Evaluation of New Methods and Measuring Systems for Characterisation of Flow Behaviour of Complex Foods

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Abstract:
Conventional methods often impose difficulties when measuring the viscosity of fluids containing particles or fibres, e.g. tomato paste or fruit preparations, mainly due to the narrow gaps of the viscometer. In order to solve these problems different geometries have been developed, e.g. different mixer systems and wide gap double concentric cylinders. However, these can not be evaluated assuming a constant shear rate throughout the fluid. In this study, three different kinds of mixer systems have been studied; a small and a large paddle and a helix. For the mixer systems an average shear rate must be determined and a quotient between torque and shear stress must be found. In addition, a wide gap double concentric cylinder (DCC) was examined and evaluated using two different methods. When evaluating the mixer systems a method based on the Couette analogy has been used successfully for a number of complex fluids, including prepared sauces and fruit samples containing particles of different size. The DCC has been evaluated using a numerical as well as an approximate method, both giving results of good accuracy. All systems had the limitation that no consistent results were obtained for tomato paste. However, when starch was added to the diluted tomato paste dispersion, satisfying results were once again obtained.

Zusammenfassung:
Herkömmliche Methoden führen oftmals zu Schwierigkeiten bei der Messung von Flüssigkeiten, die Feststoffe oder Fasern beinhalten, z. B. bei Tomatenpasten oder Fruchtansätzen, hauptsächlich wegen des engen Spalts des Viskosimeters. Um diese Probleme zu lösen, wurden verschiedene Geometrien entwickelt, z. B. verschiedene Mischsysteme und doppeltkonzentrische Zylinder mit einem großen Spalt. Jedoch können diese Geometrien nicht unter der Annahme einer konstanten Schergeschwindigkeit im gesamten Fluid ausgewertet werden. In dieser Arbeit wurden drei verschiedene Mischsysteme untersucht: eine kleine und eine große Schaufel und eine Helix. Für die Mischvorrichtungen musste eine mittlere Schergeschwindigkeit bestimmt werden und ein Quotient zwischen Drehmoment und Scherspannung gefunden werden. Darüber hinaus wurde ein doppelt-konzentrischer Zylinder mit einem großen Spalt (DCC) untersucht und mit zwei unterschiedlichen Methoden ausgewertet. Bei der Auswertung der Mischvorrichtungen wurde eine Methode basierend auf der Couette-Analogie für mehrere komplexe Flüssigkeiten einschliesslich präparierter Saucen und Früchteproben mit unterschiedlich großen Partikeln erfolgreich angewandt. Das DCC wurde mit einer numerischen und approximativen Methode ausgewertet, die beide Resultate mit einer hohen Zuverlässigkeit lieferten. Alle Systeme lieferten keine konsistenten Resultate für die Tomatenpaste. Jedoch wurden wieder zufriedenstellende Resultate erhalten, falls Stärke zu der verdünnten Dispersion von Tomatenbrei hinzugefügt wurde.

Résumé:
Les méthodes conventionnelles comportent souvent des difficultés lorsque l'on mesure la viscosité de fluides contenant des particules ou des fibres, comme par exemple les compotes de tomates ou de fruits, ce qui est principalement du aux entrefers étroits du viscosimètre. Dans le but de résoudre ces problèmes, différentes géométries ont été développées, comme par exemple différents systèmes de mixeurs et de cylindres concentriques doubles à entrefer large. Cependant, ceux-ci ne peuvent pas être évalués en supposant une vitesse de déformation de cisaillement constante dans tout le fluide. Dans cette étude, trois types différents de systèmes mixeurs ont été étudiés : une petite palette, une palette plus grande et une hélice. Pour ces systèmes de mixeurs, une vitesse de cisaillement moyenne doit être déterminée et un quotient entre le couple et la contrainte de cisaillement doit être trouvé. De plus, une géométrie de cylindres concentriques double à entrefer large (DCC) a été examinée et évaluée en utilisant deux méthodes différentes. Lors de l'évaluation des systèmes de mixeurs, une méthode basée sur l'analogie Couette a été utilisée avec succès pour un nombre de fluides complexes, incluant des sauces préparées et de échantillons de fruit contenant des particules de différentes tailles. La DCC a été évaluée en utilisant une méthode numérique ainsi qu'une méthode approximée, les deux donnant des résultats de grande précision. Tous les systèmes ont montré une limitation, dans le sens que où les résultats ne sont pas consistants pour la pâte de tomates. Cependant, quand l'amidon est additionné à la dispersion de pâte de tomates, des résultats satisfaisants ont été de nouveau obtenus.

Key words: Couette analogy, mixer viscometer, double concentric cylinder, food rheology, tomato paste, food dispersions

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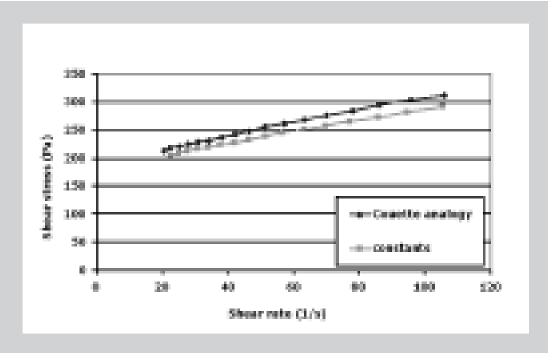
	Z3		approximate method		numerical method	
	K	*n*	*K*	*n*	*K*	*n*
Béarnaise	7.8	0.46	11	0.32	-	-
Ketchup	37	0.25	46.1	0.18	42.3	0.18
1,5% CMC	1.3	0.65	0.96	0.76	0.91	0.76
2,0% CMC	3.1	0.61	1.92	0.76	1.81	0.76
Syrup	7.4	1	7.81	1	7.4	1
Strawberry	29*	0.29*	27.1	0.20	24.8	0.20
Raspberry	21*	0.37*	17.3	0.36	15.8	0.37
Yangster	12.6	0.38	17.1	0.32	15.62	0.33
6% Microlys	20	0.39	24.5	0.30	22.9	0.30
7% Microlys	35.2	0.41	52.2	0.31	48.86	0.31
30% Tomato paste	2.38	0.42	10.9	0.21	-	-
50% Tomato paste	14.8	0.36	48.6	0.18	-	-
30% Tomato paste 3% Microlys	24.8	0.30	65.4	0.15	-	-
30% Tomato paste 5% Microlys	62.6	0.32	116.4	0.17	-	-

*results from measurements performed using mixer systems

Figure 8 (right): Shear stress versus shear rate calculated using obtained constants and the method based on the Couette analogy. Results obtained with small paddle for 30% tomato paste containing 5% Microlys.

Table 2: Results from DCC using conventional method (Z3), approximate method (Eq. 7), and numerical method.



the large paddle, since turbulence was caused in the system. Fluids with large, distinct particles did not give satisfactory results using the large paddle. This is due to the fact that the particles get stuck between the blades and the wall of the cup, leading to extremely jagged shear curves and no possibility to fit the curve to a power law equation. The viscosity of the fluids containing particles could not, apart from the raspberry sample, be evaluated using the DCC. This is due to the fact that in this system the particles were larger than the gap available.

It should be emphasized, though, that these limitations are due to the geometry of the measuring systems evaluated and not the methods used to evaluate the experimental results. Ideally, the gap should be 10 times the size of the particles.

6 CONCLUSION

The results obtained with the mixer systems coincide quite well with the ones obtained with the conventional method. The constants found give satisfying results for different kinds of fluids and the only exception found in the present work is tomato products that do not contain any or only very low amounts of starch.

The results imply that mixer rheometers evaluated using the Couette analogy method could serve as a complement to the conventional techniques. This is especially valuable for fluids that cannot be measured with conventional systems, e.g. fluids with large particles. When evaluated with the approximate or the numerical method the DCC gives satisfactory results. This implies that this system could indeed be used for measuring viscosity on complex fluids. However, there is a limitation in the gap width. This is not a limitation regarding the method, but on the geometry evaluated here. A DCC with larger gap calls for some adjustments of the viscometers available today. The torque would increase, requiring a stronger instrument that can supply the required power. Also, larger gaps would increase the total size of the DCC. Commercial viscometers do normally not have the physical possibility to hold a DCC larger than the one evaluated in this study.

In order to use the numerical method one needs access to the software used for those calculations. However, for the geometry used in this study the approximate method gives almost the same result and is quite easy to use. This means that satisfactory results can be obtained without the more exact numerical method, for the geometry examined in the current work. This is due to the small end effects which are achieved by the sharp edges and the thin walls of the DCC examined and the large distance between the bob and the bottom of the cup.

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NOMENCLATURE

D diameter [m]
g gear ratio (used for systems with more than one mixer) [-]
K power law consistency coefficient [Pa·s^n]
$K_{\dot\gamma}$ shear rate constant [1/rad]
K_τ shear stress constant [Pa/Nm]
L length [m]
n rotational speed [1/s]
n power law index [-]
R_e external radius [m]
R_i equivalent internal radius [m]
R_1 inner radius of DCC [m]
R_2 second radius of DCC [m]
R_3 third radius of DCC [m]
R_4 outer radius of DCC [m]
r radius coordinate [m]
$\dot\gamma_r$ shear rate at position r [1/s]
Γ torque [Nm]
τ_r shear stress at position r [Pa]
Ω angular velocity [rad/s]

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