Commentary on ‘On generating uniform bottom shear stress. Part I: A quantitative study of microcosm chambers’ by Khalili et al., Recent Patents on Chemical Engineering (2008) 1, 174-191

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The authors present a numerical study of a flux chamber invented by Gust [1,2,3], operating, among a range of defined radial distributions, as most attractive feature with spatially homogeneous bottom stress at uncertainty limits <10%. The authors predict the flow field and present a few examples of radial bottom stress which do not span the range of chamber geometries actually utilized to date, and of magnitudes of wall shearing stress currently in use. The authors can claim at best to provide a numerical study; they did not consider the existing data pool of the device family, and do not contribute to calibration and enhancement. The numerical technique they use is that of direct numerical simulation, utilizing a high resolution grid together with standard k-ε parameterization, which may not be best suited for boundary layer simulations as evident from their results in Fig. 3, where they validate the code for a very simple geometry far from the complexity of the microcosms. In [4], alternative numerical methods are discussed for boundary layer applications. In their paper, there are nowhere author-generated experimental data available on the most relevant parameter, the wall shearing stress τ (often expressed as friction velocity u*), neither for the microcosm in suction mode with flat stirrer disk, nor for shortened disk and skirt.

The article by Khalili et al. [5] clearly calls for corrections since it is based on an insufficiently researched pool of existing calibration features of microcosms, misleading statements about the extent of spatially homogeneous bottom stresses, and a numerical model probably too insensitive to resolve boundary-layer particulars of the devices. No adequate experimental data are presented by the authors for verification of their numerical results for the microcosm geometries selected. In contrast, existing experimental data and a semi-analytical model of the inventor’s group show that spatial homogeneity of the bottom stress is well within the 90% uncertainty levels as noted in the patent(s).

Since the mid-nineties, my group (U.Arning, S. Gubsch, J. Hensse, D. Hoffmann, V. Müller, A.Seibel, D.Vorrath) continuously enlarged the pre-1992 data base of the hydrodynamic parameters associated with the flux chambers (microcosms) at hand, ranging from 10 cm to 40 cm diameter with stirrer turning rates up to 180 rpm through independent avenues:

1. Calibration of the radial distribution of the bottom stress (magnitude) by direct measurements of the velocity gradient at selected locations in the viscous sublayer, by measurements of the skin friction right at the bottom [6], and by determining the diffusive sublayer thickness by means of the alabaster mass loss technique [7]. We also developed and applied new temperature-compensated hot-film techniques for highly accurate bottom stress measurements under variable environmental temperature conditions [8].
2. In addition to these bottom-stress measurements, the velocity field and a selection of statistical moments were measured in a 20-cm microcosm at spatially-averaged friction velocity $\langle u^* \rangle$ of 0.75 cm s^{-1} and at selected locations for other operational settings by means of 2-d Laser Doppler Anemometry (LDA), providing 1 thru 3-d information within the full water body by different alignments of the measuring plane.
3. The fully documented velocity and bottom stress data sets were used to fine-tune a semi-analytical model based on equations of rotational fluid dynamics as presented in [9,10] Additionally, the CFD-package COMET ([11], k-ε model) was used to obtain numerical results for the experimentally thoroughly calibrated microcosms. These numerical results did not come sufficiently close to the actually measured bottom stress profiles, consequently we did not publish them.

Users of microcosms, cooperating with the Institute of Ocean Engineering at Hamburg University of Technology or acquiring them from a licensed manufacturer, obtained fully documented calibration curves of the spatially averaged bottom stress for their chambers, including polynomial functions to obtain desired bottom stress fields. The 20-cm microcosm was recalibrated in other laboratories during the ALIPOR project [12]. Advanced applications and novel designs of this microcosm design are a holographic microcosm system [13], and an in-situ microcosm by which effects of sediment core displacement on erosion- and deposition functions and phosphorus flux were explored [14].

There is no indication the authors [5] had acquired a microcosm or sought joint projects, thus they missed information we shared with the user group. It is thus unfortunate that procedures applied, numerical results and conclusions presented in their paper are the result of their choice of a numerical model which do not reflect the actual performance and bottom-stress calibration curves obtained elsewhere for microcosms. That calls for corrections.

I invented the device in 1987 when I got interested in boundary layer fluxes of solids and solutes at the sediment-water interface. Inspired by [15], I developed a way to map bottom stress features of a 2-d, fully developed boundary layer flow (typically containing several m^3 flowing water) into a rotational-symmetric flow of less than three orders of magnitude of volume to allow registration of minute concentration increases and entrainment rates across liquid-solid interfaces. The chambers had to allow for experiments utilizing oxygen-microelectrodes. These requirements were achieved by starting with the rotating disk [15], changing from the laminar to the transitional and turbulent case by increasing the distance between disk and bottom, and by reducing disk diameter while adding a skirt (of selected length), thus generating a Couette flow in the fluid gap. To manipulate the radial pattern of the wall shearing stress near the center, a central fluid-removal path via suction and recirculation was introduced. The original patent [1] had to be converted into an apparatus and a methods patent in the U.S. [2,3]. After 20 years, the patents have expired by now, and an article is in preparation where all design and calibration particulars of the various geometries in existence (from 10-cm to 40-cm versions, from laboratory to deep sea versions, and bottom stress ranges up to 1 N m^{-1}) are laid open [16]. From this manuscript and [18], further information is drawn for this comment, since the evaluation of the authors does not give proper credit to microcosm performance strengths and clearly misleads the reader.

Since the first calibration data of 1987, utilized by [17], parameter settings have been refined. The pumping rate Q has been shown to be nearly as effective when keeping it at a value of 200 ml min^{-1} for the 20-cm microcosm, and at 300 ml min^{-1} for the 30-cm microcosm. Experimental data of the discussor and numerical model of the authors both show a centralized peak in u*, which COMET did not. Less than 10% of total chamber area is found to be affected by the suction process. Most relevant for spatial homogeneity is the magnitude of u* in the outer-wall domain, where the numerical-model values of the author begins to taper off at $r/R \sim 0.8$ (see their Fig. 9). In this region (commencing at $r/R \sim 0.67$), the flow is driven by the aforementioned Couette flow, which at higher Reynolds number evolves into a Taylor-Goertler type flow. These types of flows can be expected to affect flow pattern and Reynolds stress in the underlying bottom region. By measuring the radial distribution of the friction velocity by means of an automated traversing device in 0.5 cm steps, the data in this region r/R show that u* remains homogeneous for all positions r/R ≤ 0.95 at all turning-suction combinations we calibrated microcosms for. In the 30-cm and 40-cm geometries, the sensor, with an element size < 1 cm diameter (of which the actual sensing surface is 6 mm × 4 mm), when located next to the side wall, did not show any drop in the output signal. In the 20-cm geometry, at the wall-nearest location the local value of u* dropped by ~10%, indicating that the sidewall effects had reached a fraction the sensing surface. This persistence of homogeneous bottom stress profiles in the region of the Couette-type flow close to the sidewall is considered an important feature of this stirrer configuration, requiring special numerical attention. The associated flow field documented by LDA measurements will be presented in the aforementioned manuscript in preparation [16]. Suffice to mention here that the measurements do not show the strong fluid exchange from inner to outer region of the stirrer skirt past its lower edge, nor do they show a decline in u* at r/R > 0.8 as predicted by the model of [5].

[5] present their numerical results on the bottom stress in Figs. 8 thru 11. To estimate from our measured radial distribution u*(r) the homogeneity of the bottom stress, we introduced a radial weighing factor

(1) $$w_i = \frac{\left(\frac{r_{i+1}+r_i}{2}\right)^2 - \left(\frac{r_i - r_{i-1}}{2}\right)^2}{R^2}$$

by which an area-weighted arithmetic mean of the friction velocity

(2) $$\langle u_* \rangle = \sum_{i=1}^{N_R} w_i \bar{u}_{*_{r_i}}$$

is obtained, together with the parameter

(3) $$Tu_{u_*} = \frac{\sqrt{\frac{1}{N_R}\sum_{i=1}^{N_R} w_i \left[\bar{u}_{*_{r_i}} - \langle u_* \rangle\right]^2}}{\langle u_* \rangle}$$

as measure for the homogeneity of the radial distribution of the friction velocity (bottom stress). This parameter is smallest for maximum homogeneity. Applying the eqs. 1-3 to the measured radial distributions u*(r) establishes the bottom stress/friction velocity details for the operational parameters (ω, Q) of the microcosm. For a suite of field-going erosion chambers the interfacial hydrodynamics were evaluated this way for INTERCOH 1994 by

[18]. Here, for the 30-cm microcosm the homogeneity factor (eq.3) is reported at <0.07 in Fig. 18a for bottom stresses up to 1 Nm^{-1}, rendering the numerical result of [5] inaccurate. How the information given in Figs. 9 and 10 of the authors relates to the quality criteria expressed by eqs 1-3 is not seen. For all geometries and operational settings identified in the patent and of subsequent developments, the homogeneity parameter was found to be better than 90%, indicative that sidewall effects only prevailed at r/R >0.95.

The authors erroneously judge a well-working and fully experimentally calibrated device which so far has defied efforts to describe its performance by a numerical model. Readers wanting to work with a microcosm can safely apply this technique with calibration details as provided by us. Further design and performance details will be covered by [16].

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