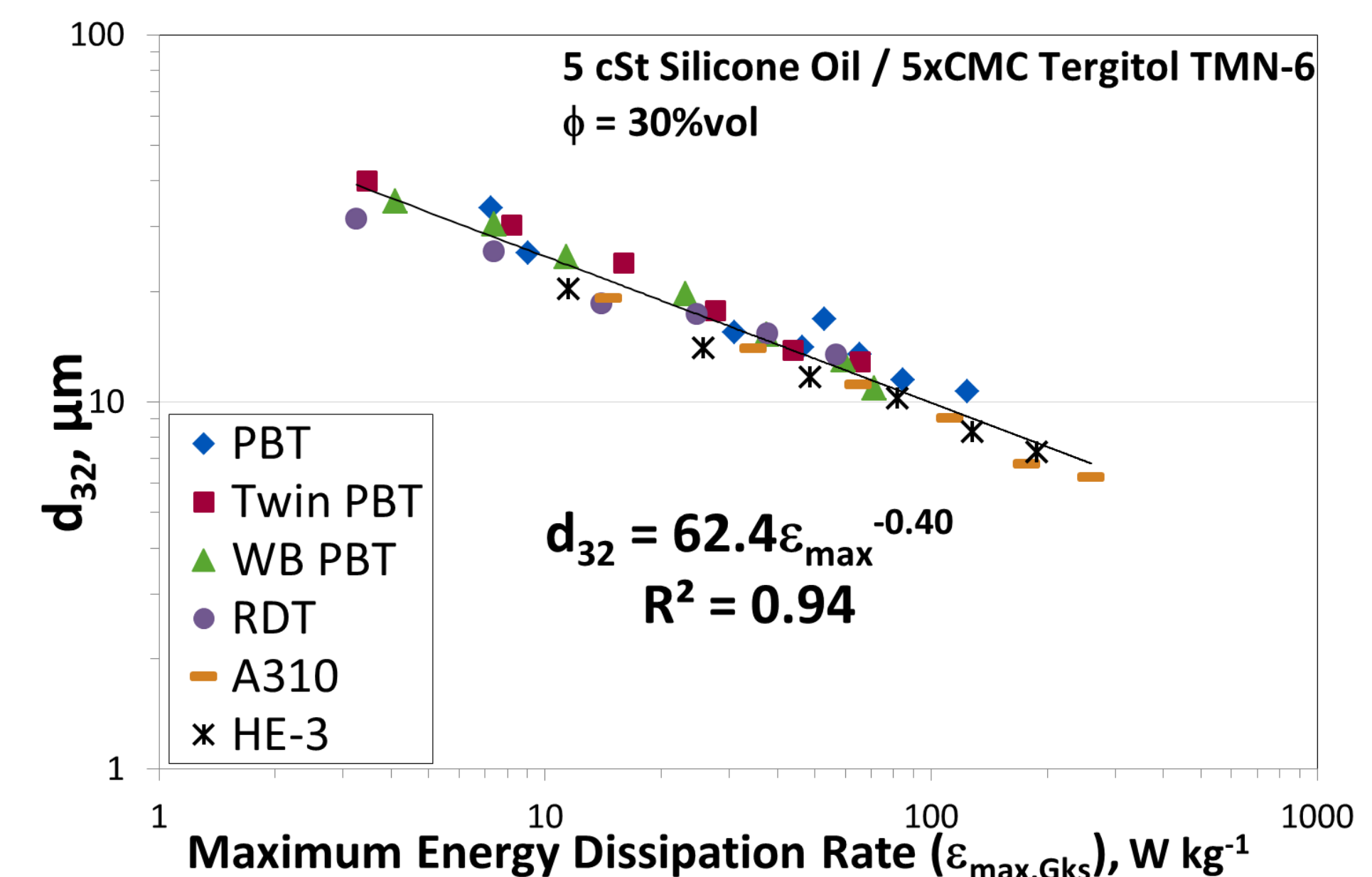
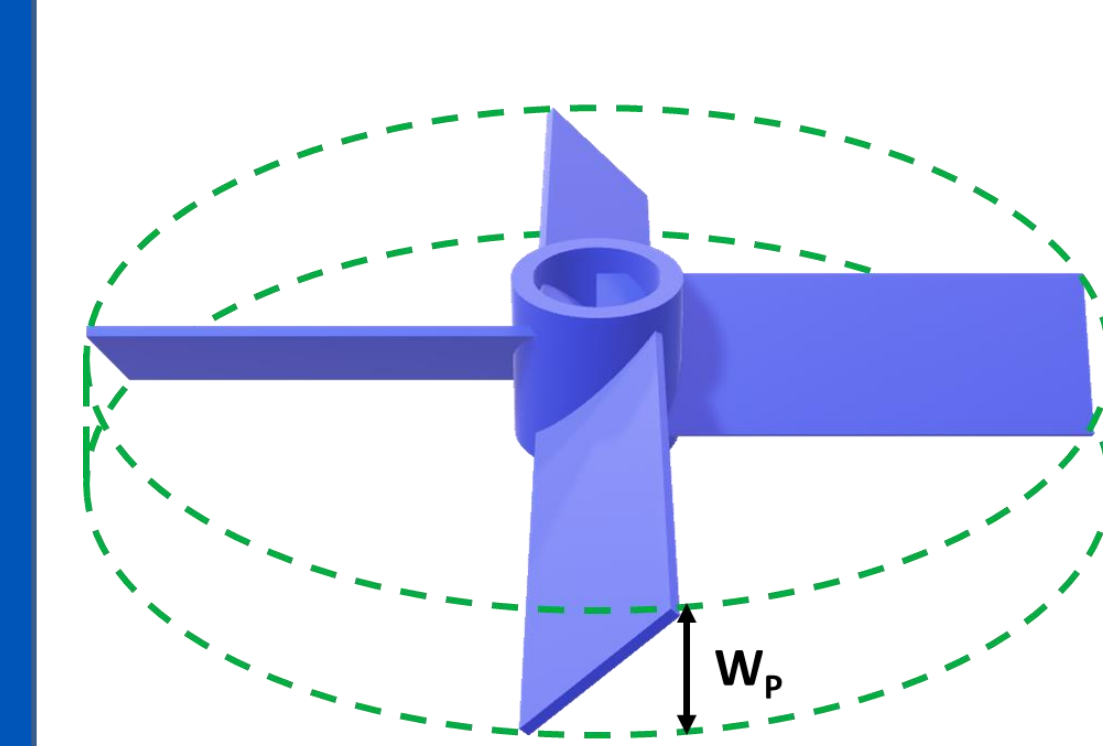


Figure 6. Equilibrium d_{32} vs $\varepsilon_{\max}$ estimated using Eq. (2), (3) & ℓ but using the single impeller Po for the twin system

$\varepsilon_{\max}$: Impeller Swept Volume Approach



$$\varepsilon_{\max, ISV} = \frac{4PoN^3D^3}{\pi W_{(p)}^{(*)}} \quad (4)$$

Where $W_{(p)}^{(*)}$ is

- W for RDTs,
- W_p for PBTs
- W_p^* for hydrofoils

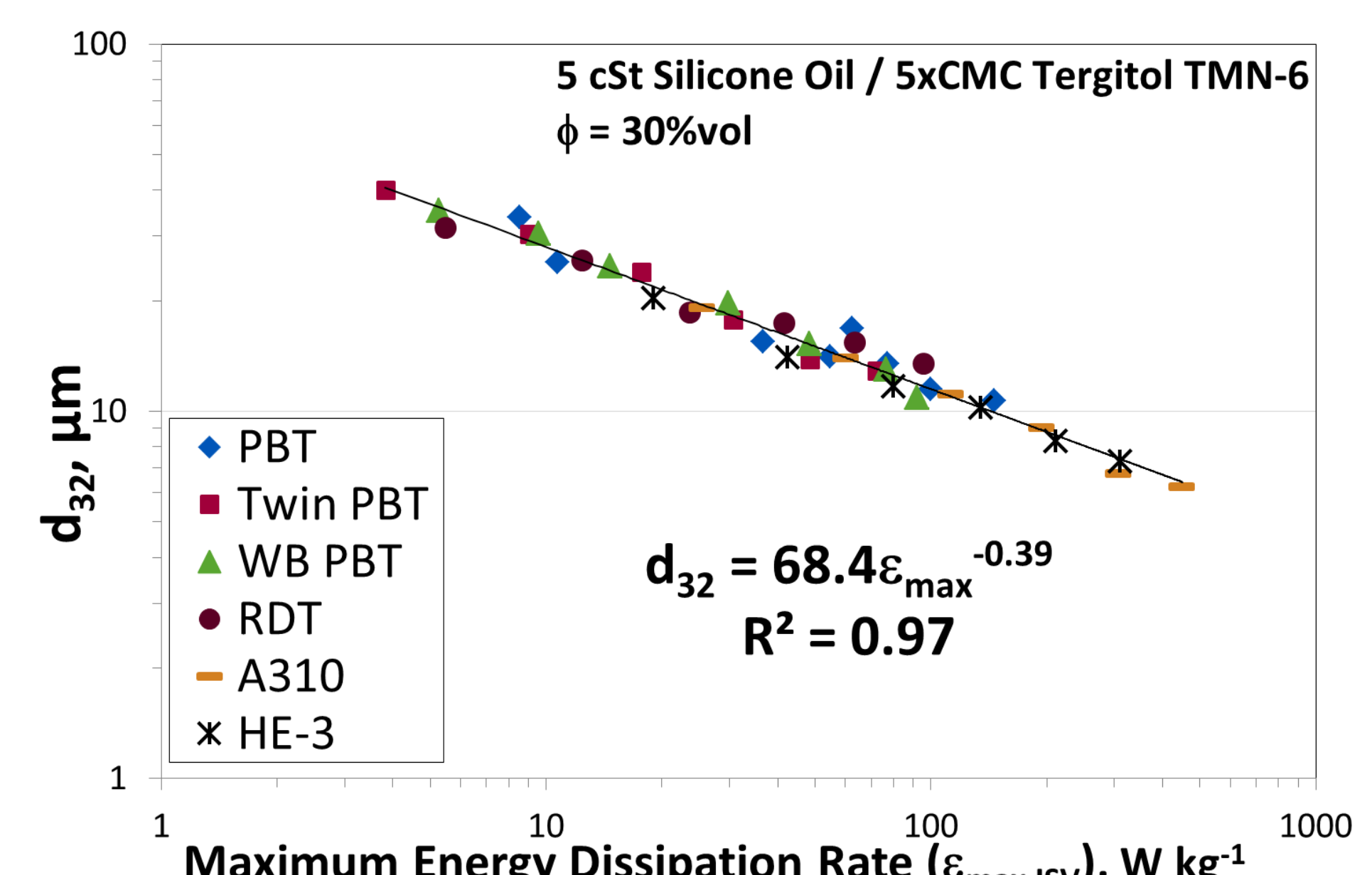


Figure 7. Equilibrium d_{32} vs $\varepsilon_{\max}$ estimated using the impeller swept volume approach (Eq. (6)).

Conclusions

Surfactants can be used to study break up under coalescence-free conditions at industrially relevant dispersed phase fractions if their concentration is adequate, which can be estimated by measuring the CMC and a surfactant mass balance. As previously shown in dilute dispersion [4], “Low shear” narrow blade hydrofoils produce the smallest drops at a given power input compared to PBTs and RDTs. However, all impellers produce the same equilibrium drop size if they operate at the same maximum energy dissipation rate. $\varepsilon_{\max}$ is usually difficult to measure but, at least for the type of impellers used in this study, it can be easily estimated using Grenville et al's [2] or the impeller swept volume approach. In twin impeller systems break up conditions close to the blades are similar to those of a single impeller operating at the same $\varepsilon_{\max}$.

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