Simple conversion of Brookfield R.V.T. readings into viscosity functions

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In the introduction to his book on industrial applications of rheometry, Walters [1] states, that "the Brookfield device is very easy to use, but the interpretation of the experimental results in terms of (η, q) data (viscosity functions) is far from straightforward". Despite recent research in this field the conversion procedure remains difficult as the treatment of the primary torque-speed data to obtain viscometric shear stress – shear rate relations, requires sophisticated computations [2, 3]. The approximate approach, mentioned in [3], suffers from the absence of concrete numerical values for use in the conversion of the primary readings into their viscometric counterparts.

The aim of this note is to draw attention to our results in this field, which have led to a relatively simple procedure enabling one to realize the above mentioned conversion with an accuracy sufficient for engineering applications of the viscosity functions. This procedure is based on theoretical studies of rotational flow of rheologically complex materials around bodies with simple geometry in basic viscometric configurations [4–8]. The rheometrical applications of these studies rely on a few empirical rules [9], which make it possible to obtain concrete results [9–11] for realistic axisymmetrical systems of the "rotating spindle – sample container" type, such as the configurations of the measuring sections used in the immersional Brookfield R.V.T. viscometer.

Our treatment of the primary readings from Brookfield viscometers is as follows:

1) As many pairs of values as possible of the scale deflection α_i on the torque dial (in scale units of the 0–100 scale) are taken with one, or preferably several, spindles for fixed values of the rotational speed N_i (in rpm).
2) Values of α_i are converted to the (average) shear stresses τ_i (in Pa) on each of the spindles used by

$$\tau_i = k_{\alpha\tau}\alpha_i\,. \tag{1}$$

3) Pairs of τ_i – N_i valid for each particular spindle are plotted in the log-log form.

4a) When this dependence is sufficiently close to a linear one, the fluid under test is of the power-law type. The slope of the log τ_i – log N_i dependence in this case is simply equal to the flow index of the fluid, n.

Using values of $k_{N\gamma}(n)$ for this flow index and the particular spindle, the corresponding (average) values of the shear rates γ_i (in s^{-1}) are then calculated as

$$\gamma_i = k_{N\gamma}(n)N_i\,. \tag{2a}$$

4b) When it is not possible to approximate the log τ_i – log N_i dependence with sufficient accuracy by a straight line, a smooth curve is drawn through the individual points. From the slopes of this curve at the points, corresponding to the rotational speeds used for the particular spindle, the local values of the apparent flow index $n_i^* = n_i^*(N_i)$ are determined by

$$n_i^* = d(\log\tau)/d(\log N)\big|_{N=N_i}\,. \tag{3}$$

The rotational speeds used in the measurements are then converted to the shear rates using

$$\gamma_i = k_{N\gamma}(n_i^*)N_i\,. \tag{2b}$$

5) The relevant pairs τ_i – γ_i are now assumed to be the points of the viscosity function of the fluid sample tested.
6) It is advisable to check that the experiments were carried out within the creeping flow regime, where the relations given above hold and where secondary (elastic or time-dependent) effects on the measured torque are usually negligible. For measurements with several spindles, a simple check of the model adequacy is also recommended. Details of both these tests can be found in [7, 11].

The conversion factors $k_{\alpha\tau}$ and $k_{N\gamma}$ occuring in eqs. (1), (2a) and (2b) are summarized in table 1, for spindles of the Brookfield R.V.T. model. The methods used to obtain these numerical values are described elsewhere; namely in the monograph [8] and the manual [12].

A verification of the proposed conversion procedure has been undertaken in this Laboratory by comparing the viscosity functions evaluated from measurements on viscometers of the Brookfield type with results, determined on a commercial Couette-type viscometer (Rheotest II, Prüfgerätewerk Medingen, GDR). Comparison of results of such

Table 1. Conversion factors for the spindles of the Brookfield R.V.T. viscometer (under standard measuring conditions)

Spindle number		1	2	3	4	5	6	7
$k_{\alpha\tau}$		0.035	0.119	0.279	0.539	1.05	2.35	8.4
$k_{N\gamma}$	n = 0.1	1.728	1.431	1.457	1.492	1.544	1.366	1.936
	0.2	0.967	0.875	0.882	0.892	0.907	0.851	1.007
	0.3	0.705	0.656	0.656	0.658	0.663	0.629	0.681
	0.4	0.576	0.535	0.530	0.529	0.528	0.503	0.515
	0.5	0.499	0.458	0.449	0.445	0.442	0.421	0.413
	0.6	0.449	0.404	0.392	0.387	0.382	0.363	0.346
	0.7	0.414	0.365	0.350	0.343	0.338	0.320	0.297
	0.8	0.387	0.334	0.317	0.310	0.304	0.286	0.261
	0.9	0.367	0.310	0.291	0.283	0.276	0.260	0.232
	1.0	0.351	0.291	0.270	0.262	0.254	0.238	0.209

measurements made with CMC solutions of different concentration, with some intermediates from styrene polymerization and with synthetic rubber latices has proved [10] that the accuracy of the proposed procedure for converting data from immersional viscometers of the Brookfield type into viscosity functions is comparable with usual viscometric techniques. The same conclusion has also been reached on the basis of experiments with an extremely pseudoplastic 24% aqueous kaoline suspension and with a concentrated 3% aqueous solution of Polyox, known to be a strongly elastic liquid [11].

The applicability of this method can further be demonstrated by the results of the evaluation of two recently published data sets of other authors, obtained on a Brookfield R.V.T. viscometer. The first set are the data from the Warren Spring Laboratory (WSL) research report [13], the author of which was not able to arrange the data into the form of a viscosity function, primarily because of the lack of a suitable conversion procedure. The comparison of the Brookfield data [13] with those obtained by the use of other classical viscometers tested has remained open. As can be seen from figure 1, Cheng's data [13], evaluated using our procedure, agree reasonable well with his viscosity function of the model fluid used.

In figure 2 some results of the complex computations made by Williams [2] are compared with the results of our considerably simpler conversion method. Satisfactory agreement of the results from both these methods can also be observed here.

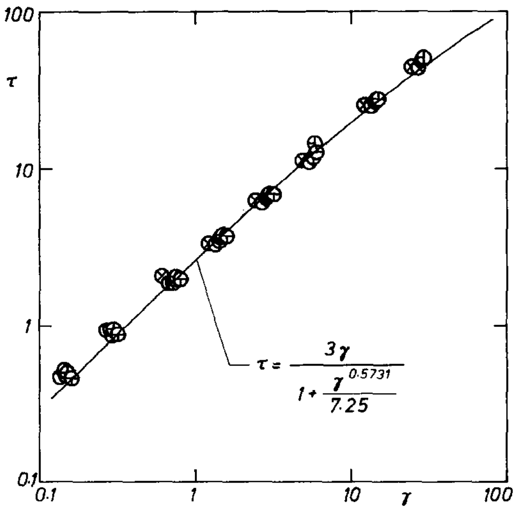

Fig. 1. Comparison of the WSL data [13] evaluated by the procedure proposed in this work (circles, with different centres for each spindle) with the flow curve (bold line) given by Cheng

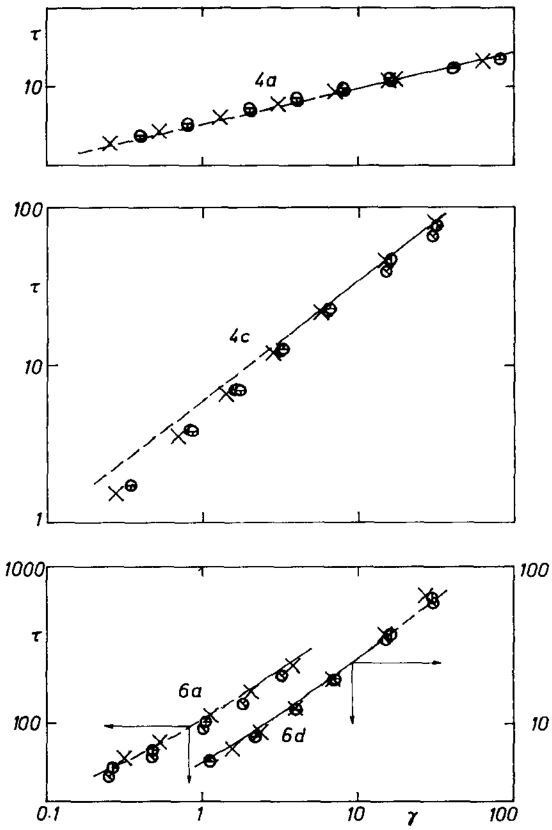

Fig. 2. Comparison of some data sets from [2] evaluated by the proposed conversion procedure (circles) with Williams' computer results (crosses) and with his flow curves (bold lines). The numbering of the liquids is identical with that in figure 4 and 6 in [2]

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