



## **Second International Symposium on Marine Propulsors 2011**

### **Workshop: Propeller Performance**

**Potsdam Propeller Test Case (PPTC)**

**Open Water Test with the Model Propeller VP1304**

**Case 2.1**

Potsdam, May 2011

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## **Case 2.1**

### **Open Water Tests**

### **Test Description**

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## 1 Introduction

In the intention to offer research groups the possibility to test and validate their numerical tools the SVA Potsdam GmbH (SVA) investigated the controllable pitch propeller VP1304. The test results are published in course of the propeller workshop of the Second International Symposium on Marine Propulsors 2011 (smp'11). The geometry and results of the propeller are presented by the name PPTC, an acronym for “Potsdam Propeller Test Case”.

In the following the measurements of the open water tests and the comparison between measurements and calculations are presented.

A more detailed description of the open water tests conducted at the towing tank of the SVA is presented in the SVA report 3752 [1], which can be found on the website [sva-potsdam.de](http://sva-potsdam.de).

## 2 Model propeller VP1304

The propeller is a controllable pitch propeller. This affects the propeller blade design near the hub and results in a 0.3 mm gap between hub and propeller blade near the leading and trailing edge of the propeller.

The hub cap and aft fairing were designed according to the 22<sup>nd</sup> ITTC (1999) proceedings. The gap between aft fairing and hub has a width of 3 mm. Also a dummy hub, having the same dimensions and mass as the propeller hub, was manufactured.

In Table 1 the main data of the propeller is given.

**Table 1: Main data of model propeller VP1304**

| <b>VP1304</b>            |                |     |                              |
|--------------------------|----------------|-----|------------------------------|
| Diameter                 | $D$            | [m] | 0.250                        |
| Pitch ratio $r/R = 0.7$  | $P_{0.7}/D$    | [–] | 1.635                        |
| Area ratio               | $A_E/A_0$      | [–] | 0.77896                      |
| Chord length $r/R = 0.7$ | $c_{0.7}$      | [m] | 0.10417                      |
| Skew                     | $\theta_{EXT}$ | [°] | 18.837                       |
| Hub ratio                | $d_h/D$        | [–] | 0.300                        |
| Number of blades         | $Z$            | [–] | 5                            |
| Sense of rotation        |                | [–] | right                        |
| Type                     |                | [–] | controllable pitch propeller |

### 3 Open water tests

The propeller is investigated in a pull configuration in the towing tank of the SVA. For the open water tests the dynamometer H39 from Kempf & Remmers has been used. During the tests the propeller shaft is submerged by  $1.5 D$ .

Measurements with a dummy hub were conducted, in order to get data of the idle torque, the force in the gap between the hub and the aft fairing and the resistance of the hub cap.

The open water tests were carried out at two different numbers of revolutions to evaluate the dependency on the Reynolds number. However for the evaluation of the computational results solely the tests with  $n = 15 \text{ s}^{-1}$  are taken into account.

**Table 2: Details of model tests**

| <b>PPTC</b>                 |                                  |
|-----------------------------|----------------------------------|
| Towing tank                 |                                  |
| Dimensions of towing tank   | 280 x 9 x 4.5 m                  |
| Propeller:                  | VP1304                           |
| Propeller type              | controllable pitch propeller     |
| Material of model propeller | brass                            |
| Diameter of the propeller   | 0.25 m                           |
| Sense of rotation           | right (looking on pressure side) |
| Arrangement:                |                                  |
| Shaft inclination           | 0°                               |
| Dynamometer shaft           | behind the propeller             |
| Measuring equipment:        | dynamometer H39                  |
|                             | $n_{\max} = 60 \text{ s}^{-1}$   |
|                             | $T_{\max} = 1 \text{ kN}$        |
|                             | $Q_{\max} = 50 \text{ Nm}$       |

### 4 Requested computations

It was requested to calculate the open water characteristics of the propeller for the advanced coefficients  $J = 0.6, 0.8, 1.0, 1.2$  and  $1.4$ . The computations should be conducted according to the operation conditions given in Table 4.

**Table 4: Operation conditions**

|   |        |                      |           |
|---|--------|----------------------|-----------|
| Water density ( $t_w = 17.5 \text{ }^{\circ}\text{C}$ )       | $\rho$ | [kg/m <sup>3</sup> ] | 998.67    |
| Kinematic viscosity ( $t_w = 17.5 \text{ }^{\circ}\text{C}$ ) | $\nu$  | [m <sup>2</sup> /s]  | 1.070E-06 |
| Number of revolutions   | $n$    | [1/s]                | 15.00     |

The thrust and torque of the propeller should be made dimensionless employing the rate of revolution  $n$ , the propeller diameter  $D$  and the density of water  $\rho$  as follows:

Advance coefficient 
$$J = \frac{V_A}{n \cdot D}$$

Thrust coefficient 
$$K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$$

Torque coefficient 
$$K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$$

Open water efficiency 
$$\eta_0 = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$$

with  $V_A$  being the advance speed,  $T$  the thrust and  $Q$  the propeller torque

## 5 Open water test results

The measured values in the open water tests were corrected with the values of the idle torque and the gap force.

The measured and corrected open water characteristics for the five requested advance coefficients are given in Table 4 for the number of revolutions  $n = 15 \text{ s}^{-1}$ .

**Table 4: Measured open water characteristics (by polynomials)**

| $J$  | $K_T$  | $10K_Q$ | $\eta_0$ |
|------|--------|---------|----------|
| 0.60 | 0.6288 | 1.3964  | 0.4300   |
| 0.80 | 0.5100 | 1.1780  | 0.5512   |
| 1.00 | 0.3994 | 0.9749  | 0.6520   |
| 1.20 | 0.2949 | 0.7760  | 0.7258   |
| 1.40 | 0.1878 | 0.5588  | 0.7487   |

## 6 Reference

- [1] Barkmann, U.  
Potsdam Propeller Test Case (PPTC) - Open Water Tests with the Model Propeller VP1304,  
Report 3752, Schiffbau-Versuchsanstalt Potsdam, April 2011

## **Case 2.1**

### **Open Water Tests**

### **Evaluation**

## 7 Evaluation

Calculations from 14 different groups were obtained for the evaluation of the open water characteristics, employing 13 different solvers and submitting 19 calculations, of which are two for the comparison of different turbulence models. In the following all participants and the used solvers are listed:

| Group                | Solver       | Acronym              |
|----------------------|--------------|----------------------|
| Berg-Propulsion      | OpenFOAM     | Berg-OpenFOAM        |
| Cradle               | SC/Tetra     | Cradle-SC/Tetra      |
| CSSRC                | ANSYS Fluent | CSSRC-Fluent         |
| HSVA                 | PPB          | HSVA-PPB             |
|                      | QCM          | HSVA-QCM             |
| INSEAN               | PFC          | INSEAN-PFC           |
| MARIC                | ANSYS Fluent | MARIC-Fluent         |
| SSPA                 | ANSYS Fluent | SSPA-Fluent          |
| SVA                  | Vortex       | SVA-Vortex           |
| TUHH                 | FreSCO+      | TUHH-FreSCO          |
| University of Genua  | Panel        | UniGenua-Panel       |
|                      | OpenFOAM     | UniGenua-OpenFOAM    |
|                      | StarCCM+     | UniGenua-StarCCM(kw) |
|                      | StarCCM+     | UniGenua-StarCCM(ke) |
| University of Triest | ANSYS CFX    | UniTriest-CFX        |
| VicusDT              | StarCCM+     | VicusDT-StarCCM      |
| VOITH                | Comet        | VOITH-Comet          |
|                      | OpenFOAM     | VOITH-OpenFOAM       |
| VTT                  | FinFlo       | VTT-FinFlo           |

In the following the data is evaluated with respect to the thrust coefficient  $K_T$  and torque coefficient  $10K_Q$  and the open water efficiency  $\eta_0$ . For each value an absolute (e.g.  $\Delta K_T$ ) and a relative comparison (e.g.  $\Delta K_T [\%]$ ) to the measured values are given. The absolute difference is defined as the difference between the calculated and the measured value, while the relative difference is the same value expressed as percentage with respect to the measured value.

## 7.1 Berg-OpenFOAM

**Characteristic of propeller (model scale)**

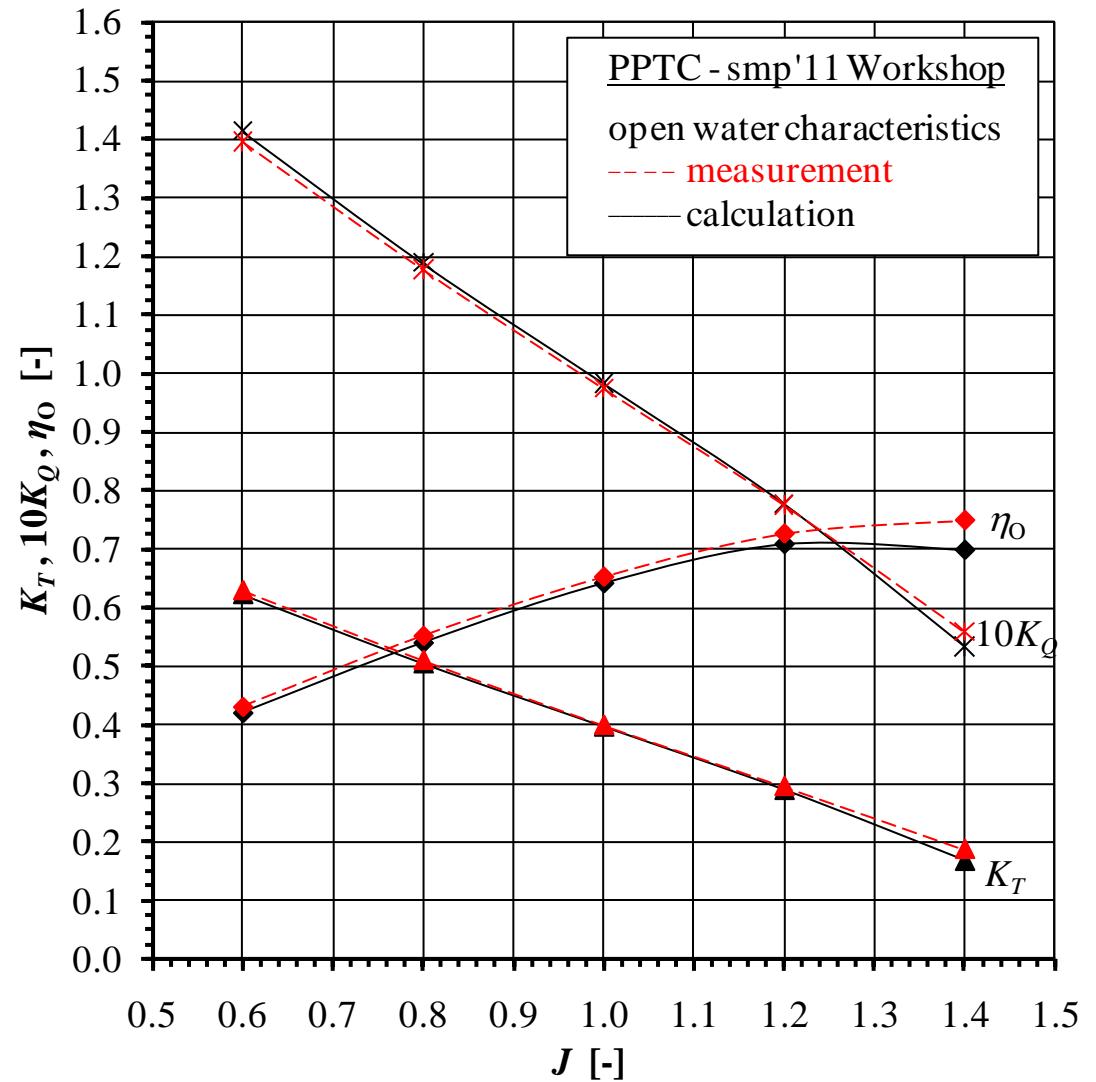
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6230       | -0.0058      | -0.93               |
| 0.80 | 0.5100       | 0.5050       | -0.0050      | -0.97               |
| 1.00 | 0.3994       | 0.3970       | -0.0024      | -0.59               |
| 1.20 | 0.2949       | 0.2890       | -0.0059      | -2.01               |
| 1.40 | 0.1878       | 0.1680       | -0.0198      | -10.53              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4150         | 0.0186         | 1.33                  |
| 0.80 | 1.1780         | 1.1890         | 0.0110         | 0.93                  |
| 1.00 | 0.9749         | 0.9840         | 0.0091         | 0.94                  |
| 1.20 | 0.7760         | 0.7780         | 0.0020         | 0.25                  |
| 1.40 | 0.5588         | 0.5340         | -0.0248        | -4.44                 |

| $J$  | $\eta_0$<br>EFD | $\eta_0$<br>CFD | $\Delta \eta_0$ | $\Delta \eta_0$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4210          | -0.0090         | -2.10                  |
| 0.80 | 0.5512          | 0.5410          | -0.0102         | -1.85                  |
| 1.00 | 0.6520          | 0.6430          | -0.0090         | -1.38                  |
| .20  | 0.7258          | 0.7100          | -0.0150         | -2.18                  |
| 1.40 | 0.7487          | 0.7000          | -0.0487         | -6.50                  |



## 7.2 Cradle-SC/Tetra

Characteristic of propeller (model scale)

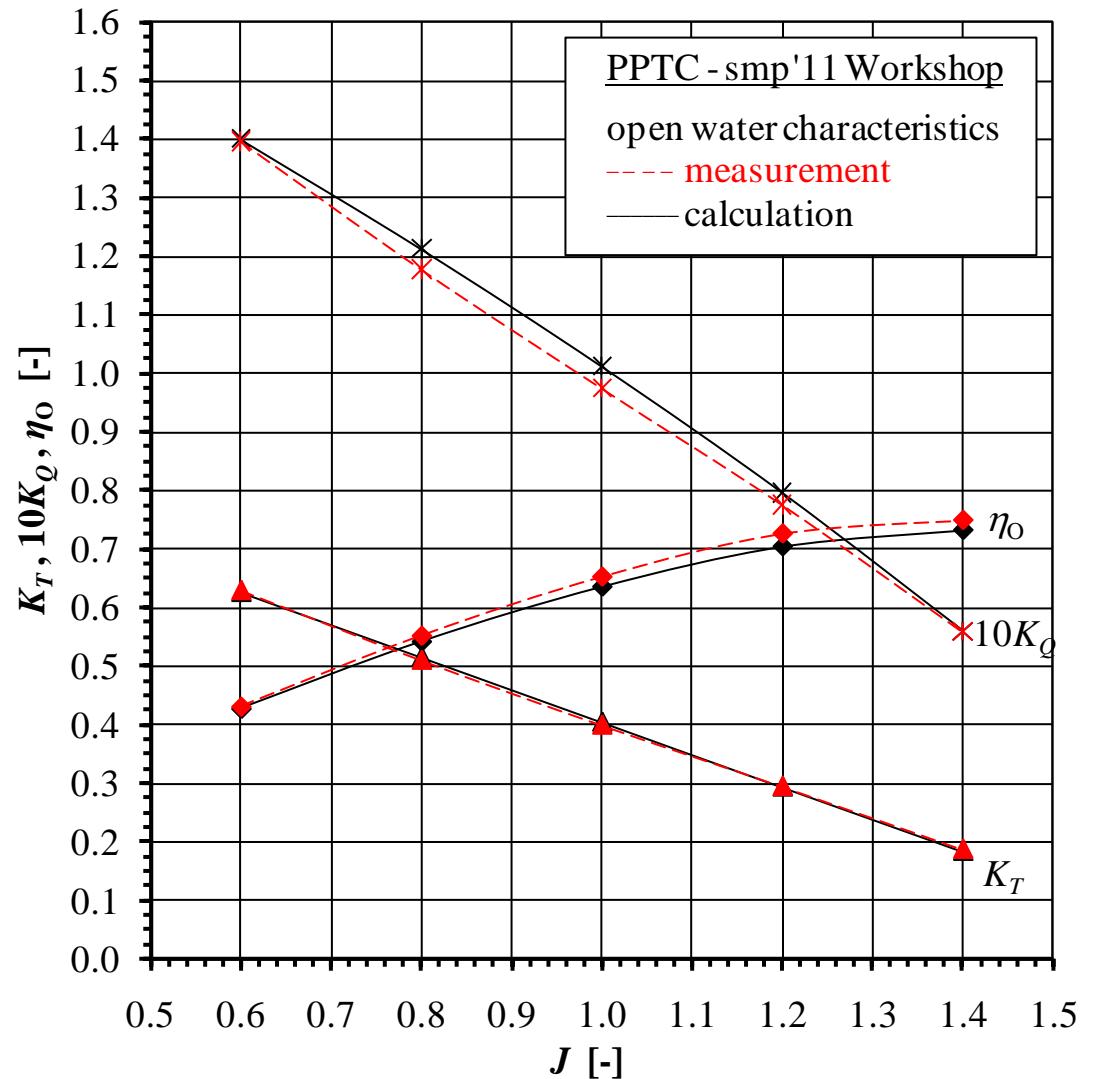
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6270       | -0.0018      | -0.29               |
| 0.80 | 0.5100       | 0.5160       | 0.0060       | 1.18                |
| 1.00 | 0.3994       | 0.4050       | 0.0056       | 1.41                |
| 1.20 | 0.2949       | 0.2940       | -0.0009      | -0.31               |
| 1.40 | 0.1878       | 0.1840       | -0.0038      | -2.00               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4010         | 0.0046         | 0.33                  |
| 0.80 | 1.1780         | 1.2130         | 0.0350         | 2.97                  |
| 1.00 | 0.9749         | 1.0120         | 0.0371         | 3.81                  |
| 1.20 | 0.7760         | 0.7960         | 0.0200         | 2.57                  |
| 1.40 | 0.5588         | 0.5600         | 0.0012         | 0.21                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4270          | -0.0030         | -0.71                  |
| 0.80 | 0.5512          | 0.5420          | -0.0092         | -1.67                  |
| 1.00 | 0.6520          | 0.6360          | -0.0160         | -2.45                  |
| 1.20 | 0.7258          | 0.7050          | -0.0208         | -2.87                  |
| 1.40 | 0.7487          | 0.7330          | -0.0157         | -2.09                  |



### 7.3 CSSRC-Fluent

**Characteristic of propeller (model scale)**

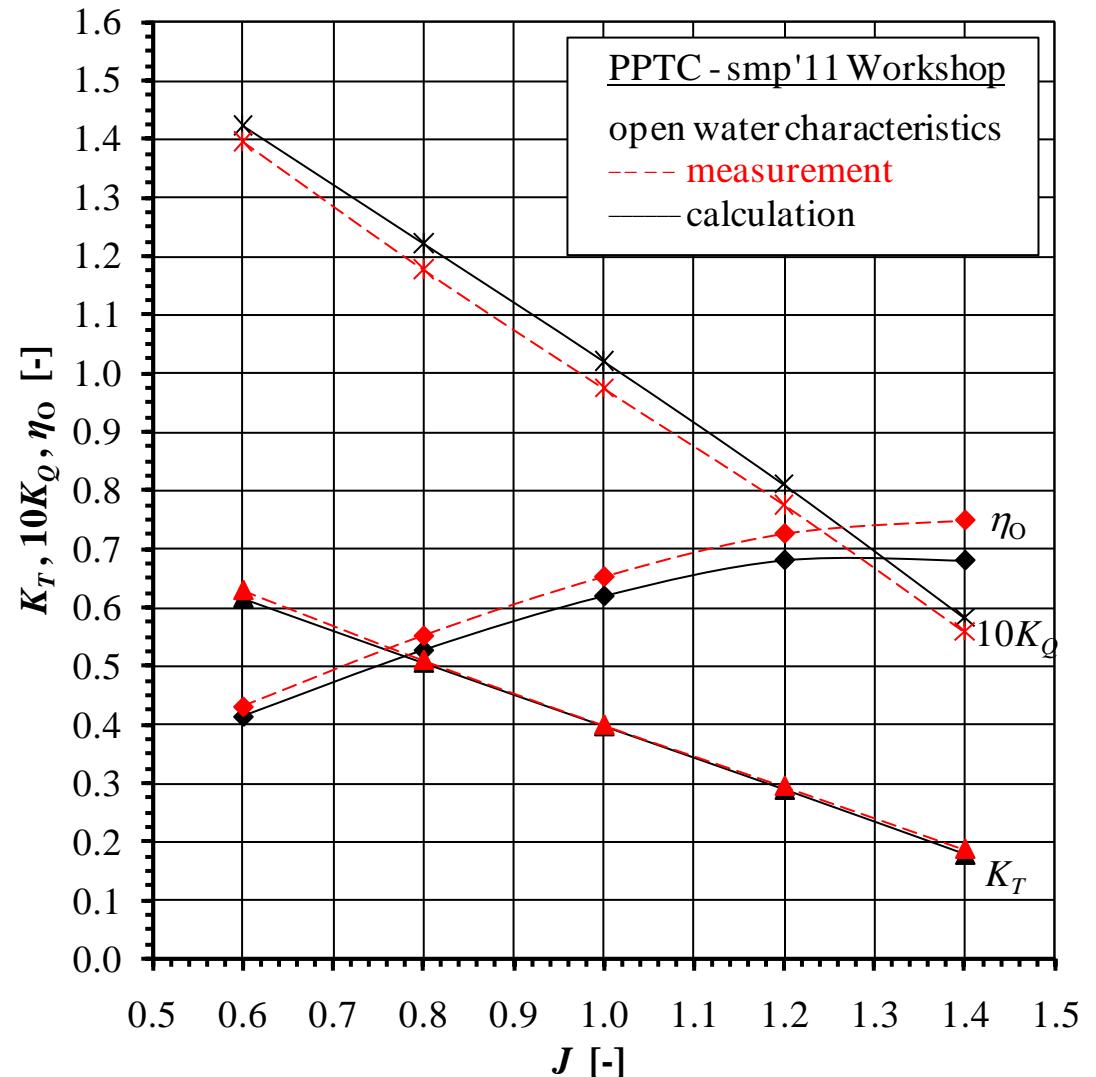
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6158       | -0.0130      | -2.07               |
| 0.80 | 0.5100       | 0.5055       | -0.0045      | -0.88               |
| 1.00 | 0.3994       | 0.3971       | -0.0023      | -0.57               |
| 1.20 | 0.2949       | 0.2887       | -0.0062      | -2.11               |
| 1.40 | 0.1878       | 0.1779       | -0.0099      | -5.25               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4239         | 0.0275         | 1.97                  |
| 0.80 | 1.1780         | 1.2230         | 0.0450         | 3.82                  |
| 1.00 | 0.9749         | 1.0215         | 0.0466         | 4.78                  |
| 1.20 | 0.7760         | 0.8107         | 0.0347         | 4.47                  |
| 1.40 | 0.5588         | 0.5832         | 0.0244         | 4.36                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4130          | -0.0170         | -3.96                  |
| 0.80 | 0.5512          | 0.5263          | -0.0249         | -4.52                  |
| 1.00 | 0.6520          | 0.6187          | -0.0333         | -5.11                  |
| 1.20 | 0.7258          | 0.6801          | -0.0457         | -6.30                  |
| 1.40 | 0.7487          | 0.6797          | -0.0690         | -9.21                  |



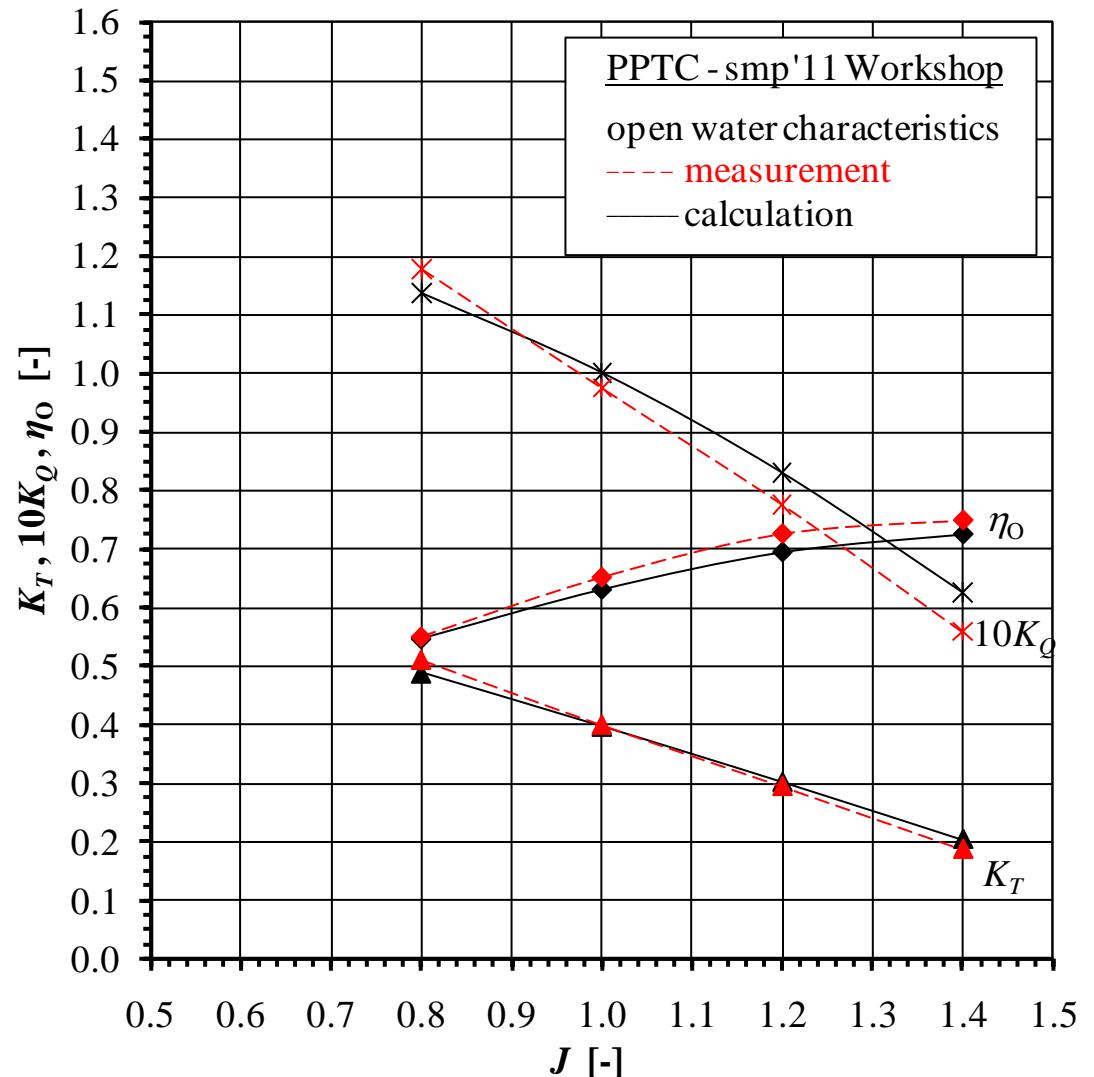
## 7.4 HSVA-PPB

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       |              |              |                     |
| 0.80 | 0.5100       | 0.4888       | -0.0212      | -4.15               |
| 1.00 | 0.3994       | 0.3972       | -0.0022      | -0.54               |
| 1.20 | 0.2949       | 0.3023       | 0.0074       | 2.50                |
| 1.40 | 0.1878       | 0.2039       | 0.0161       | 8.59                |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         |                |                |                       |
| 0.80 | 1.1780         | 1.1369         | -0.0411        | -3.49                 |
| 1.00 | 0.9749         | 1.0013         | 0.0264         | 2.71                  |
| 1.20 | 0.7760         | 0.8305         | 0.0545         | 7.02                  |
| 1.40 | 0.5588         | 0.6264         | 0.0676         | 12.09                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          |                 |                 |                        |
| 0.80 | 0.5512          | 0.5472          | -0.0040         | -0.72                  |
| 1.00 | 0.6520          | 0.6310          | -0.0210         | -3.22                  |
| 1.20 | 0.7258          | 0.6947          | -0.0311         | -4.29                  |
| 1.40 | 0.7487          | 0.7251          | -0.0236         | -3.15                  |



## 7.5 HSVA-QCM

Characteristic of propeller (model scale)

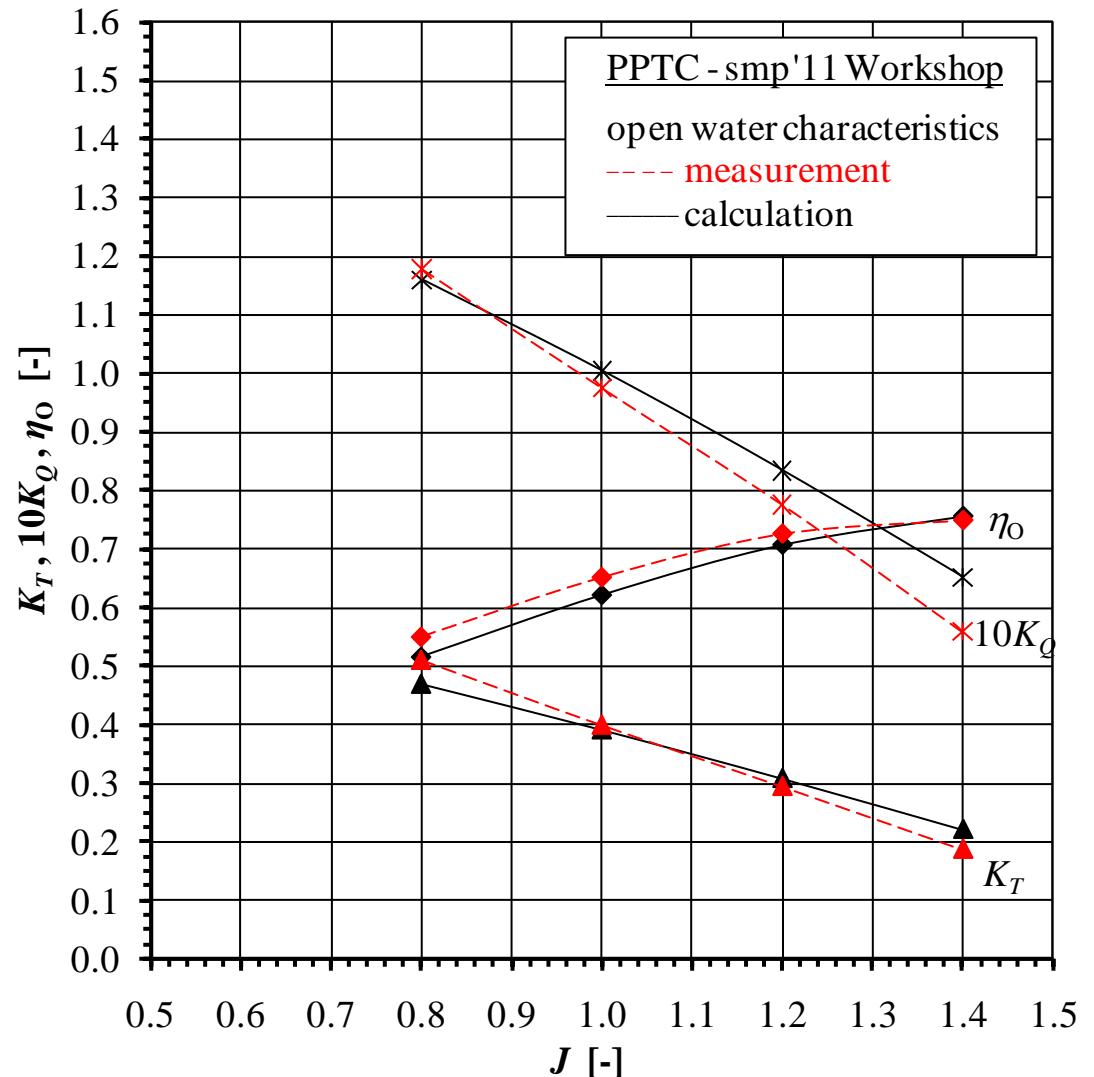
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       |              |              |                     |
| 0.80 | 0.5100       | 0.4700       | -0.0400      | -7.84               |
| 1.00 | 0.3994       | 0.3920       | -0.0074      | -1.85               |
| 1.20 | 0.2949       | 0.3090       | 0.0141       | 4.77                |
| 1.40 | 0.1878       | 0.2220       | 0.0342       | 18.23               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         |                |                |                       |
| 0.80 | 1.1780         | 1.1600         | -0.0180        | -1.53                 |
| 1.00 | 0.9749         | 1.0040         | 0.0291         | 2.99                  |
| 1.20 | 0.7760         | 0.8340         | 0.0580         | 7.47                  |
| 1.40 | 0.5588         | 0.6520         | 0.0932         | 16.67                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta\eta_o$ | $\Delta\eta_o$<br>[%] |
|------|-----------------|-----------------|----------------|-----------------------|
| 0.60 | 0.4300          |                 |                |                       |
| 0.80 | 0.5512          | 0.5160          | -0.0352        | -6.38                 |
| 1.00 | 0.6520          | 0.6220          | -0.0300        | -4.60                 |
| 1.20 | 0.7258          | 0.7080          | -0.0178        | -2.45                 |
| 1.40 | 0.7487          | 0.7570          | 0.0083         | 1.11                  |



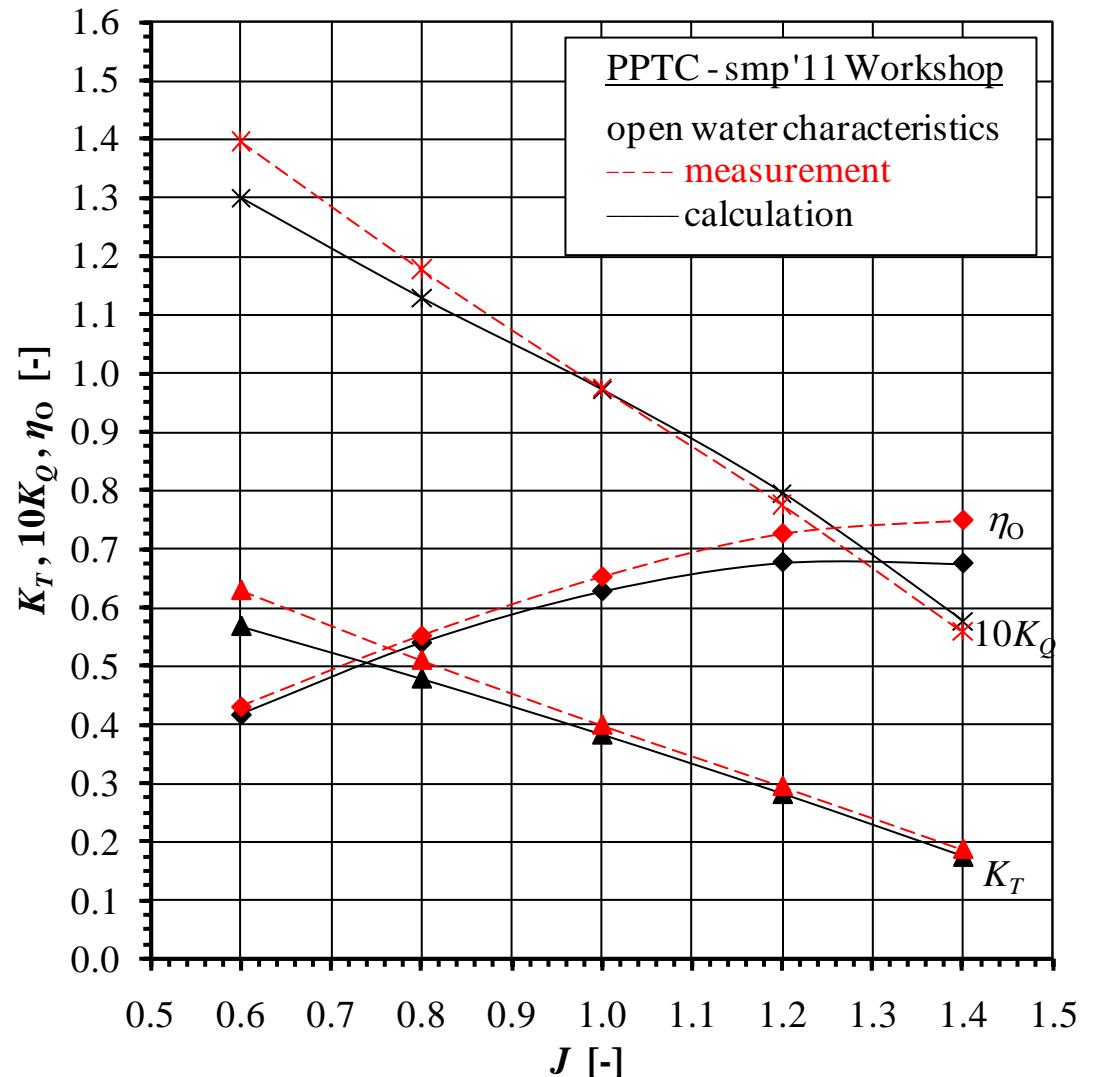
## 7.6 INSEAN-PFC

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.5690       | -0.0599      | -9.52               |
| 0.80 | 0.5100       | 0.4791       | -0.0308      | -6.04               |
| 1.00 | 0.3994       | 0.3835       | -0.0159      | -3.97               |
| 1.20 | 0.2949       | 0.2821       | -0.0128      | -4.35               |
| 1.40 | 0.1878       | 0.1748       | -0.0129      | -6.89               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.2994         | -0.0970        | -6.94                 |
| 0.80 | 1.1780         | 1.1286         | -0.0494        | -4.20                 |
| 1.00 | 0.9749         | 0.9718         | -0.0030        | -0.31                 |
| 1.20 | 0.7760         | 0.7954         | 0.0194         | 2.50                  |
| 1.40 | 0.5588         | 0.5767         | 0.0179         | 3.20                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4181          | -0.0119         | -2.77                  |
| 0.80 | 0.5512          | 0.5406          | -0.0106         | -1.93                  |
| 1.00 | 0.6520          | 0.6281          | -0.0239         | -3.67                  |
| 1.20 | 0.7258          | 0.6773          | -0.0485         | -6.68                  |
| 1.40 | 0.7487          | 0.6755          | -0.0731         | -9.77                  |



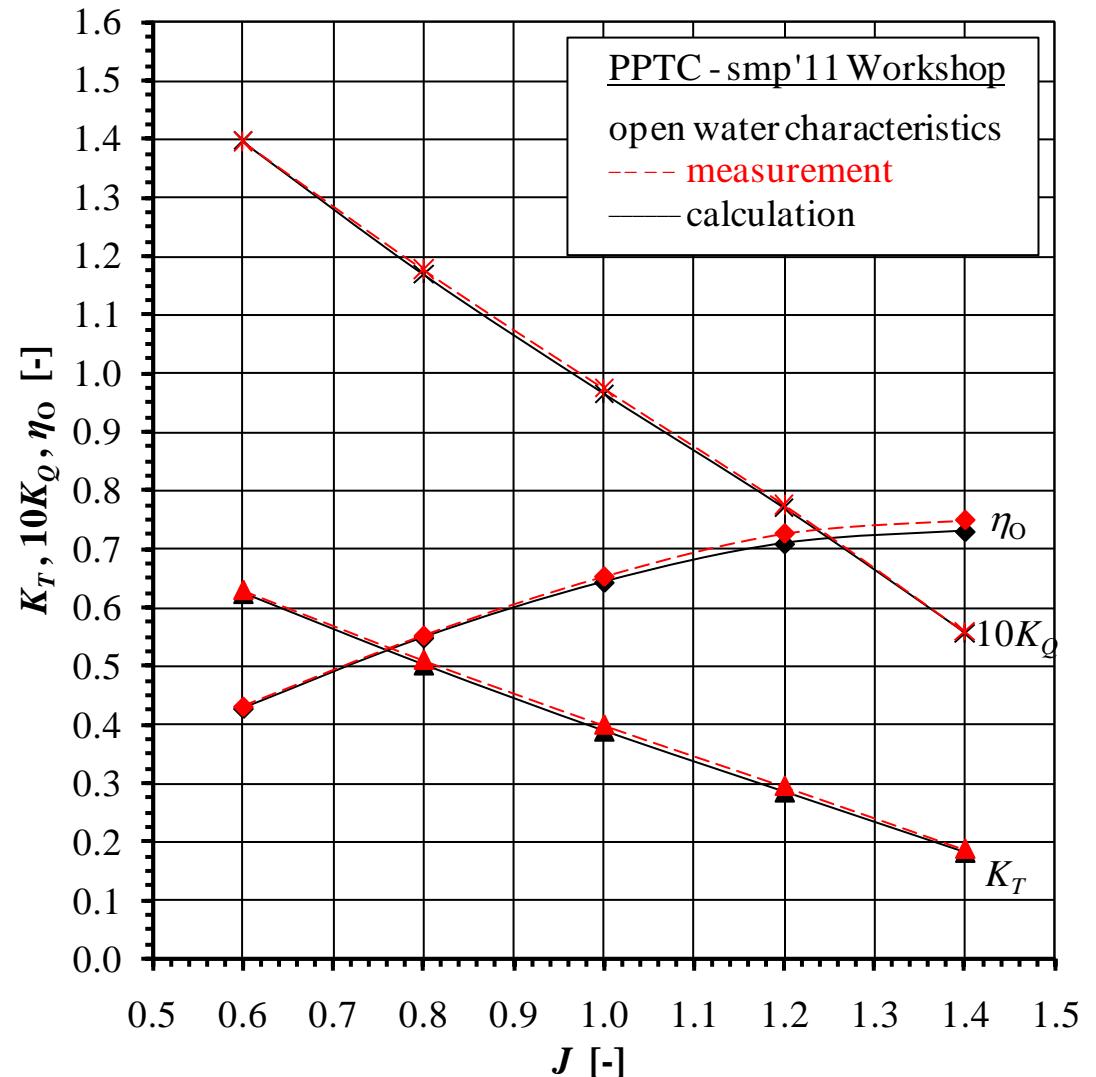
## 7.7 MARIC-Fluent

Characteristic of propeller (model scale)

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6250       | -0.0038      | -0.61               |
| 0.80 | 0.5100       | 0.5030       | -0.0070      | -1.37               |
| 1.00 | 0.3994       | 0.3900       | -0.0094      | -2.35               |
| 1.20 | 0.2949       | 0.2860       | -0.0089      | -3.02               |
| 1.40 | 0.1878       | 0.1830       | -0.0048      | -2.54               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.3970         | 0.0006         | 0.04                  |
| 0.80 | 1.1780         | 1.1700         | -0.0080        | -0.68                 |
| 1.00 | 0.9749         | 0.9660         | -0.0089        | -0.91                 |
| 1.20 | 0.7760         | 0.7700         | -0.0060        | -0.78                 |
| 1.40 | 0.5588         | 0.5570         | -0.0018        | -0.33                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4270          | -0.0030         | -0.71                  |
| 0.80 | 0.5512          | 0.5480          | -0.0032         | -0.58                  |
| 1.00 | 0.6520          | 0.6430          | -0.0090         | -1.40                  |
| 1.20 | 0.7258          | 0.7090          | -0.0168         | -2.37                  |
| 1.40 | 0.7487          | 0.7300          | -0.0187         | -2.56                  |



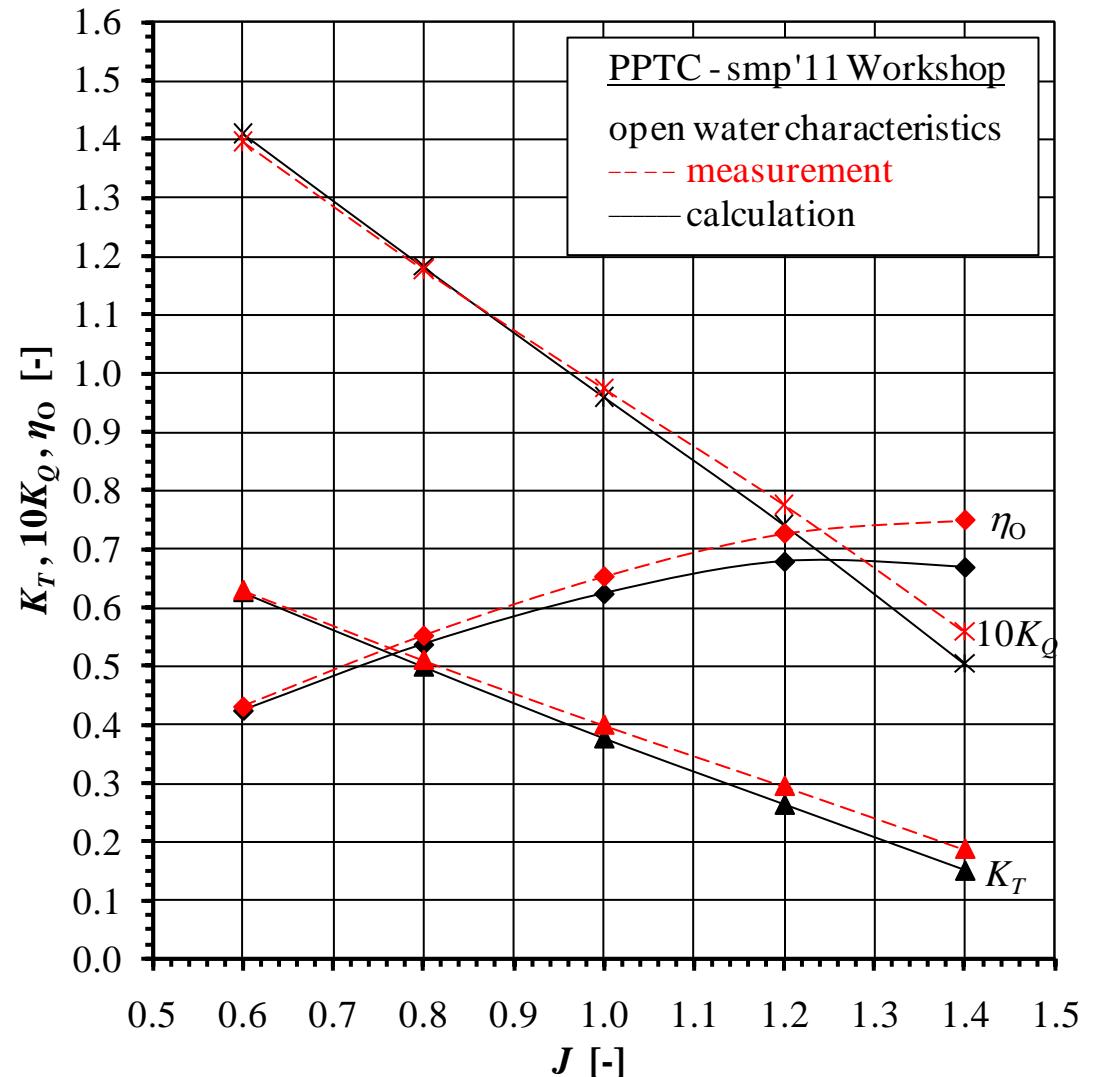
## 7.8 SSPA-Fluent

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6258       | -0.0030      | -0.48               |
| 0.80 | 0.5100       | 0.4990       | -0.0110      | -2.15               |
| 1.00 | 0.3994       | 0.3769       | -0.0225      | -5.63               |
| 1.20 | 0.2949       | 0.2640       | -0.0309      | -10.48              |
| 1.40 | 0.1878       | 0.1518       | -0.0360      | -19.15              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>C | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|--------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4096       | 0.0132         | 0.95                  |
| 0.80 | 1.1780         | 1.1822       | 0.0041         | 0.35                  |
| 1.00 | 0.9749         | 0.9605       | -0.0143        | -1.47                 |
| 1.20 | 0.7760         | 0.7418       | -0.0343        | -4.42                 |
| 1.40 | 0.5588         | 0.5049       | -0.0540        | -9.66                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4240          | -0.0061         | -1.41                  |
| 0.80 | 0.5512          | 0.5375          | -0.0137         | -2.49                  |
| 1.00 | 0.6520          | 0.6245          | -0.0275         | -4.22                  |
| 1.20 | 0.7258          | 0.6797          | -0.0461         | -6.35                  |
| 1.40 | 0.7487          | 0.6700          | -0.0787         | -10.51                 |



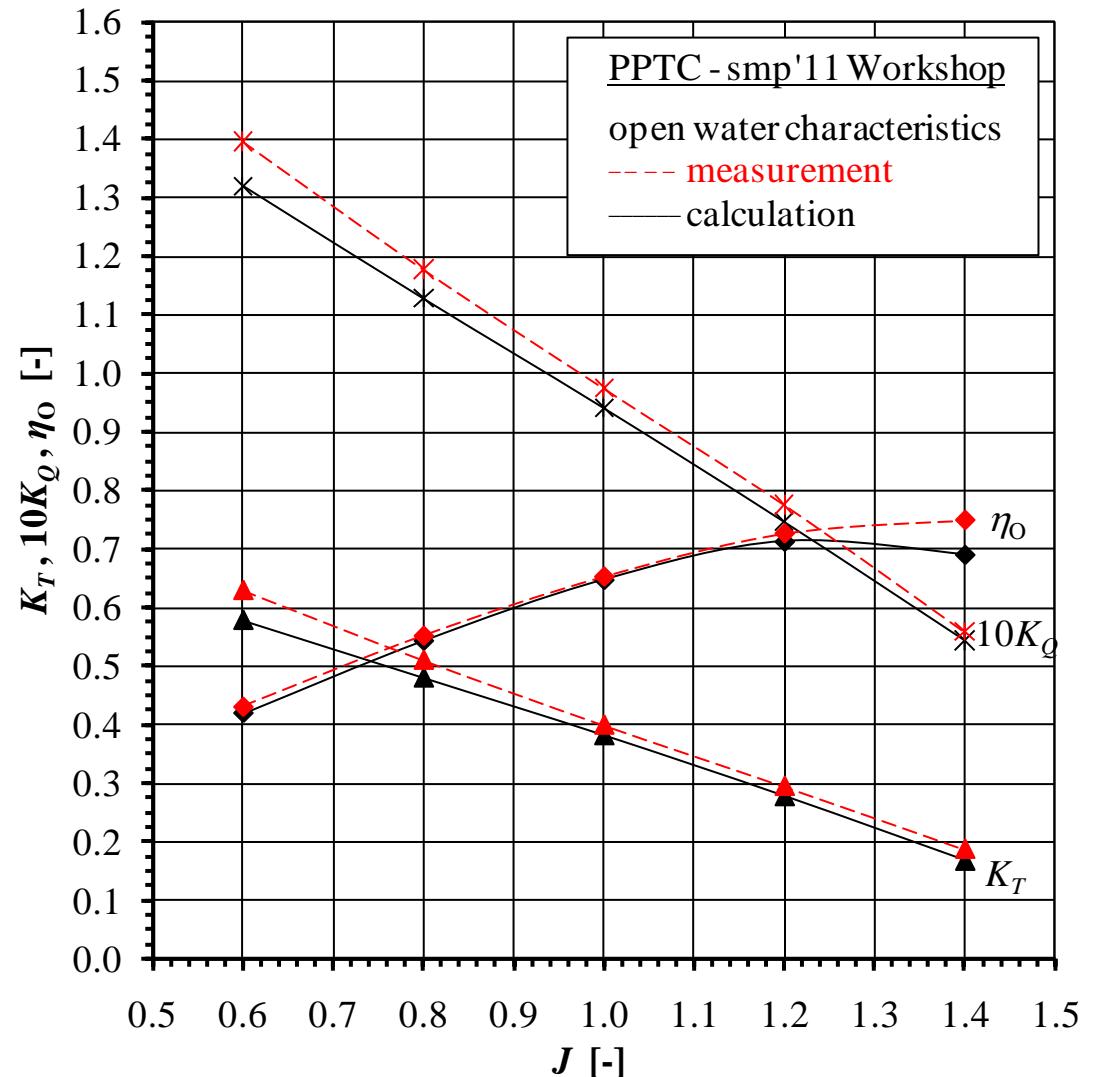
## 7.9 SVA-Vortex

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.5796       | -0.0492      | -7.82               |
| 0.80 | 0.5100       | 0.4814       | -0.0285      | -5.60               |
| 1.00 | 0.3994       | 0.3831       | -0.0163      | -4.08               |
| 1.20 | 0.2949       | 0.2791       | -0.0159      | -5.38               |
| 1.40 | 0.1878       | 0.1689       | -0.0189      | -10.07              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.3203         | -0.0761        | -5.45                 |
| 0.80 | 1.1780         | 1.1278         | -0.0502        | -4.26                 |
| 1.00 | 0.9749         | 0.9407         | -0.0342        | -3.51                 |
| 1.20 | 0.7760         | 0.7465         | -0.0296        | -3.81                 |
| 1.40 | 0.5588         | 0.5442         | -0.0146        | -2.61                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4192          | -0.0108         | -2.51                  |
| 0.80 | 0.5512          | 0.5435          | -0.0077         | -1.39                  |
| 1.00 | 0.6520          | 0.6481          | -0.0039         | -0.59                  |
| 1.20 | 0.7258          | 0.7140          | -0.0119         | -1.63                  |
| 1.40 | 0.7487          | 0.6914          | -0.0573         | -7.65                  |



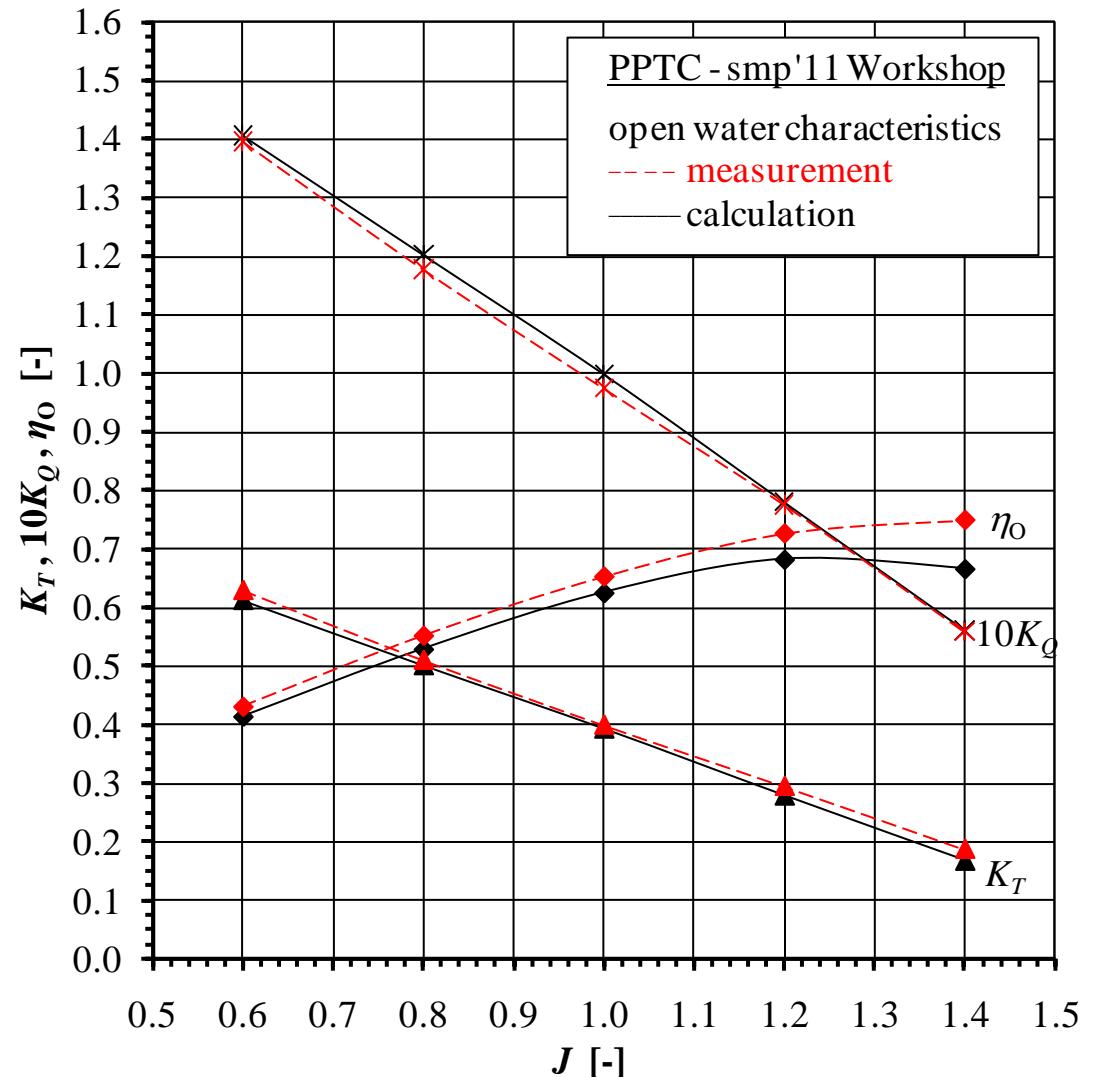
## 7.10 TUHH-FreSCO

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.629        | 0.612        | -0.017       | -2.676              |
| 0.80 | 0.510        | 0.501        | -0.009       | -1.758              |
| 1.00 | 0.399        | 0.393        | -0.006       | -1.595              |
| 1.20 | 0.295        | 0.279        | -0.016       | -5.398              |
| 1.40 | 0.188        | 0.168        | -0.020       | -10.525             |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.396          | 1.407          | 0.011          | 0.761                 |
| 0.80 | 1.178          | 1.203          | 0.025          | 2.122                 |
| 1.00 | 0.975          | 0.999          | 0.024          | 2.474                 |
| 1.20 | 0.776          | 0.780          | 0.004          | 0.509                 |
| 1.40 | 0.559          | 0.561          | 0.002          | 0.390                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.430           | 0.415           | -0.015          | -3.496                 |
| 0.80 | 0.551           | 0.530           | -0.021          | -3.845                 |
| 1.00 | 0.652           | 0.626           | -0.026          | -3.987                 |
| 1.20 | 0.726           | 0.683           | -0.043          | -5.897                 |
| 1.40 | 0.749           | 0.667           | -0.082          | -10.907                |



## 7.11 UniGenua-Panel

**Characteristic of propeller (model scale)**

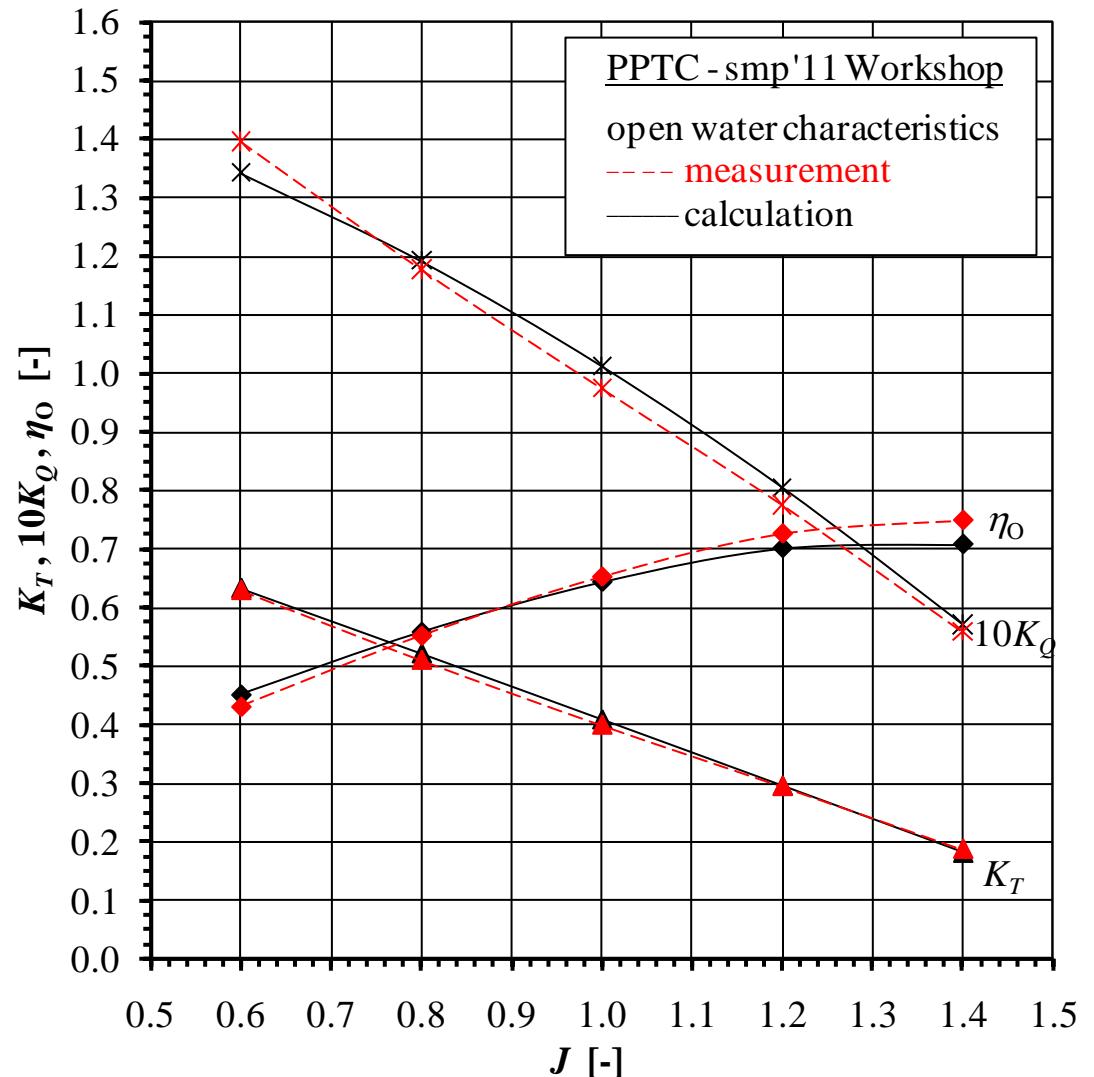
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6343       | 0.0054       | 0.86                |
| 0.80 | 0.5100       | 0.5225       | 0.0126       | 2.47                |
| 1.00 | 0.3994       | 0.4096       | 0.0102       | 2.56                |
| 1.20 | 0.2949       | 0.2959       | 0.0009       | 0.32                |
| 1.40 | 0.1878       | 0.1816       | -0.0062      | -3.30               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.3426         | -0.0538        | -3.85                 |
| 0.80 | 1.1780         | 1.1924         | 0.0144         | 1.22                  |
| 1.00 | 0.9749         | 1.0131         | 0.0382         | 3.92                  |
| 1.20 | 0.7760         | 0.8060         | 0.0299         | 3.85                  |
| 1.40 | 0.5588         | 0.5716         | 0.0128         | 2.29                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4511          | 0.0211          | 4.91                   |
| 0.80 | 0.5512          | 0.5580          | 0.0068          | 1.23                   |
| 1.00 | 0.6520          | 0.6435          | -0.0085         | -1.31                  |
| 1.20 | 0.7258          | 0.7011          | -0.0247         | -3.41                  |
| 1.40 | 0.7487          | 0.7077          | -0.0409         | -5.46                  |



## 7.12 UniGenua-OpenFOAM

Characteristic of propeller (model scale)

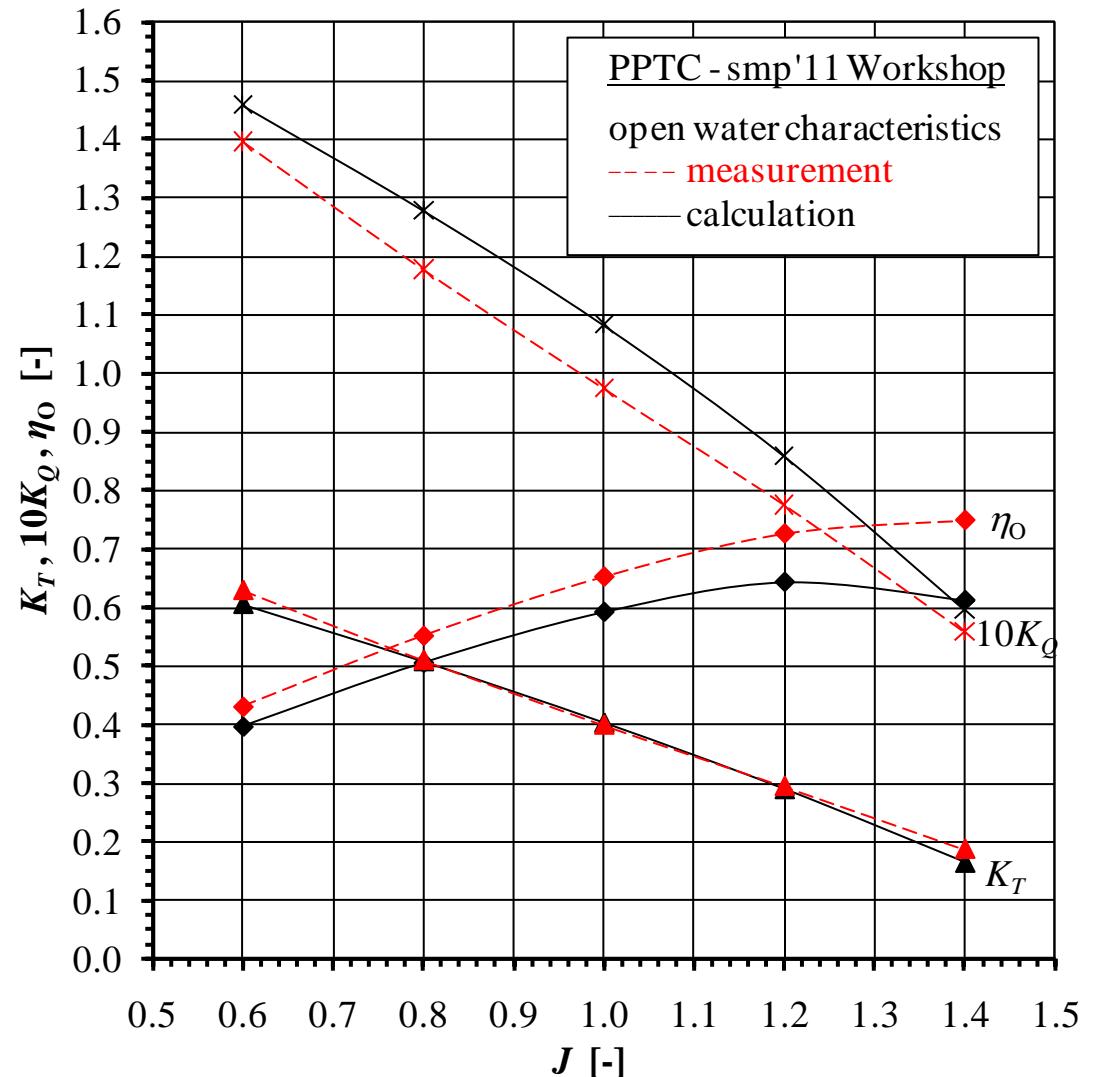
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6067       | -0.0222      | -3.53               |
| 0.80 | 0.5100       | 0.5088       | -0.0012      | -0.23               |
| 1.00 | 0.3994       | 0.4039       | 0.0045       | 1.13                |
| 1.20 | 0.2949       | 0.2902       | -0.0048      | -1.61               |
| 1.40 | 0.1878       | 0.1643       | -0.0234      | -12.47              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4592         | 0.0628         | 4.50                  |
| 0.80 | 1.1780         | 1.2796         | 0.1016         | 8.63                  |
| 1.00 | 0.9749         | 1.0837         | 0.1088         | 11.16                 |
| 1.20 | 0.7760         | 0.8599         | 0.0839         | 10.81                 |
| 1.40 | 0.5588         | 0.5970         | 0.0381         | 6.83                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.3970          | -0.0330         | -7.68                  |
| 0.80 | 0.5512          | 0.5063          | -0.0449         | -8.15                  |
| 1.00 | 0.6520          | 0.5932          | -0.0588         | -9.03                  |
| 1.20 | 0.7258          | 0.6445          | -0.0813         | -11.21                 |
| 1.40 | 0.7487          | 0.6134          | -0.1353         | -18.07                 |



### 7.13 UniGenua-StarCCM(kw)

Characteristic of propeller (model scale)

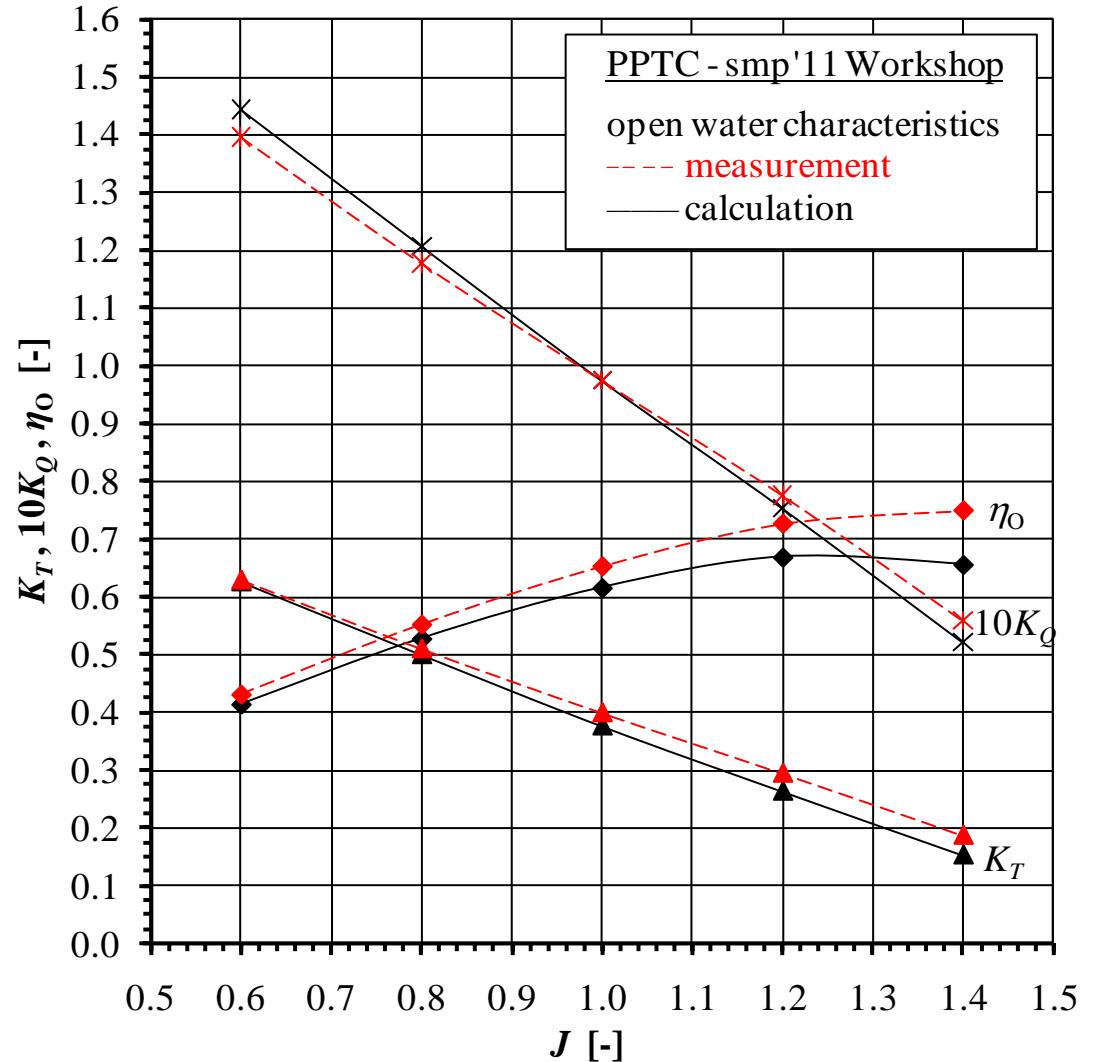
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6269       | -0.0020      | -0.31               |
| 0.80 | 0.5100       | 0.5007       | -0.0093      | -1.82               |
| 1.00 | 0.3994       | 0.3770       | -0.0223      | -5.60               |
| 1.20 | 0.2949       | 0.2639       | -0.0310      | -10.52              |
| 1.40 | 0.1878       | 0.1534       | -0.0343      | -18.29              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4443         | 0.0479         | 3.43                  |
| 0.80 | 1.1780         | 1.2076         | 0.0296         | 2.51                  |
| 1.00 | 0.9749         | 0.9743         | -0.0005        | -0.06                 |
| 1.20 | 0.7760         | 0.7535         | -0.0225        | -2.90                 |
| 1.40 | 0.5588         | 0.5211         | -0.0378        | -6.76                 |

| $J$  | $\eta_O$<br>EFD | $\eta_O$<br>CFD | $\Delta \eta_O$ | $\Delta \eta_O$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4145          | -0.0156         | -3.62                  |
| 0.80 | 0.5512          | 0.5279          | -0.0233         | -4.22                  |
| 1.00 | 0.6520          | 0.6159          | -0.0361         | -5.54                  |
| 1.20 | 0.7258          | 0.6689          | -0.0569         | -7.84                  |
| 1.40 | 0.7487          | 0.6561          | -0.0926         | -12.37                 |



## 7.14 UniGenua-StarCCM(ke)

Characteristic of propeller (model scale)

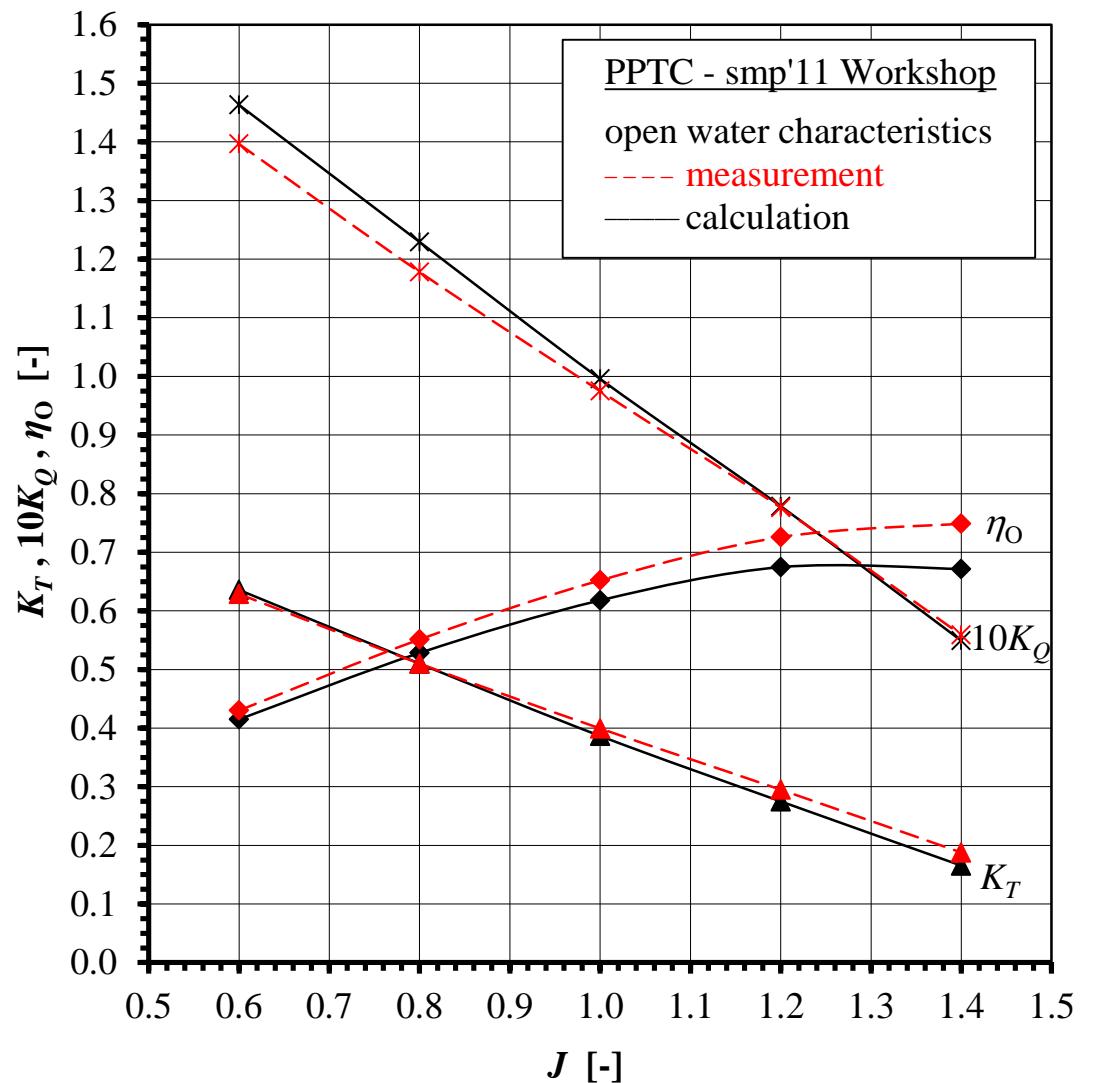
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6357       | 0.0069       | 1.09                |
| 0.80 | 0.5100       | 0.5099       | 0.0000       | -0.01               |
| 1.00 | 0.3994       | 0.3866       | -0.0128      | -3.21               |
| 1.20 | 0.2949       | 0.2750       | -0.0200      | -6.77               |
| 1.40 | 0.1878       | 0.1654       | -0.0223      | -11.90              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4630         | 0.0667         | 4.77                  |
| 0.80 | 1.1780         | 1.2292         | 0.0512         | 4.35                  |
| 1.00 | 0.9749         | 0.9956         | 0.0208         | 2.13                  |
| 1.20 | 0.7760         | 0.7785         | 0.0024         | 0.31                  |
| 1.40 | 0.5588         | 0.5491         | -0.0098        | -1.75                 |

| $J$  | $\eta_O$<br>EFD | $\eta_O$<br>CFD | $\Delta \eta_O$ | $\Delta \eta_O$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4149          | -0.0151         | -3.52                  |
| 0.80 | 0.5512          | 0.5282          | -0.0230         | -4.18                  |
| 1.00 | 0.6520          | 0.6179          | -0.0341         | -5.23                  |
| 1.20 | 0.7258          | 0.6746          | -0.0512         | -7.05                  |
| 1.40 | 0.7487          | 0.6713          | -0.0773         | -10.33                 |



## 7.15 UniTriest-CFX

**Characteristic of propeller (model scale)**

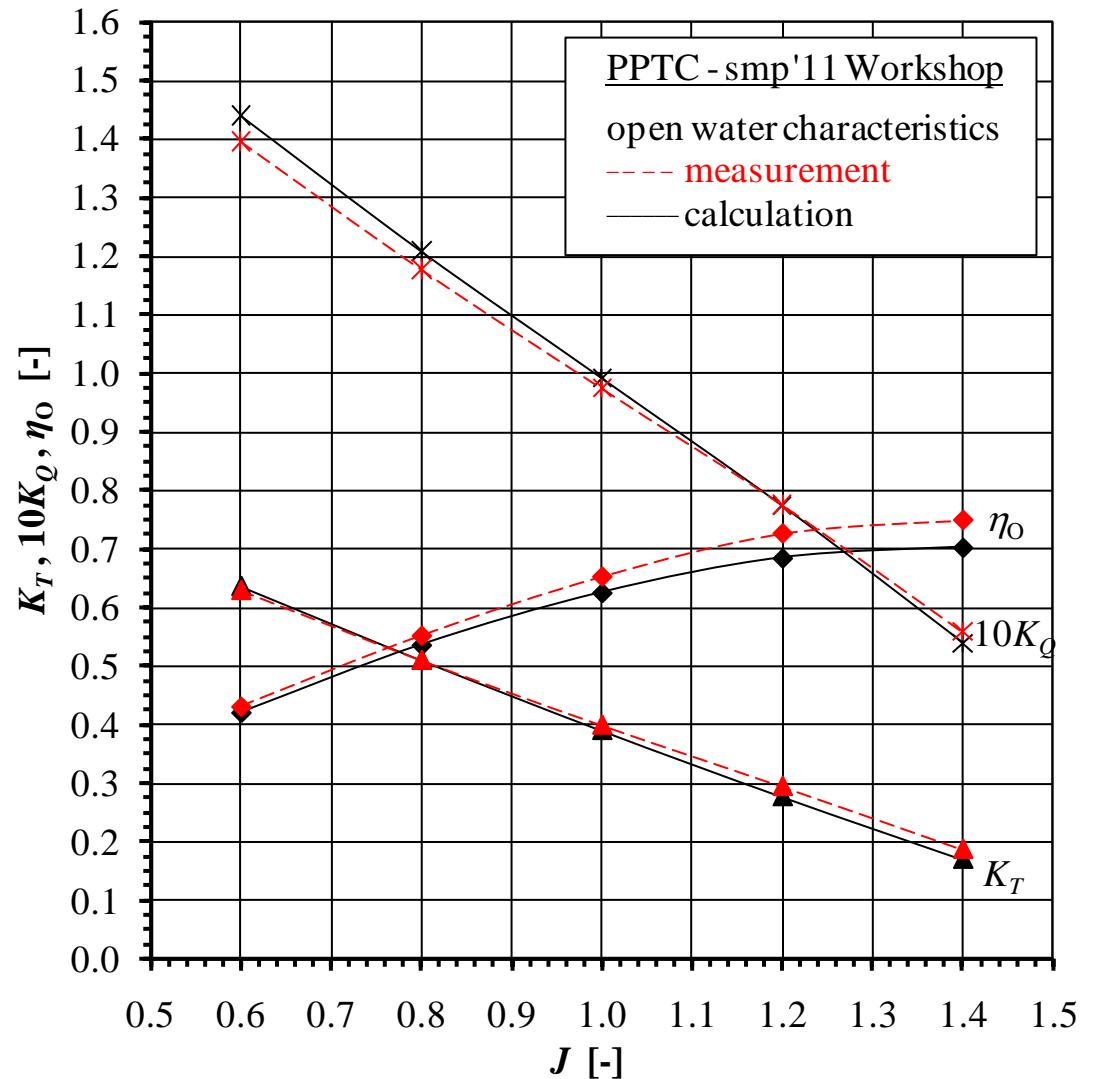
| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6360       | 0.0072       | 1.14                |
| 0.80 | 0.5100       | 0.5100       | 0.0000       | 0.01                |
| 1.00 | 0.3994       | 0.3900       | -0.0094      | -2.35               |
| 1.20 | 0.2949       | 0.2770       | -0.0179      | -6.08               |
| 1.40 | 0.1878       | 0.1700       | -0.0178      | -9.46               |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4410         | 0.0446         | 3.20                  |
| 0.80 | 1.1780         | 1.2090         | 0.0310         | 2.63                  |
| 1.00 | 0.9749         | 0.9920         | 0.0171         | 1.76                  |
| 1.20 | 0.7760         | 0.7740         | -0.0020        | -0.26                 |
| 1.40 | 0.5588         | 0.5400         | -0.0188        | -3.37                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4220          | -0.0080         | -1.87                  |
| 0.80 | 0.5512          | 0.5370          | -0.0142         | -2.57                  |
| 1.00 | 0.6520          | 0.6260          | -0.0260         | -3.99                  |
| 1.20 | 0.7258          | 0.6850          | -0.0408         | -5.62                  |
| 1.40 | 0.7487          | 0.7030          | -0.0457         | -6.10                  |



## 7.16 VicusDT-StarCCM

Characteristic of propeller (model scale)

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.5950       | -0.0338      | -5.38               |
| 0.80 | 0.5100       | 0.4850       | -0.0250      | -4.90               |
| 1.00 | 0.3994       | 0.3800       | -0.0194      | -4.85               |
| 1.20 | 0.2949       | 0.2750       | -0.0199      | -6.75               |
| 1.40 | 0.1878       | 0.1600       | -0.0278      | -14.79              |

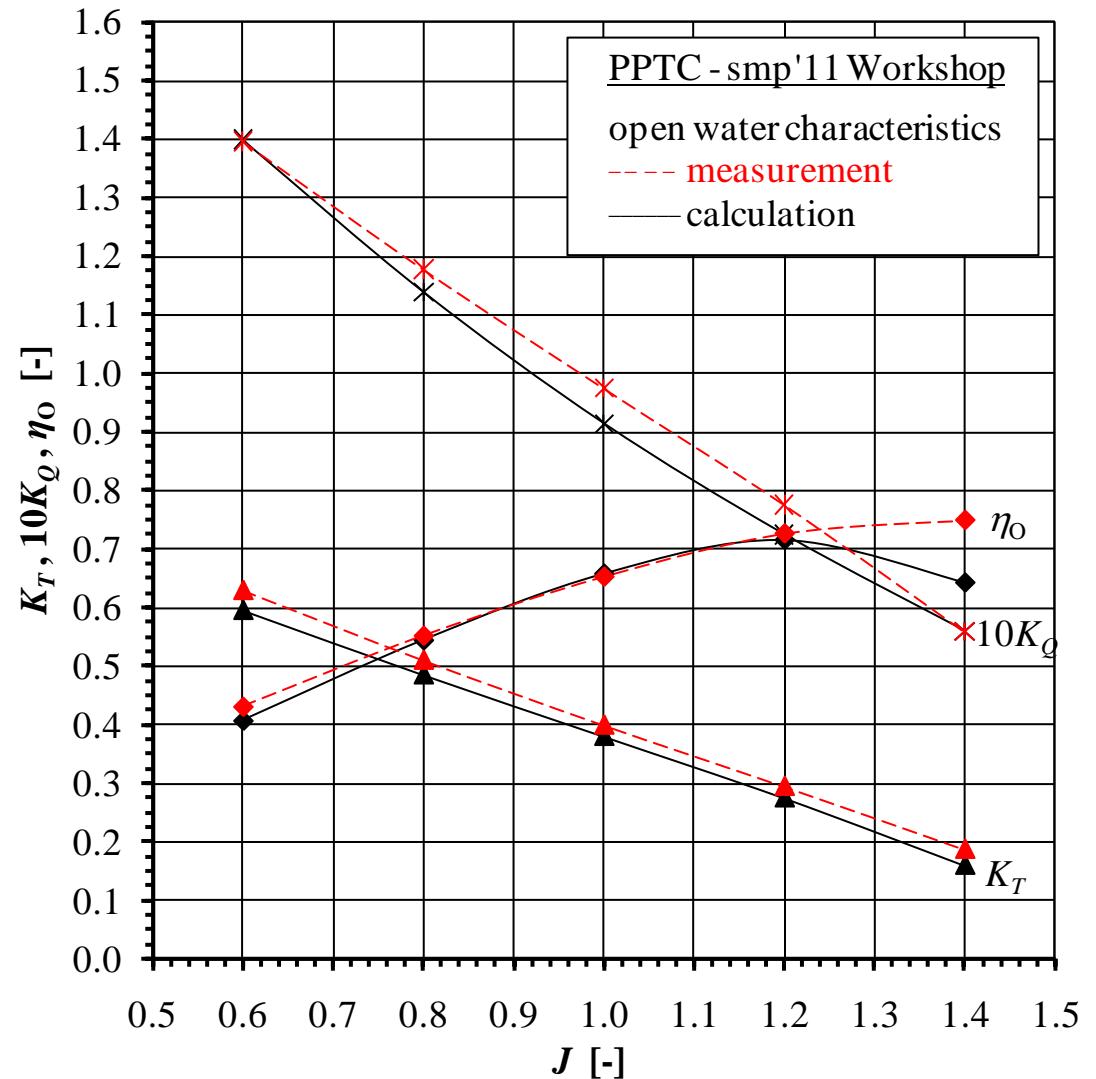
  

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4000         | 0.0036         | 0.26                  |
| 0.80 | 1.1780         | 1.1400         | -0.0380        | -3.23                 |
| 1.00 | 0.9749         | 0.9150         | -0.0599        | -6.14                 |
| 1.20 | 0.7760         | 0.7250         | -0.0510        | -6.58                 |
| 1.40 | 0.5588         | 0.5600         | 0.0012         | 0.21                  |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4070          | -0.0230         | -5.36                  |
| 0.80 | 0.5512          | 0.5450          | -0.0062         | -1.12                  |
| 1.00 | 0.6520          | 0.6590          | 0.0070          | 1.07                   |
| 1.20 | 0.7258          | 0.7170          | -0.0088         | -1.21                  |
| 1.40 | 0.7487          | 0.6440          | -0.1047         | -13.98                 |

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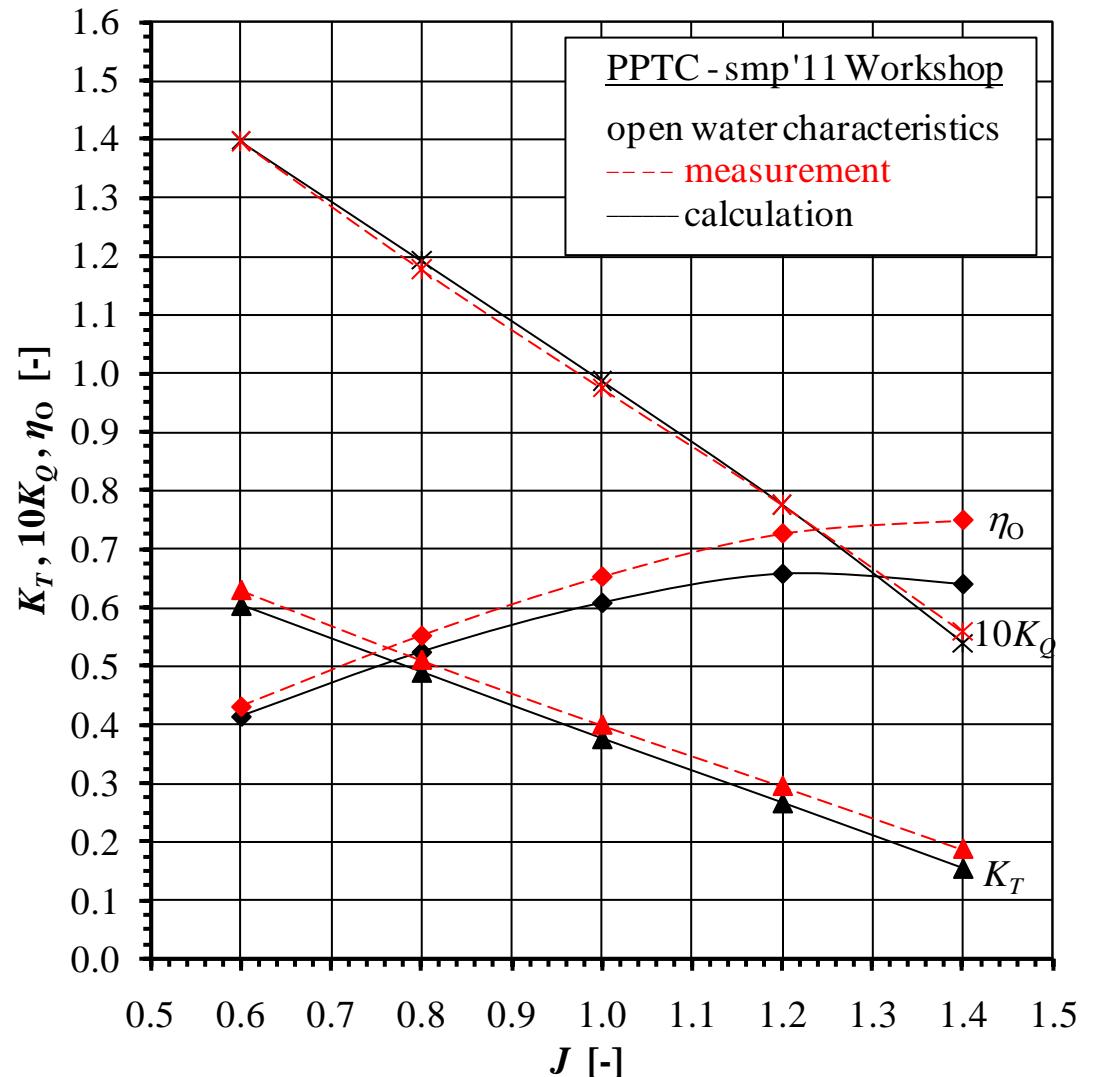
## 7.17 VOITH-Comet

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6044       | -0.0244      | -3.88               |
| 0.80 | 0.5100       | 0.4901       | -0.0198      | -3.89               |
| 1.00 | 0.3994       | 0.3765       | -0.0229      | -5.74               |
| 1.20 | 0.2949       | 0.2667       | -0.0283      | -9.58               |
| 1.40 | 0.1878       | 0.1547       | -0.0331      | -17.62              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.3977         | 0.0013         | 0.10                  |
| 0.80 | 1.1780         | 1.1932         | 0.0152         | 1.29                  |
| 1.00 | 0.9749         | 0.9874         | 0.0125         | 1.28                  |
| 1.20 | 0.7760         | 0.7757         | -0.0003        | -0.04                 |
| 1.40 | 0.5588         | 0.5394         | -0.0194        | -3.48                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4130          | -0.0171         | -3.97                  |
| 0.80 | 0.5512          | 0.5230          | -0.0282         | -5.11                  |
| 1.00 | 0.6520          | 0.6068          | -0.0452         | -6.93                  |
| 1.20 | 0.7258          | 0.6565          | -0.0693         | -9.55                  |
| 1.40 | 0.7487          | 0.6390          | -0.1097         | -14.65                 |



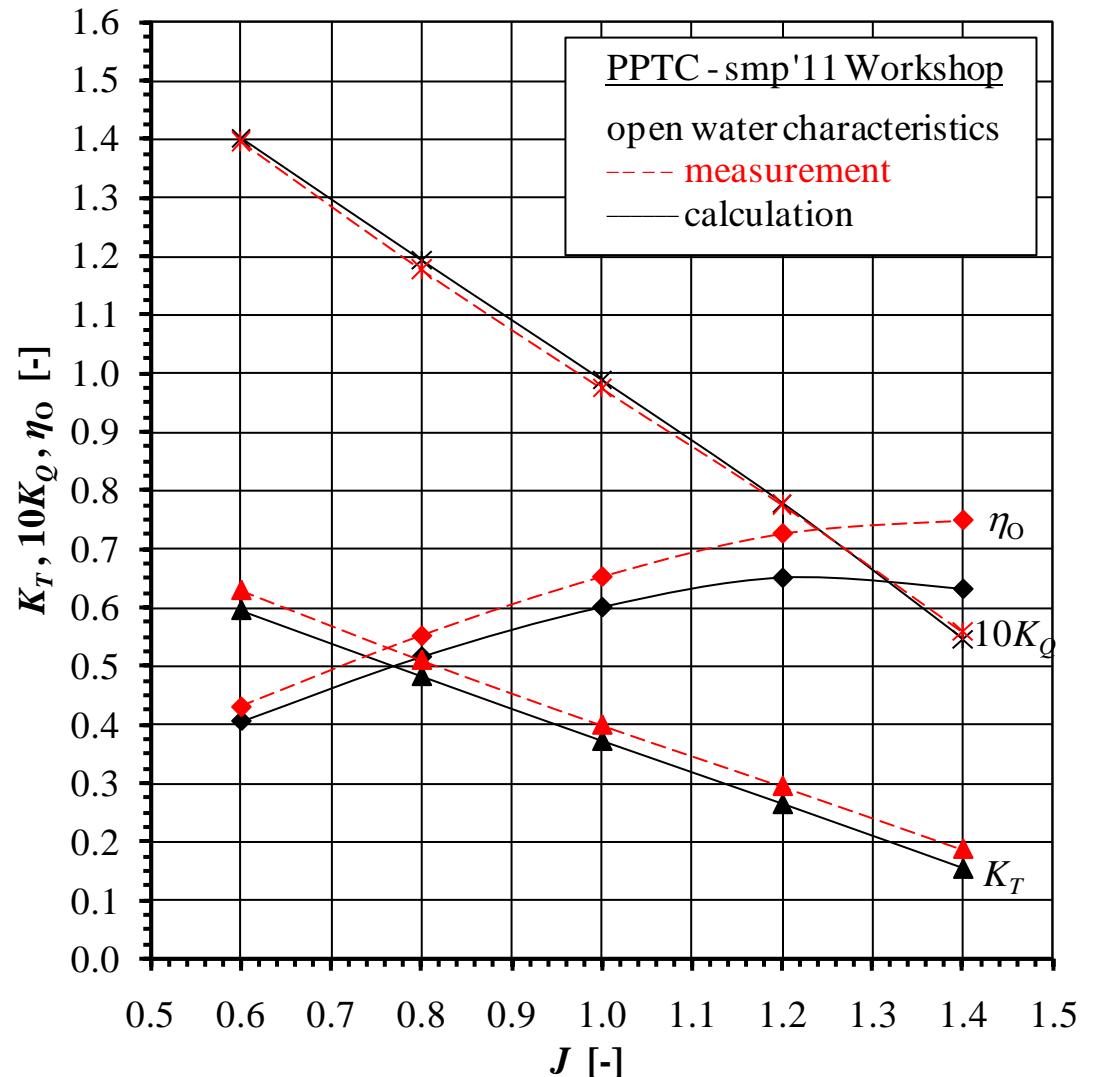
## 7.18 VOITH-OpenFOAM

Characteristic of propeller (model scale)

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.5957       | -0.0331      | -5.27               |
| 0.80 | 0.5100       | 0.4832       | -0.0268      | -5.25               |
| 1.00 | 0.3994       | 0.3727       | -0.0267      | -6.68               |
| 1.20 | 0.2949       | 0.2650       | -0.0299      | -10.15              |
| 1.40 | 0.1878       | 0.1548       | -0.0330      | -17.56              |

| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4021         | 0.0057         | 0.41                  |
| 0.80 | 1.1780         | 1.1933         | 0.0153         | 1.30                  |
| 1.00 | 0.9749         | 0.9884         | 0.0135         | 1.39                  |
| 1.20 | 0.7760         | 0.7783         | 0.0023         | 0.29                  |
| 1.40 | 0.5588         | 0.5463         | -0.0125        | -2.24                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4057          | -0.0243         | -5.66                  |
| 0.80 | 0.5512          | 0.5156          | -0.0356         | -6.46                  |
| 1.00 | 0.6520          | 0.6001          | -0.0519         | -7.96                  |
| 1.20 | 0.7258          | 0.6503          | -0.0755         | -10.40                 |
| 1.40 | 0.7487          | 0.6314          | -0.1173         | -15.66                 |



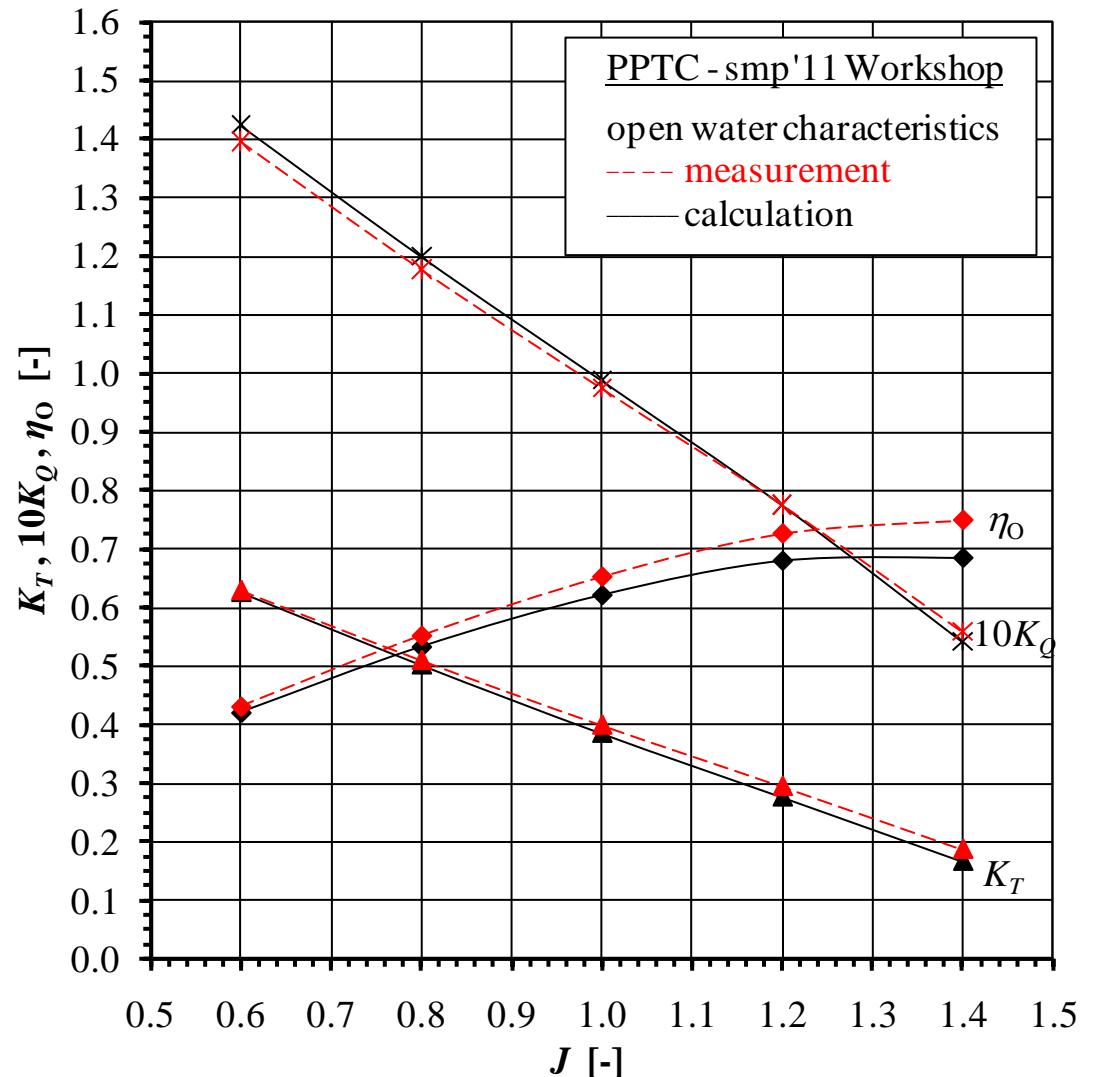
## 7.19 VTT-FinFlo

**Characteristic of propeller (model scale)**

| $J$  | $K_T$<br>EFD | $K_T$<br>CFD | $\Delta K_T$ | $\Delta K_T$<br>[%] |
|------|--------------|--------------|--------------|---------------------|
| 0.60 | 0.6288       | 0.6270       | -0.0018      | -0.29               |
| 0.80 | 0.5100       | 0.5030       | -0.0070      | -1.37               |
| 1.00 | 0.3994       | 0.3860       | -0.0134      | -3.35               |
| 1.20 | 0.2949       | 0.2770       | -0.0179      | -6.08               |
| 1.40 | 0.1878       | 0.1670       | -0.0208      | -11.06              |

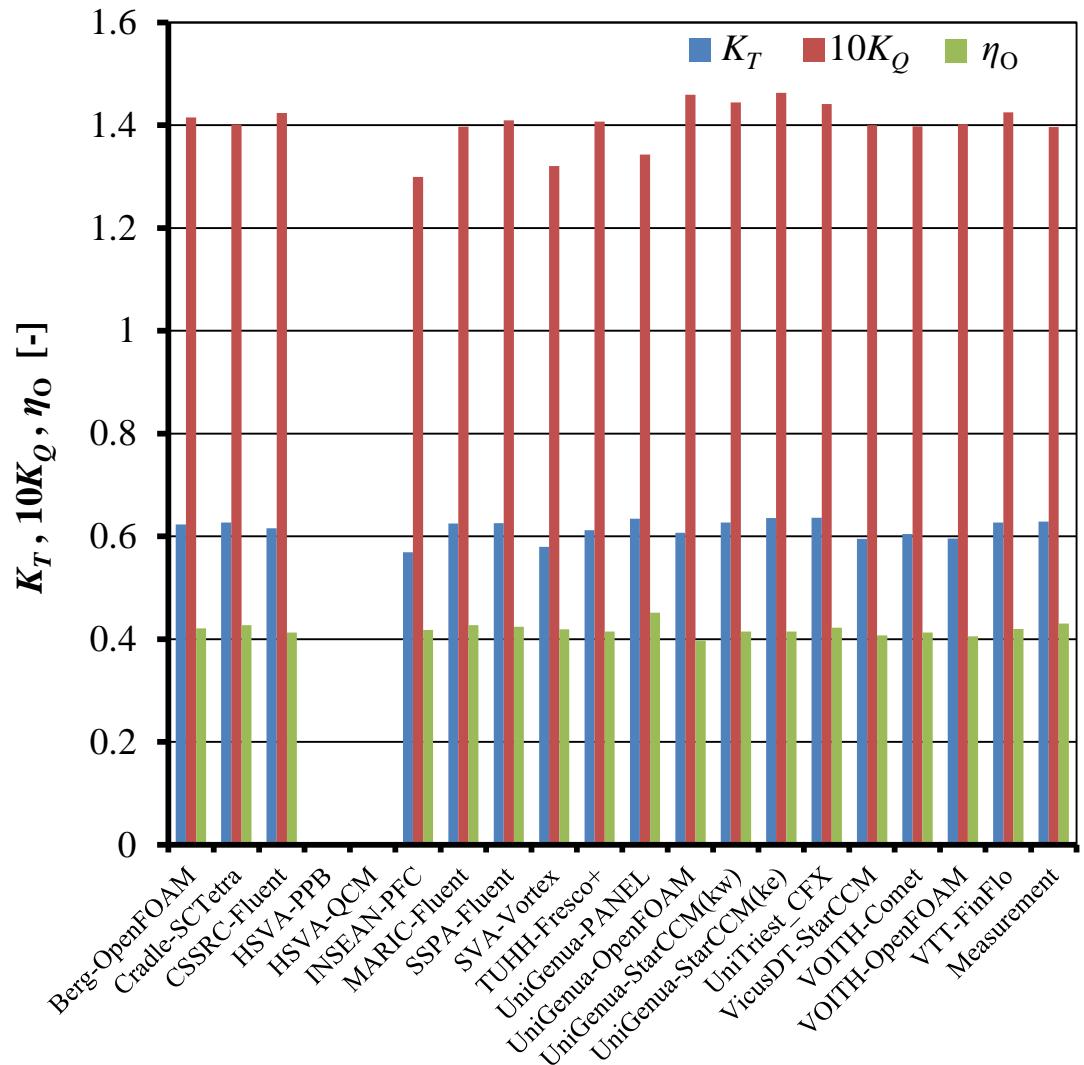
| $J$  | $10K_Q$<br>EFD | $10K_Q$<br>CFD | $\Delta 10K_Q$ | $\Delta 10K_Q$<br>[%] |
|------|----------------|----------------|----------------|-----------------------|
| 0.60 | 1.3964         | 1.4250         | 0.0286         | 2.05                  |
| 0.80 | 1.1780         | 1.2010         | 0.0230         | 1.95                  |
| 1.00 | 0.9749         | 0.9890         | 0.0141         | 1.45                  |
| 1.20 | 0.7760         | 0.7760         | 0.0000         | -0.01                 |
| 1.40 | 0.5588         | 0.5420         | -0.0168        | -3.01                 |

| $J$  | $\eta_o$<br>EFD | $\eta_o$<br>CFD | $\Delta \eta_o$ | $\Delta \eta_o$<br>[%] |
|------|-----------------|-----------------|-----------------|------------------------|
| 0.60 | 0.4300          | 0.4200          | -0.0100         | -2.33                  |
| 0.80 | 0.5512          | 0.5330          | -0.0182         | -3.30                  |
| 1.00 | 0.6520          | 0.6220          | -0.0300         | -4.60                  |
| 1.20 | 0.7258          | 0.6810          | -0.0448         | -6.17                  |
| 1.40 | 0.7487          | 0.6860          | -0.0627         | -8.37                  |



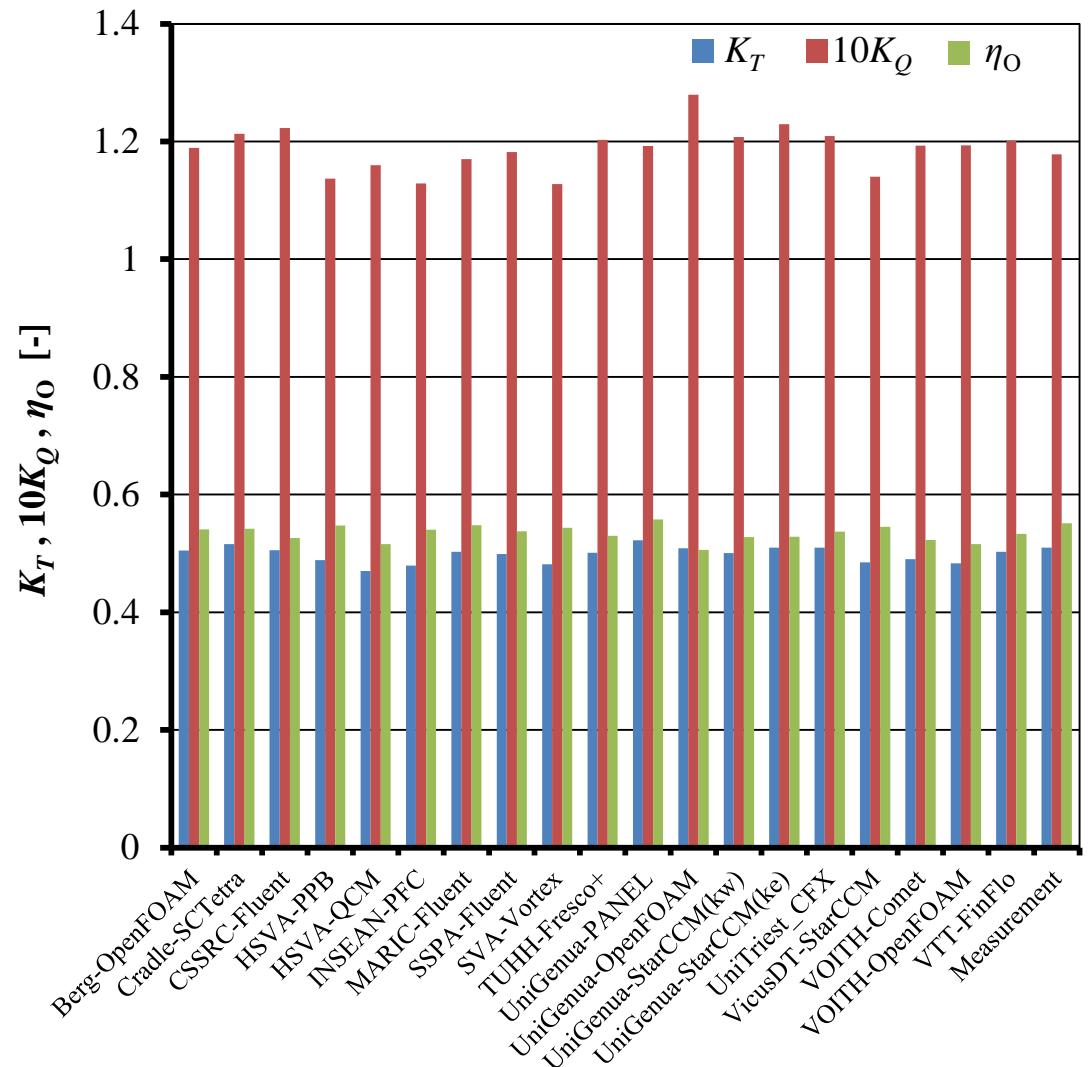
## 7.20 Comparison of open water characteristics, $J = 0.6$

|                      | $K_T$<br>[-] | $10K_Q$<br>[-] | $\eta_O$<br>[-] |
|----------------------|--------------|----------------|-----------------|
| Berg-OpenFOAM        | 0.623        | 1.415          | 0.421           |
| Cradle-SCTetra       | 0.627        | 1.401          | 0.427           |
| CSSRC-Fluent         | 0.616        | 1.424          | 0.413           |
| HSVA-PPB             |              |                |                 |
| HSVA-QCM             |              |                |                 |
| INSEAN-PFC           | 0.569        | 1.299          | 0.418           |
| MARIC-Fluent         | 0.625        | 1.397          | 0.427           |
| SSPA-Fluent          | 0.626        | 1.410          | 0.424           |
| SVA-Vortex           | 0.580        | 1.320          | 0.419           |
| TUHH-Fresco+         | 0.612        | 1.407          | 0.415           |
| UniGenua-PANEL       | 0.634        | 1.343          | 0.451           |
| UniGenua-OpenFOAM    | 0.607        | 1.459          | 0.397           |
| UniGenua-StarCCM(kw) | 0.627        | 1.444          | 0.414           |
| UniGenua-StarCCM(ke) | 0.636        | 1.463          | 0.415           |
| UniTriest            | 0.636        | 1.441          | 0.422           |
| VicusDT-StarCCM      | 0.595        | 1.400          | 0.407           |
| VOITH-Comet          | 0.604        | 1.398          | 0.413           |
| VOITH-OpenFOAM       | 0.596        | 1.402          | 0.406           |
| VTT-FinFlo           | 0.627        | 1.425          | 0.420           |
| Measurement          | 0.629        | 1.396          | 0.430           |



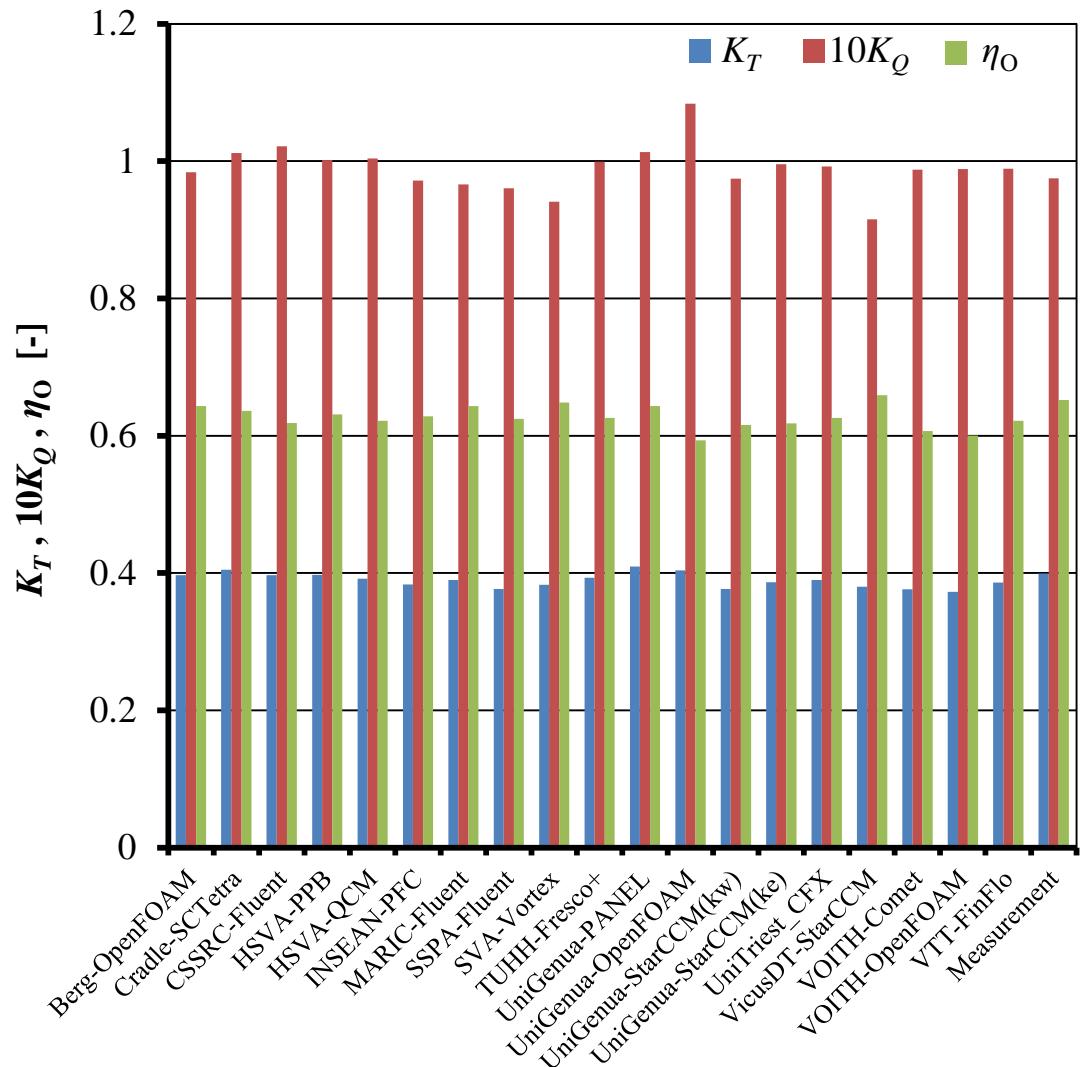
## 7.21 Comparison of open water characteristics, $J = 0.8$

|                      | $K_T$<br>[-] | $10K_Q$<br>[-] | $\eta_O$<br>[-] |
|----------------------|--------------|----------------|-----------------|
| Berg-OpenFOAM        | 0.505        | 1.189          | 0.541           |
| Cradle-SCTetra       | 0.516        | 1.213          | 0.542           |
| CSSRC-Fluent         | 0.506        | 1.223          | 0.526           |
| HSVVA-PPB            | 0.489        | 1.137          | 0.547           |
| HSVVA-QCM            | 0.470        | 1.160          | 0.516           |
| INSEAN-PFC           | 0.479        | 1.129          | 0.541           |
| MARIC-Fluent         | 0.503        | 1.170          | 0.548           |
| SSPA-Fluent          | 0.499        | 1.182          | 0.537           |
| SVA-Vortex           | 0.481        | 1.128          | 0.544           |
| TUHH-Fresco+         | 0.501        | 1.203          | 0.530           |
| UniGenua-PANEL       | 0.523        | 1.192          | 0.558           |
| UniGenua-OpenFOAM    | 0.509        | 1.280          | 0.506           |
| UniGenua-StarCCM(kw) | 0.501        | 1.208          | 0.528           |
| UniGenua-StarCCM(ke) | 0.510        | 1.229          | 0.528           |
| UniTriest            | 0.510        | 1.209          | 0.537           |
| VicusDT-StarCCM      | 0.485        | 1.140          | 0.545           |
| VOITH-Comet          | 0.490        | 1.193          | 0.523           |
| VOITH-OpenFOAM       | 0.483        | 1.193          | 0.516           |
| VTT-FinFlo           | 0.503        | 1.201          | 0.533           |
| Measurement          | 0.510        | 1.178          | 0.551           |



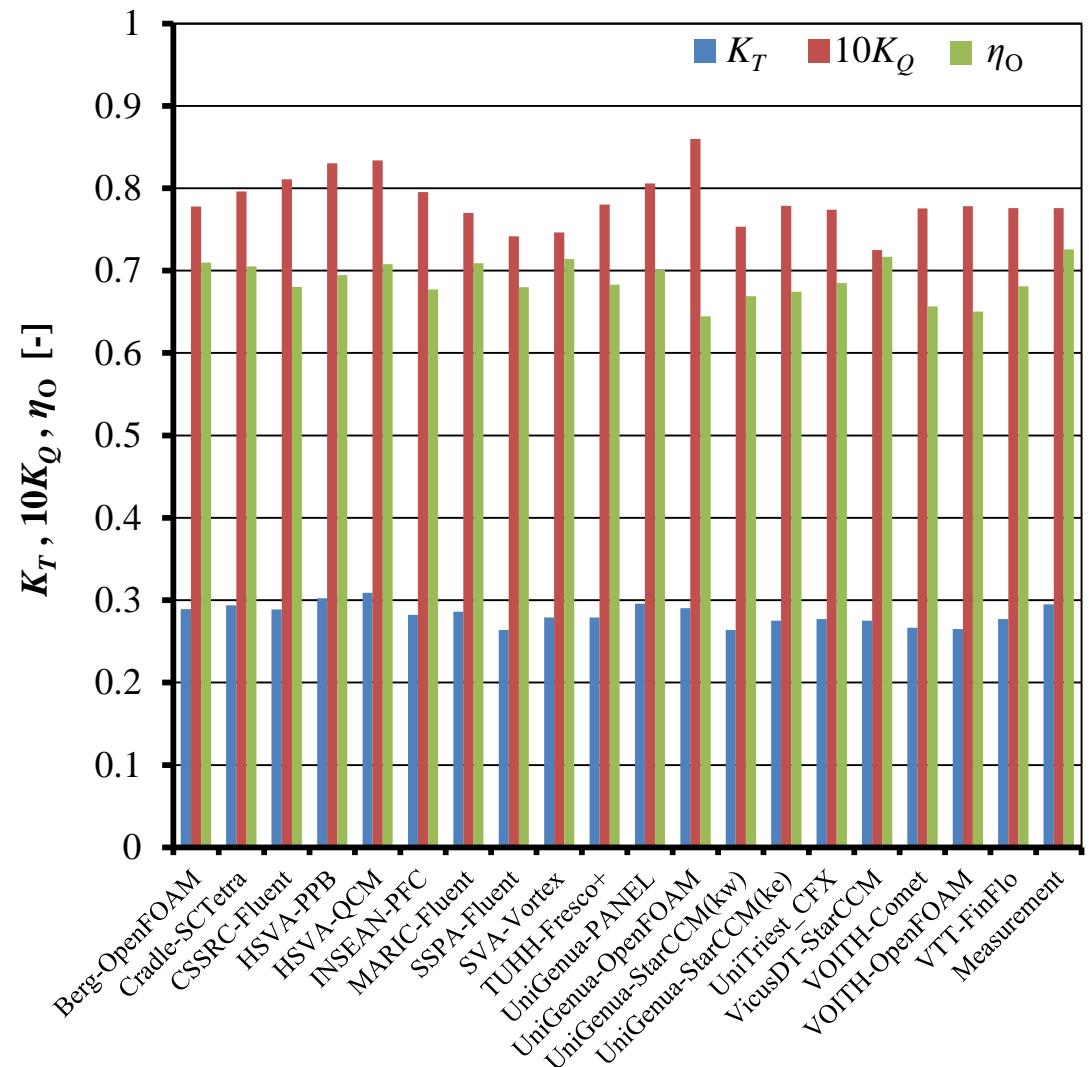
## 7.22 Comparison of open water characteristics, $J = 1.0$

|                      | $K_T$<br>[-] | $10K_Q$<br>[-] | $\eta_O$<br>[-] |
|----------------------|--------------|----------------|-----------------|
| Berg-OpenFOAM        | 0.397        | 0.984          | 0.643           |
| Cradle-SCTetra       | 0.405        | 1.012          | 0.636           |
| CSSRC-Fluent         | 0.397        | 1.022          | 0.619           |
| HSVVA-PPB            | 0.397        | 1.001          | 0.631           |
| HSVVA-QCM            | 0.392        | 1.004          | 0.622           |
| INSEAN-PFC           | 0.384        | 0.972          | 0.628           |
| MARIC-Fluent         | 0.390        | 0.966          | 0.643           |
| SSPA-Fluent          | 0.377        | 0.961          | 0.624           |
| SVA-Vortex           | 0.383        | 0.941          | 0.648           |
| TUHH-Fresco+         | 0.393        | 0.999          | 0.626           |
| UniGenua-PANEL       | 0.410        | 1.013          | 0.643           |
| UniGenua-OpenFOAM    | 0.404        | 1.084          | 0.593           |
| UniGenua-StarCCM(kw) | 0.377        | 0.974          | 0.616           |
| UniGenua-StarCCM(ke) | 0.387        | 0.996          | 0.618           |
| UniTriest            | 0.390        | 0.992          | 0.626           |
| VicusDT-StarCCM      | 0.380        | 0.915          | 0.659           |
| VOITH-Comet          | 0.376        | 0.987          | 0.607           |
| VOITH-OpenFOAM       | 0.373        | 0.988          | 0.600           |
| VTT-FinFlo           | 0.386        | 0.989          | 0.622           |
| Measurement          | 0.399        | 0.975          | 0.652           |



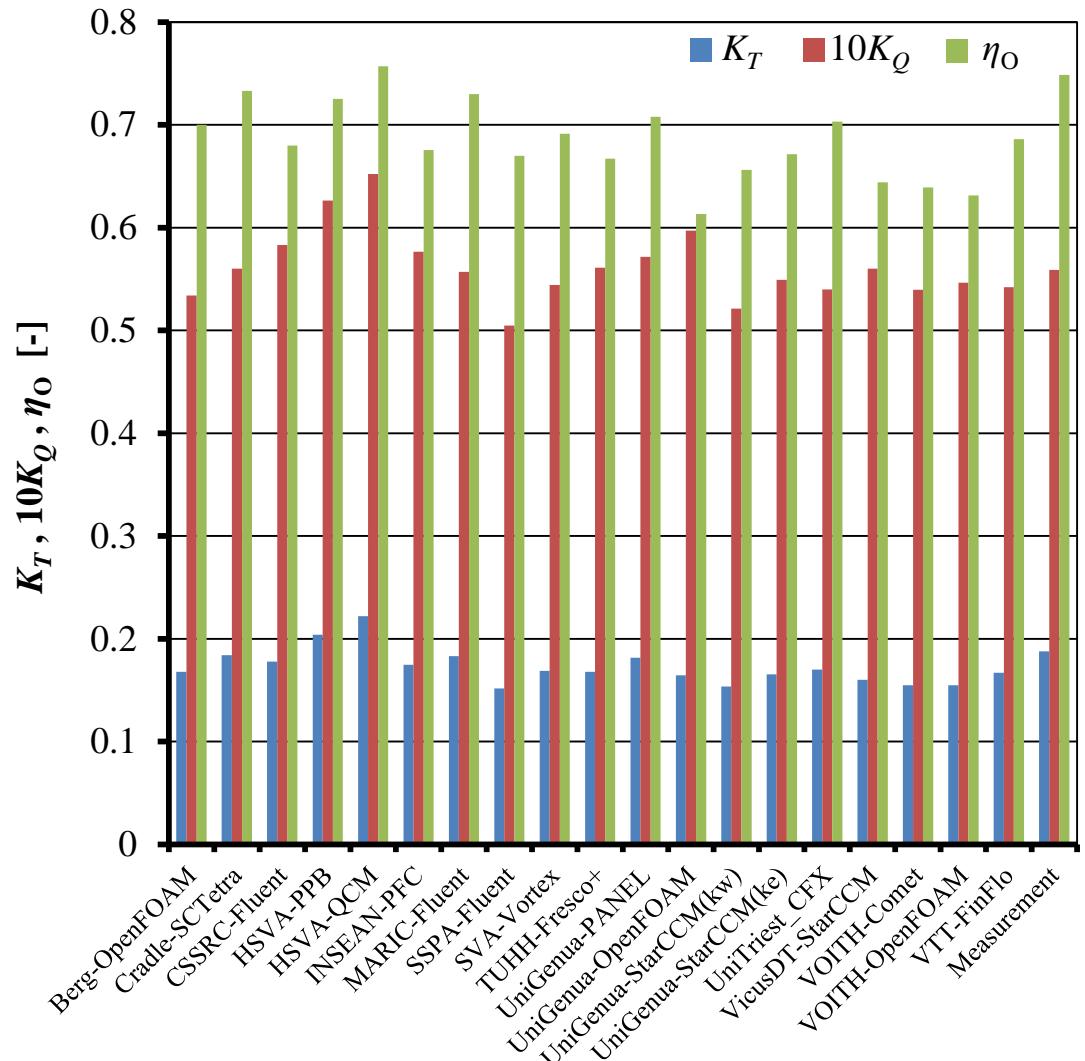
### 7.23 Comparison of open water characteristics, $J = 1.2$

|                      | $K_T$<br>[-] | $10K_Q$<br>[-] | $\eta_O$<br>[-] |
|----------------------|--------------|----------------|-----------------|
| Berg-OpenFOAM        | 0.289        | 0.778          | 0.710           |
| Cradle-SCTetra       | 0.294        | 0.796          | 0.705           |
| CSSRC-Fluent         | 0.289        | 0.811          | 0.680           |
| HSVVA-PPB            | 0.302        | 0.831          | 0.695           |
| HSVVA-QCM            | 0.309        | 0.834          | 0.708           |
| INSEAN-PFC           | 0.282        | 0.795          | 0.677           |
| MARIC-Fluent         | 0.286        | 0.770          | 0.709           |
| SSPA-Fluent          | 0.264        | 0.742          | 0.680           |
| SVA-Vortex           | 0.279        | 0.746          | 0.714           |
| TUHH-Fresco+         | 0.279        | 0.780          | 0.683           |
| UniGenua-PANEL       | 0.296        | 0.806          | 0.701           |
| UniGenua-OpenFOAM    | 0.290        | 0.860          | 0.644           |
| UniGenua-StarCCM(kw) | 0.264        | 0.754          | 0.669           |
| UniGenua-StarCCM(ke) | 0.275        | 0.778          | 0.675           |
| UniTriest            | 0.277        | 0.774          | 0.685           |
| VicusDT-StarCCM      | 0.275        | 0.725          | 0.717           |
| VOITH-Comet          | 0.267        | 0.776          | 0.657           |
| VOITH-OpenFOAM       | 0.265        | 0.778          | 0.650           |
| VTT-FinFlo           | 0.277        | 0.776          | 0.681           |
| Measurement          | 0.295        | 0.776          | 0.726           |



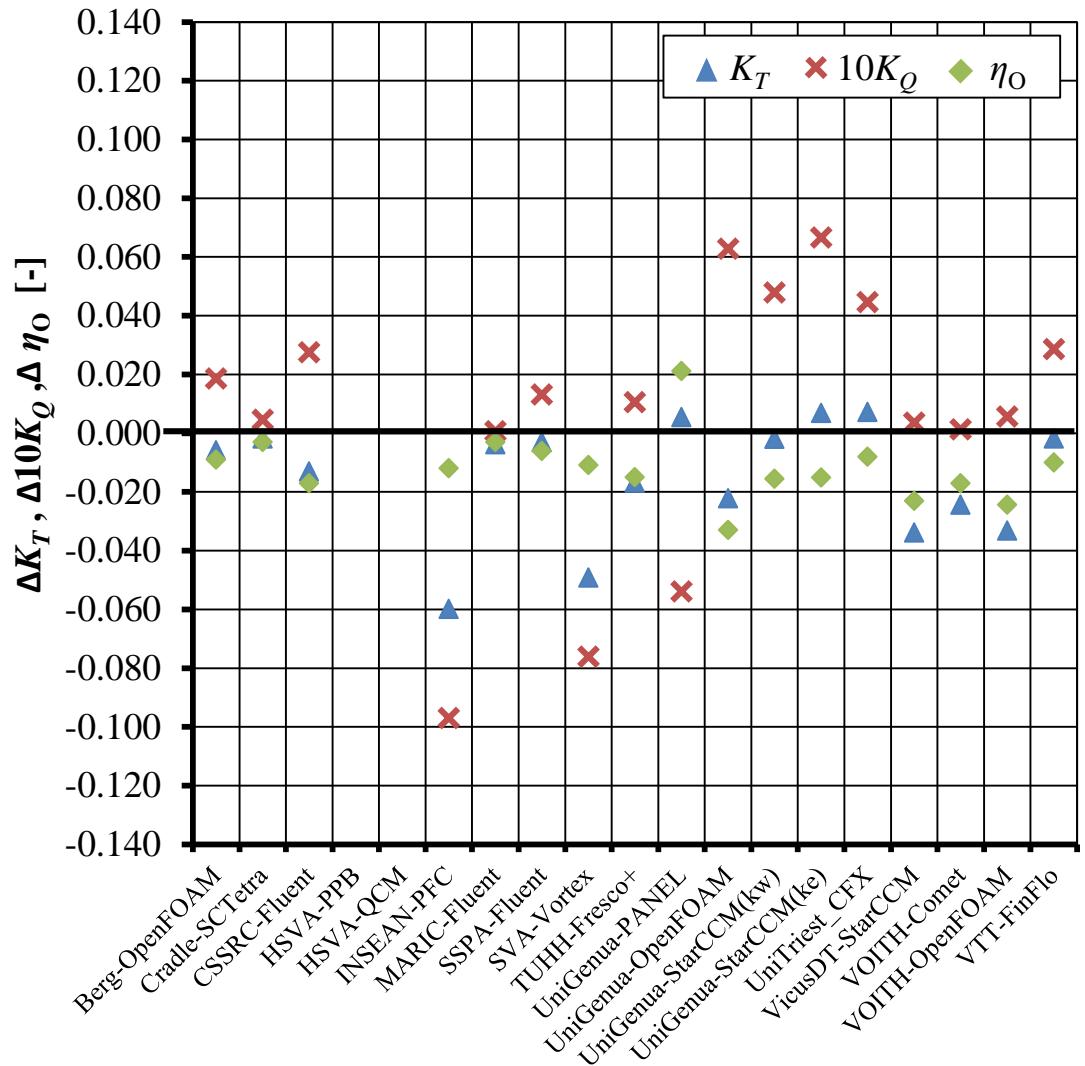
## 7.24 Comparison of open water characteristics, $J = 1.4$

|                      | $K_T$<br>[-] | $10K_Q$<br>[-] | $\eta_O$<br>[-] |
|----------------------|--------------|----------------|-----------------|
| Berg-OpenFOAM        | 0.168        | 0.534          | 0.700           |
| Cradle-SCTetra       | 0.184        | 0.560          | 0.733           |
| CSSRC-Fluent         | 0.178        | 0.583          | 0.680           |
| HSVA-PPB             | 0.204        | 0.626          | 0.725           |
| HSVA-QCM             | 0.222        | 0.652          | 0.757           |
| INSEAN-PFC           | 0.175        | 0.577          | 0.676           |
| MARIC-Fluent         | 0.183        | 0.557          | 0.730           |
| SSPA-Fluent          | 0.152        | 0.505          | 0.670           |
| SVA-Vortex           | 0.169        | 0.544          | 0.691           |
| TUHH-Fresco+         | 0.168        | 0.561          | 0.667           |
| UniGenua-PANEL       | 0.182        | 0.572          | 0.708           |
| UniGenua-OpenFOAM    | 0.164        | 0.597          | 0.613           |
| UniGenua-StarCCM(kw) | 0.153        | 0.521          | 0.656           |
| UniGenua-StarCCM(ke) | 0.165        | 0.549          | 0.671           |
| UniTriest            | 0.170        | 0.540          | 0.703           |
| VicusDT-StarCCM      | 0.160        | 0.560          | 0.644           |
| VOITH-Comet          | 0.155        | 0.539          | 0.639           |
| VOITH-OpenFOAM       | 0.155        | 0.546          | 0.631           |
| VTT-FinFlo           | 0.167        | 0.542          | 0.686           |
| Measurement          | 0.188        | 0.559          | 0.749           |



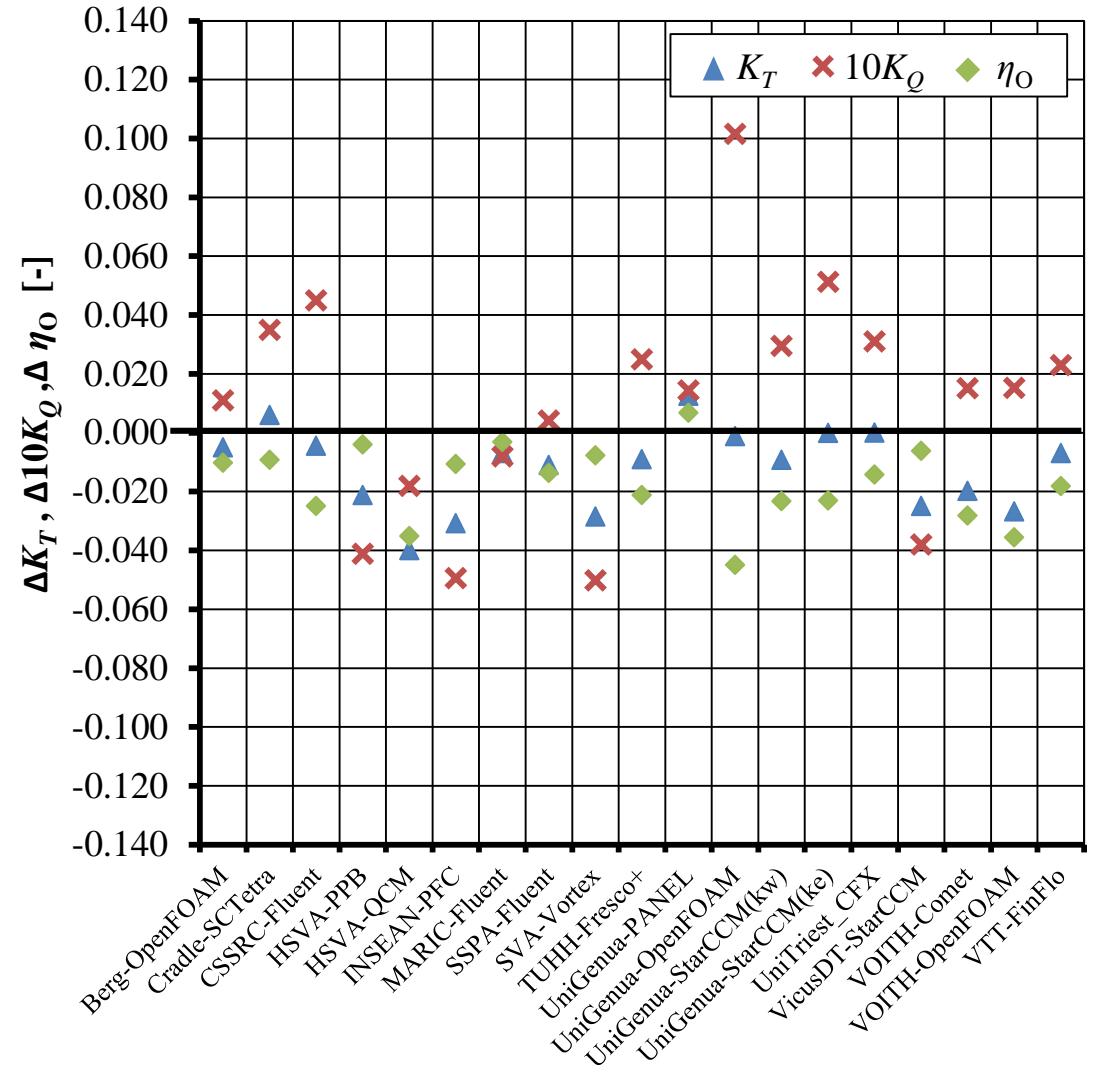
## 7.25 Absolute difference between measurement and calculation, $J = 0.6$

|                      | $\Delta K_T$<br>[-] | $\Delta 10K_Q$<br>[-] | $\Delta \eta_O$<br>[-] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.006              | 0.019                 | -0.009                 |
| Cradle-SCTetra       | -0.002              | 0.005                 | -0.003                 |
| CSSRC-Fluent         | -0.013              | 0.028                 | -0.017                 |
| HSVA-PPB             |                     |                       |                        |
| HSVA-QCM             |                     |                       |                        |
| INSEAN-PFC           | -0.060              | -0.097                | -0.012                 |
| MARIC-Fluent         | -0.004              | 0.001                 | -0.003                 |
| SSPA-Fluent          | -0.003              | 0.013                 | -0.006                 |
| SVA-Vortex           | -0.049              | -0.076                | -0.011                 |
| TUHH-Fresco+         | -0.017              | 0.011                 | -0.015                 |
| UniGenua-PANEL       | 0.005               | -0.054                | 0.021                  |
| UniGenua-OpenFOAM    | -0.022              | 0.063                 | -0.033                 |
| UniGenua-StarCCM(kw) | -0.002              | 0.048                 | -0.016                 |
| UniGenua-StarCCM(ke) | 0.007               | 0.067                 | -0.015                 |
| UniTriest            | 0.007               | 0.045                 | -0.008                 |
| VicusDT-StarCCM      | -0.034              | 0.004                 | -0.023                 |
| VOITH-Comet          | -0.024              | 0.001                 | -0.017                 |
| VOITH-OpenFOAM       | -0.033              | 0.006                 | -0.024                 |
| VTT-FinFlo           | -0.002              | 0.029                 | -0.010                 |



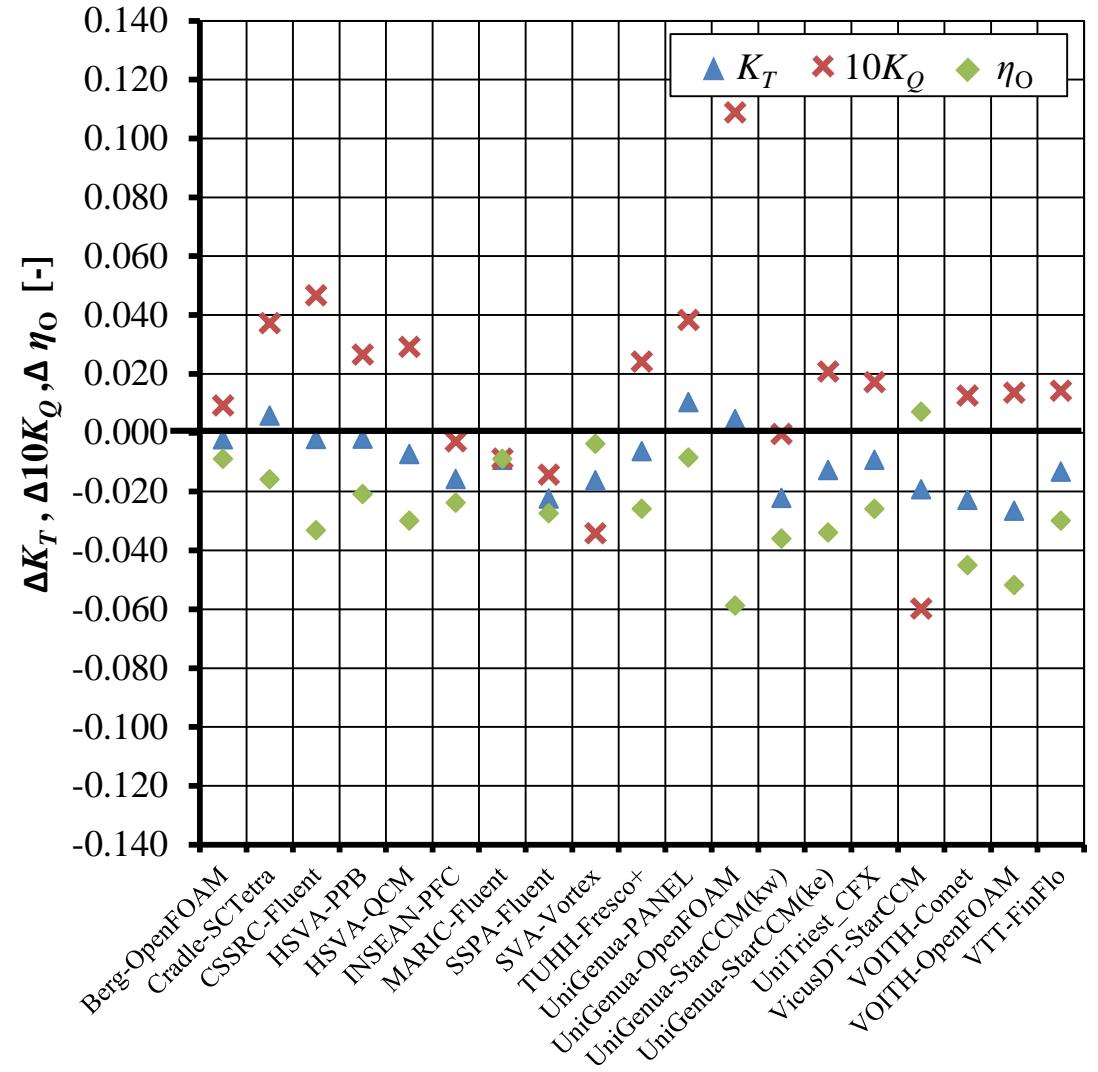
## 7.26 Absolute difference between measurement and calculation, $J = 0.8$

|                      | $\Delta K_T$<br>[-] | $\Delta 10K_Q$<br>[-] | $\Delta \eta_O$<br>[-] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.005              | 0.011                 | -0.010                 |
| Cradle-SCTetra       | 0.006               | 0.035                 | -0.009                 |
| CSSRC-Fluent         | -0.004              | 0.045                 | -0.025                 |
| HSVA-PPB             | -0.021              | -0.041                | -0.004                 |
| HSVA-QCM             | -0.040              | -0.018                | -0.035                 |
| INSEAN-PFC           | -0.031              | -0.049                | -0.011                 |
| MARIC-Fluent         | -0.007              | -0.008                | -0.003                 |
| SSPA-Fluent          | -0.011              | 0.004                 | -0.014                 |
| SVA-Vortex           | -0.029              | -0.050                | -0.008                 |
| TUHH-Fresco+         | -0.009              | 0.025                 | -0.021                 |
| UniGenua-PANEL       | 0.013               | 0.014                 | 0.007                  |
| UniGenua-OpenFOAM    | -0.001              | 0.102                 | -0.045                 |
| UniGenua-StarCCM(kw) | -0.009              | 0.030                 | -0.023                 |
| UniGenua-StarCCM(ke) | 0.000               | 0.051                 | -0.023                 |
| UniTriest            | 0.000               | 0.031                 | -0.014                 |
| VicusDT-StarCCM      | -0.025              | -0.038                | -0.006                 |
| VOITH-Comet          | -0.020              | 0.015                 | -0.028                 |
| VOITH-OpenFOAM       | -0.027              | 0.015                 | -0.036                 |
| VTT-FinFlo           | -0.007              | 0.023                 | -0.018                 |



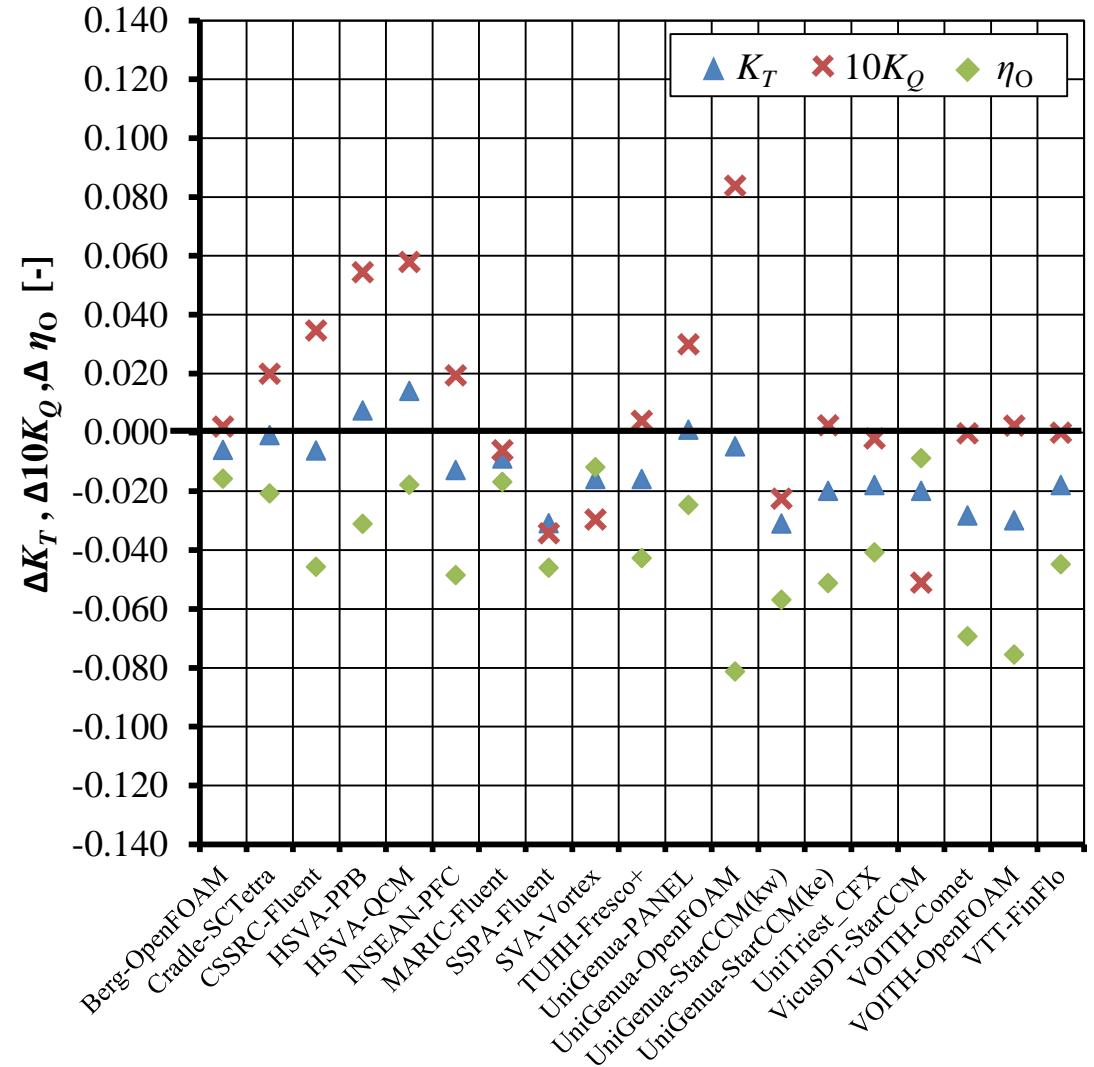
### 7.27 Absolute difference between measurement and calculation, $J = 1.0$

|                      | $\Delta K_T$<br>[-] | $\Delta 10K_Q$<br>[-] | $\Delta \eta_O$<br>[-] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.002              | 0.009                 | -0.009                 |
| Cradle-SCTetra       | 0.006               | 0.037                 | -0.016                 |
| CSSRC-Fluent         | -0.002              | 0.047                 | -0.033                 |
| HSVA-PPB             | -0.002              | 0.026                 | -0.021                 |
| HSVA-QCM             | -0.007              | 0.029                 | -0.030                 |
| INSEAN-PFC           | -0.016              | -0.003                | -0.024                 |
| MARIC-Fluent         | -0.009              | -0.009                | -0.009                 |
| SSPA-Fluent          | -0.022              | -0.014                | -0.027                 |
| SVA-Vortex           | -0.016              | -0.034                | -0.004                 |
| TUHH-Fresco+         | -0.006              | 0.024                 | -0.026                 |
| UniGenua-PANEL       | 0.010               | 0.038                 | -0.009                 |
| UniGenua-OpenFOAM    | 0.004               | 0.109                 | -0.059                 |
| UniGenua-StarCCM(kw) | -0.022              | -0.001                | -0.036                 |
| UniGenua-StarCCM(ke) | -0.013              | 0.021                 | -0.034                 |
| UniTriest            | -0.009              | 0.017                 | -0.026                 |
| VicusDT-StarCCM      | -0.019              | -0.060                | 0.007                  |
| VOITH-Comet          | -0.023              | 0.013                 | -0.045                 |
| VOITH-OpenFOAM       | -0.027              | 0.014                 | -0.052                 |
| VTT-FinFlo           | -0.013              | 0.014                 | -0.030                 |



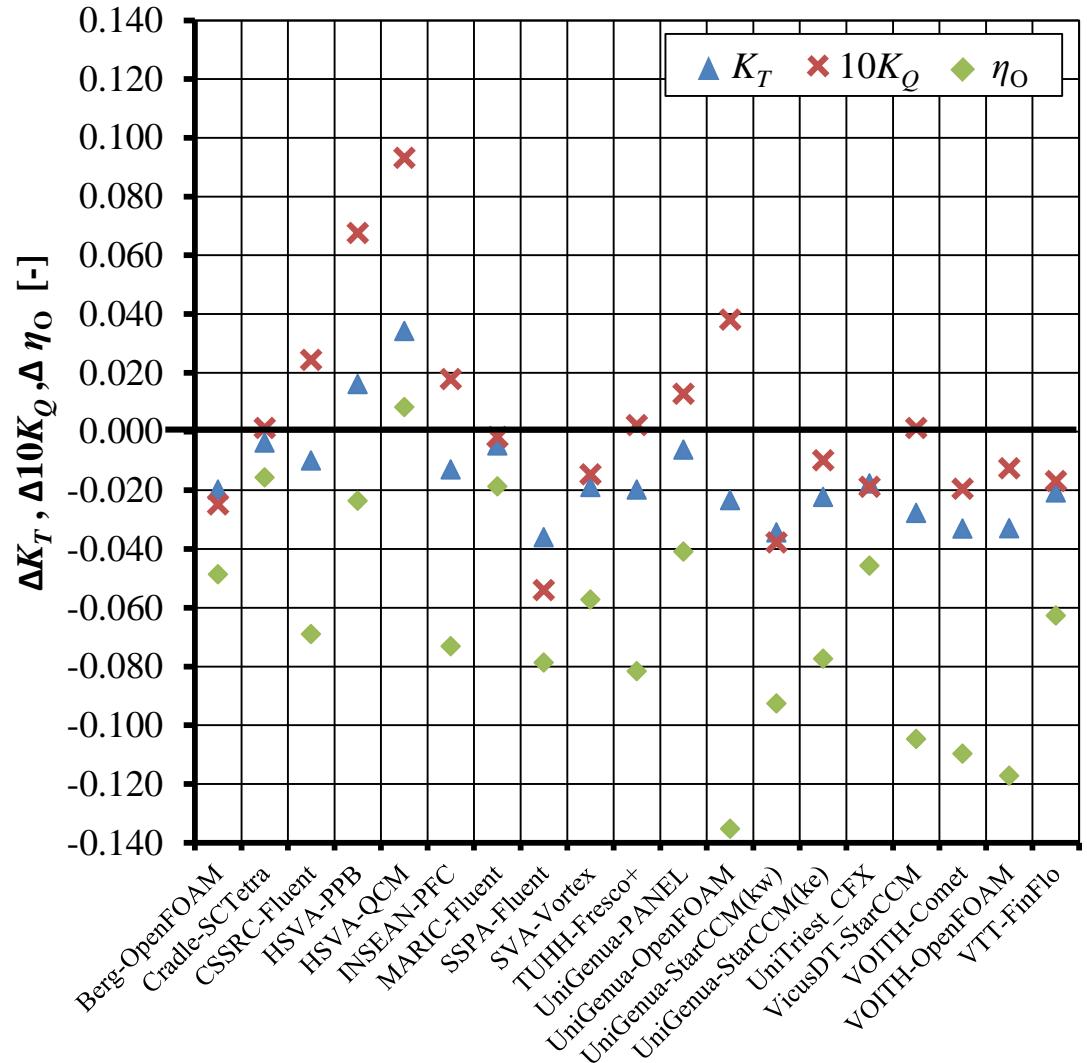
## 7.28 Absolute difference between measurement and calculation, $J = 1.2$

|                      | $\Delta K_T$<br>[-] | $\Delta 10K_Q$<br>[-] | $\Delta \eta_O$<br>[-] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.006              | 0.002                 | -0.016                 |
| Cradle-SCTetra       | -0.001              | 0.020                 | -0.021                 |
| CSSRC-Fluent         | -0.006              | 0.035                 | -0.046                 |
| HSVA-PPB             | 0.007               | 0.054                 | -0.031                 |
| HSVA-QCM             | 0.014               | 0.058                 | -0.018                 |
| INSEAN-PFC           | -0.013              | 0.019                 | -0.049                 |
| MARIC-Fluent         | -0.009              | -0.006                | -0.017                 |
| SSPA-Fluent          | -0.031              | -0.034                | -0.046                 |
| SVA-Vortex           | -0.016              | -0.030                | -0.012                 |
| TUHH-Fresco+         | -0.016              | 0.004                 | -0.043                 |
| UniGenua-PANEL       | 0.001               | 0.030                 | -0.025                 |
| UniGenua-OpenFOAM    | -0.005              | 0.084                 | -0.081                 |
| UniGenua-StarCCM(kw) | -0.031              | -0.023                | -0.057                 |
| UniGenua-StarCCM(ke) | -0.020              | 0.002                 | -0.051                 |
| UniTriest            | -0.018              | -0.002                | -0.041                 |
| VicusDT-StarCCM      | -0.020              | -0.051                | -0.009                 |
| VOITH-Comet          | -0.028              | 0.000                 | -0.069                 |
| VOITH-OpenFOAM       | -0.030              | 0.002                 | -0.076                 |
| VTT-FinFlo           | -0.018              | 0.000                 | -0.045                 |



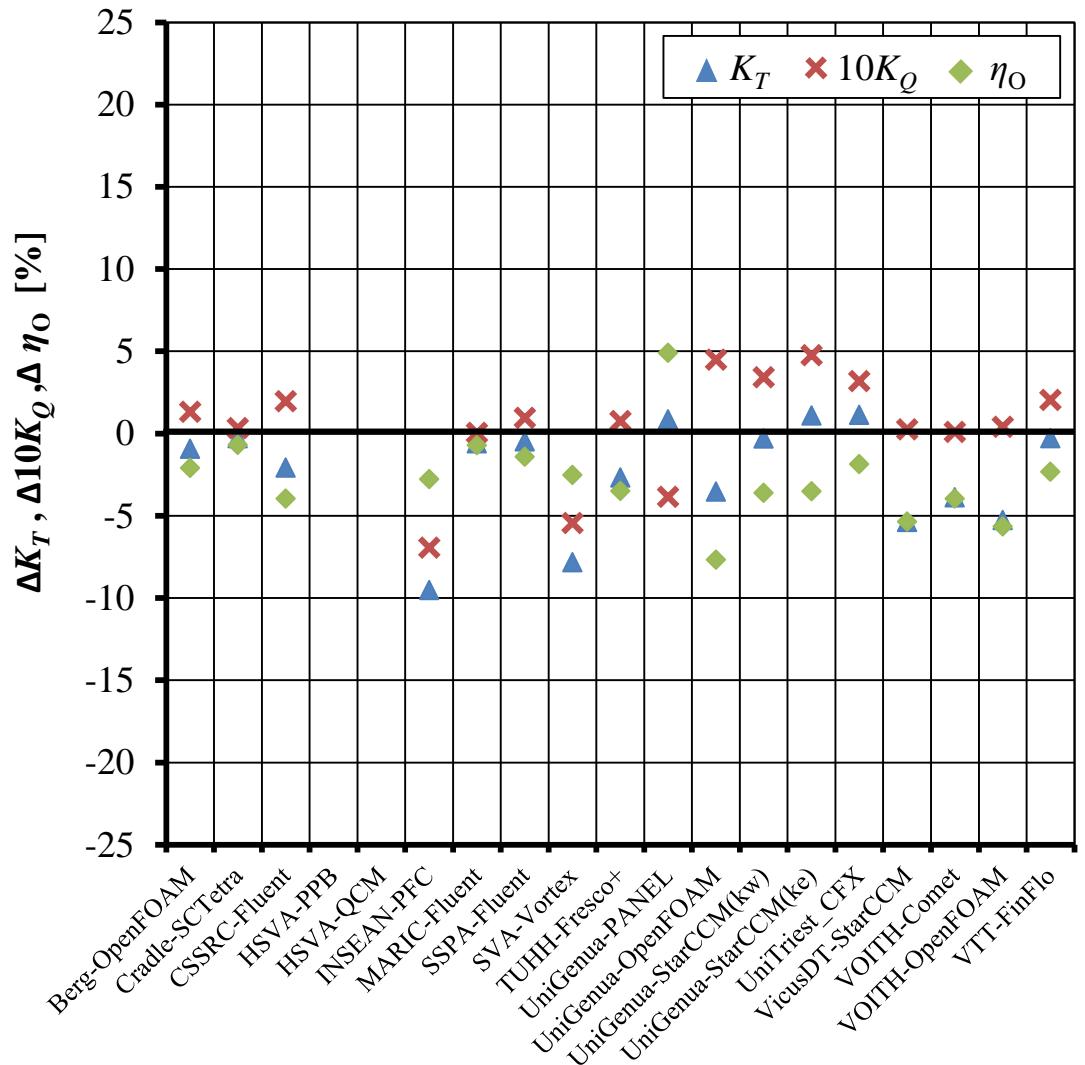
## 7.29 Absolute difference between measurement and calculation, $J = 1.4$

|                      | $\Delta K_T$<br>[-] | $\Delta 10K_Q$<br>[-] | $\Delta \eta_O$<br>[-] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.020              | -0.025                | -0.049                 |
| Cradle-SCTetra       | -0.004              | 0.001                 | -0.016                 |
| CSSRC-Fluent         | -0.010              | 0.024                 | -0.069                 |
| HSVA-PPB             | 0.016               | 0.068                 | -0.024                 |
| HSVA-QCM             | 0.034               | 0.093                 | 0.008                  |
| INSEAN-PFC           | -0.013              | 0.018                 | -0.073                 |
| MARIC-Fluent         | -0.005              | -0.002                | -0.019                 |
| SSPA-Fluent          | -0.036              | -0.054                | -0.079                 |
| SVA-Vortex           | -0.019              | -0.015                | -0.057                 |
| TUHH-Fresco+         | -0.020              | 0.002                 | -0.082                 |
| UniGenua-PANEL       | -0.006              | 0.013                 | -0.041                 |
| UniGenua-OpenFOAM    | -0.023              | 0.038                 | -0.135                 |
| UniGenua-StarCCM(kw) | -0.034              | -0.038                | -0.093                 |
| UniGenua-StarCCM(ke) | -0.022              | -0.010                | -0.077                 |
| UniTriest            | -0.018              | -0.019                | -0.046                 |
| VicusDT-StarCCM      | -0.028              | 0.001                 | -0.105                 |
| VOITH-Comet          | -0.033              | -0.019                | -0.110                 |
| VOITH-OpenFOAM       | -0.033              | -0.013                | -0.117                 |
| VTT-FinFlo           | -0.021              | -0.017                | -0.063                 |



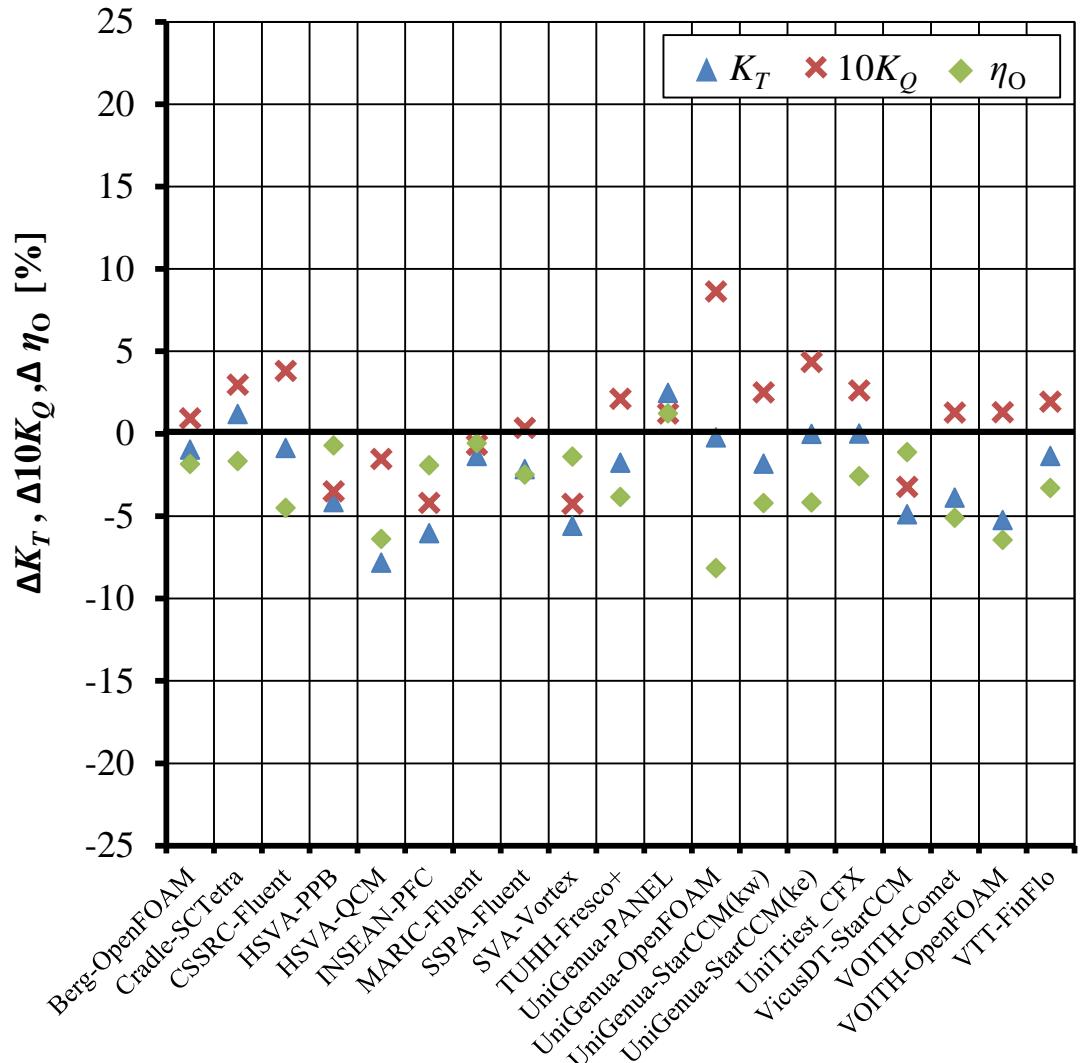
### 7.30 Relative difference between measurement and calculation, $J = 0.6$

|                      | $\Delta K_T$<br>[%] | $\Delta 10K_Q$<br>[%] | $\Delta \eta_O$<br>[%] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.927              | 1.334                 | -2.101                 |
| Cradle-SCTetra       | -0.291              | 0.331                 | -0.706                 |
| CSSRC-Fluent         | -2.072              | 1.971                 | -3.961                 |
| HSV-A-PPB            |                     |                       |                        |
| HSV-A-QCM            |                     |                       |                        |
| INSEAN-PFC           | -9.521              | -6.944                | -2.770                 |
| MARIC-Fluent         | -0.609              | 0.045                 | -0.711                 |
| SSPA-Fluent          | -0.477              | 0.947                 | -1.411                 |
| SVA-Vortex           | -7.824              | -5.448                | -2.515                 |
| TUHH-Fresco+         | -2.676              | 0.761                 | -3.496                 |
| UniGenua-PANEL       | 0.864               | -3.854                | 4.907                  |
| UniGenua-OpenFOAM    | -3.526              | 4.496                 | -7.677                 |
| UniGenua-StarCCM(kw) | -0.314              | 3.431                 | -3.620                 |
| UniGenua-StarCCM(ke) | 1.090               | 4.775                 | -3.517                 |
| UniTriest            | 1.140               | 3.196                 | -1.868                 |
| VicusDT-StarCCM      | -5.380              | 0.260                 | -5.356                 |
| VOITH-Comet          | -3.879              | 0.095                 | -3.970                 |
| VOITH-OpenFOAM       | -5.268              | 0.410                 | -5.659                 |
| VTT-FinFlo           | -0.291              | 2.050                 | -2.333                 |



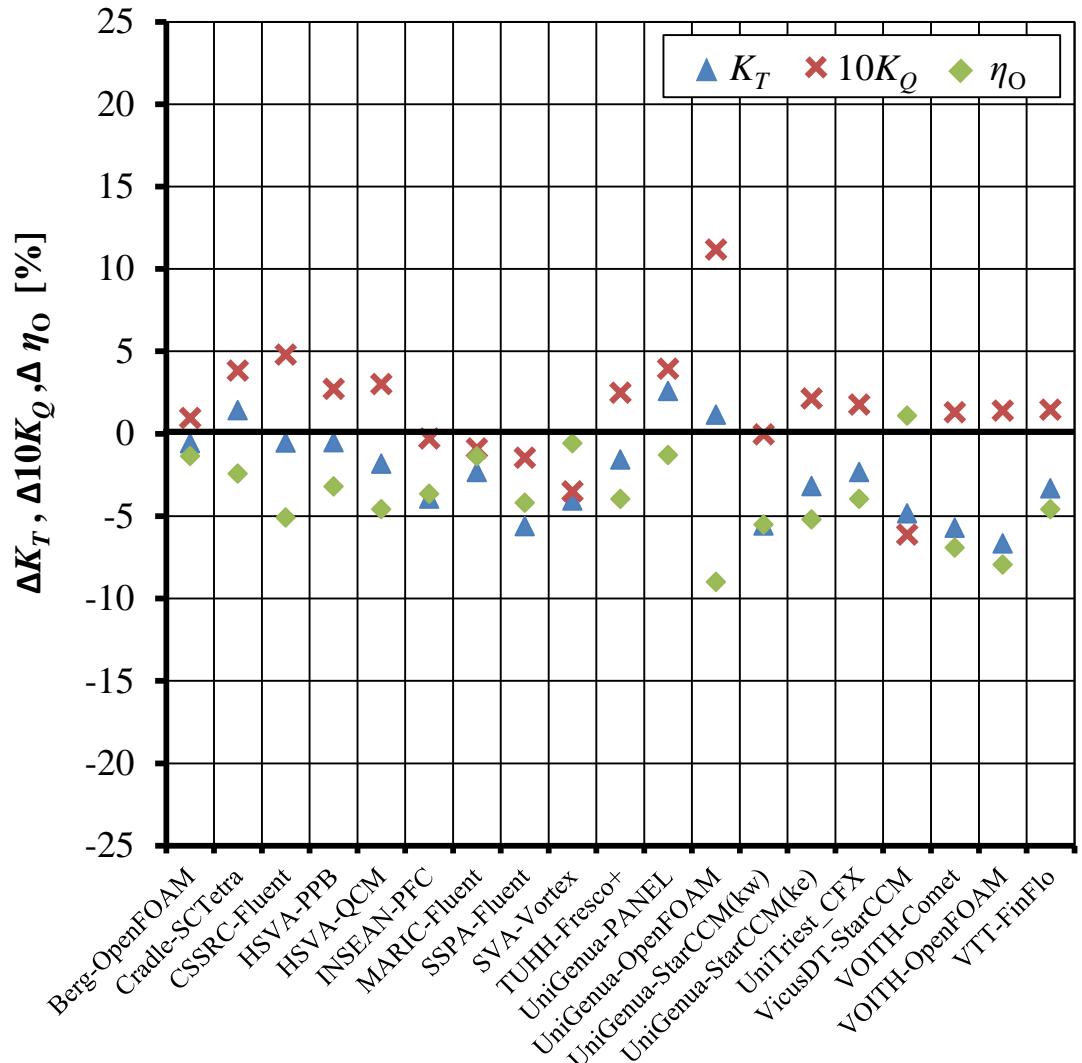
### 7.31 Relative difference between measurement and calculation, $J = 0.8$

|                      | $\Delta K_T$<br>[%] | $\Delta 10K_Q$<br>[%] | $\Delta \eta_O$<br>[%] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.974              | 0.933                 | -1.849                 |
| Cradle-SCTetra       | 1.183               | 2.971                 | -1.668                 |
| CSSRC-Fluent         | -0.876              | 3.819                 | -4.516                 |
| HSV-A-PPB            | -4.150              | -3.490                | -0.724                 |
| HSV-A-QCM            | -7.837              | -1.529                | -6.385                 |
| INSEAN-PFC           | -6.043              | -4.196                | -1.928                 |
| MARIC-Fluent         | -1.366              | -0.680                | -0.582                 |
| SSPA-Fluent          | -2.150              | 0.352                 | -2.493                 |
| SVA-Vortex           | -5.597              | -4.262                | -1.392                 |
| TUHH-Fresco+         | -1.758              | 2.122                 | -3.845                 |
| UniGenua-PANEL       | 2.467               | 1.222                 | 1.230                  |
| UniGenua-OpenFOAM    | -0.230              | 8.626                 | -8.152                 |
| UniGenua-StarCCM(kw) | -1.820              | 2.509                 | -4.223                 |
| UniGenua-StarCCM(ke) | -0.009              | 4.350                 | -4.178                 |
| UniTriest            | 0.007               | 2.631                 | -2.575                 |
| VicusDT-StarCCM      | -4.895              | -3.226                | -1.123                 |
| VOITH-Comet          | -3.889              | 1.290                 | -5.113                 |
| VOITH-OpenFOAM       | -5.248              | 1.298                 | -6.457                 |
| VTT-FinFlo           | -1.366              | 1.952                 | -3.300                 |



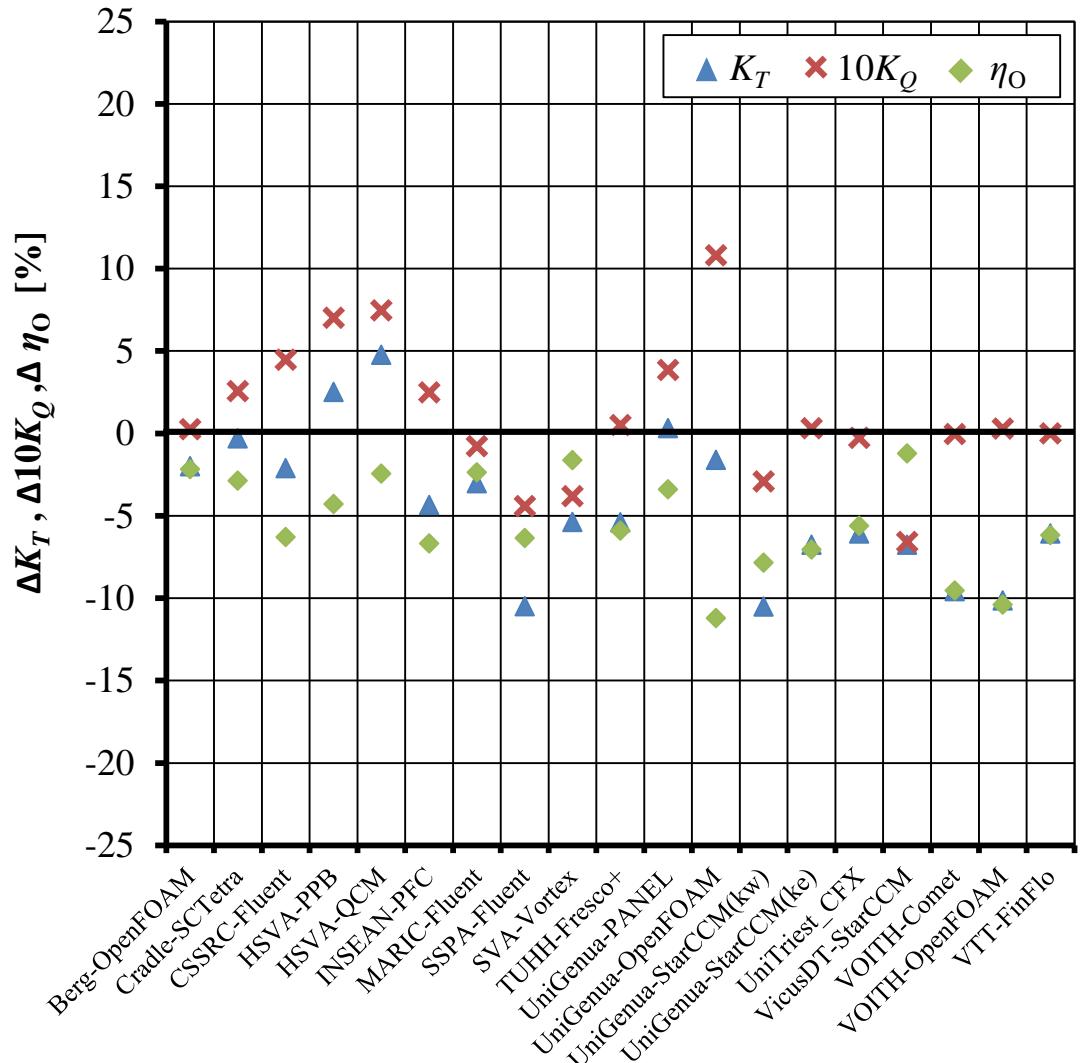
### 7.32 Relative difference between measurement and calculation, $J = 1.0$

|                      | $\Delta K_T$<br>[%] | $\Delta 10K_Q$<br>[%] | $\Delta \eta_O$<br>[%] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -0.594              | 0.936                 | -1.380                 |
| Cradle-SCTetra       | 1.409               | 3.808                 | -2.454                 |
| CSSRC-Fluent         | -0.569              | 4.782                 | -5.107                 |
| HSV-A-PPB            | -0.544              | 2.710                 | -3.220                 |
| HSV-A-QCM            | -1.846              | 2.987                 | -4.601                 |
| INSEAN-PFC           | -3.969              | -0.312                | -3.669                 |
| MARIC-Fluent         | -2.346              | -0.911                | -1.399                 |
| SSPA-Fluent          | -5.627              | -1.471                | -4.218                 |
| SVA-Vortex           | -4.084              | -3.511                | -0.593                 |
| TUHH-Fresco+         | -1.595              | 2.474                 | -3.987                 |
| UniGenua-PANEL       | 2.561               | 3.923                 | -1.310                 |
| UniGenua-OpenFOAM    | 1.127               | 11.158                | -9.026                 |
| UniGenua-StarCCM(kw) | -5.595              | -0.056                | -5.542                 |
| UniGenua-StarCCM(ke) | -3.210              | 2.128                 | -5.227                 |
| UniTriest            | -2.346              | 1.756                 | -3.987                 |
| VicusDT-StarCCM      | -4.850              | -6.142                | 1.074                  |
| VOITH-Comet          | -5.737              | 1.284                 | -6.929                 |
| VOITH-OpenFOAM       | -6.678              | 1.387                 | -7.960                 |
| VTT-FinFlo           | -3.348              | 1.448                 | -4.601                 |



### 7.33 Relative difference between measurement and calculation, $J = 1.2$

|                      | $\Delta K_T$<br>[%] | $\Delta 10K_Q$<br>[%] | $\Delta \eta_O$<br>[%] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -2.008              | 0.251                 | -2.177                 |
| Cradle-SCTetra       | -0.312              | 2.571                 | -2.866                 |
| CSSRC-Fluent         | -2.109              | 4.465                 | -6.297                 |
| HSV-A-PPB            | 2.502               | 7.017                 | -4.285                 |
| HSV-A-QCM            | 4.774               | 7.468                 | -2.453                 |
| INSEAN-PFC           | -4.354              | 2.496                 | -6.683                 |
| MARIC-Fluent         | -3.025              | -0.779                | -2.370                 |
| SSPA-Fluent          | -10.485             | -4.417                | -6.348                 |
| SVA-Vortex           | -5.382              | -3.810                | -1.633                 |
| TUHH-Fresco+         | -5.398              | 0.509                 | -5.897                 |
| UniGenua-PANEL       | 0.317               | 3.854                 | -3.406                 |
| UniGenua-OpenFOAM    | -1.611              | 10.806                | -11.207                |
| UniGenua-StarCCM(kw) | -10.520             | -2.903                | -7.845                 |
| UniGenua-StarCCM(ke) | -6.766              | 0.310                 | -7.054                 |
| UniTriest            | -6.077              | -0.264                | -5.622                 |
| VicusDT-StarCCM      | -6.755              | -6.578                | -1.213                 |
| VOITH-Comet          | -9.583              | -0.045                | -9.547                 |
| VOITH-OpenFOAM       | -10.145             | 0.290                 | -10.403                |
| VTT-FinFlo           | -6.077              | -0.006                | -6.173                 |



### 7.34 Relative difference between measurement and calculation, $J = 1.4$

|                      | $\Delta K_T$<br>[%] | $\Delta 10K_Q$<br>[%] | $\Delta \eta_O$<br>[%] |
|----------------------|---------------------|-----------------------|------------------------|
| Berg-OpenFOAM        | -10.525             | -4.442                | -6.499                 |
| Cradle-SCTetra       | -2.004              | 0.211                 | -2.092                 |
| CSSRC-Fluent         | -5.253              | 4.362                 | -9.211                 |
| HSV-A-PPB            | 8.594               | 12.093                | -3.147                 |
| HSV-A-QCM            | 18.234              | 16.674                | 1.114                  |
| INSEAN-PFC           | -6.886              | 3.197                 | -9.770                 |
| MARIC-Fluent         | -2.537              | -0.326                | -2.556                 |
| SSPA-Fluent          | -19.153             | -9.656                | -10.512                |
| SVA-Vortex           | -10.067             | -2.615                | -7.652                 |
| TUHH-Fresco+         | -10.525             | 0.390                 | -10.907                |
| UniGenua-PANEL       | -3.296              | 2.293                 | -5.464                 |
| UniGenua-OpenFOAM    | -12.475             | 6.826                 | -18.070                |
| UniGenua-StarCCM(kw) | -18.289             | -6.759                | -12.366                |
| UniGenua-StarCCM(ke) | -11.895             | -1.746                | -10.330                |
| UniTriest            | -9.460              | -3.368                | -6.099                 |
| VicusDT-StarCCM      | -14.786             | 0.211                 | -13.980                |
| VOITH-Comet          | -17.619             | -3.476                | -14.653                |
| VOITH-OpenFOAM       | -17.556             | -2.241                | -15.663                |
| VTT-FinFlo           | -11.058             | -3.010                | -8.370                 |

