STUDIA UNIVERSITATIS BABEŞ-BOLYAI, CHEMIA, LIV, 4, 2009

THE CONSTRUCTION AND CALIBRATION OF A ROTATING VISCOMETER

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ABSTRACT. The paper describes the construction and calibration of a modified Couette rotating rheometer for the study of the hydraulic effects that are specific to the motion in ring-shaped spaces limited by two glass concentric cylinders; the inner cylinder is mechanically driven, the outer one is positioned by the balance which is established between the viscous friction force and the torsion force developed in the elastic muff used for its fixation.The measurement and adjustment of the rotation speed by modulating the frequency of the electric current are presented, as well as the measurement of the torsion moment on the outer cylinder, at different elongation forces and elastic muff thicknesses, in correlation with constructive-functional characteristics.

Keywords: coaxial cylinders, rotational rheometer, sheear rate, shear stress, torsion, viscosity

INTRODUCTION

The liquids rotational motion is especially encountered to the devices working from chemical industry: centrifugal pumps, vessels with stirring, centrifugal separators, some types of evaporators, rotating columns (for absorption, rectification, extraction). The hydrodynamic regime of the flow process is expressed by Reynolds criteria (Re), defined as the ratio of inertia forces to viscous forces, or by Taylor number (Ta), which represents the ratio of centrifugal and viscous forces. The flow characterization in ring-shaped spaces is expressed by the Reynolds-Taylor criteria [1,2] which depends on the cylinders geometry, the liquid nature and the intensity of rotational motion (revolution n, angular velocity Ω):

$$\mathrm{Re}=\frac{n\cdot d^2\cdot\rho}{\eta};\ Ta=\frac{\pi\cdot n\cdot\left(r_o^2-r_i^2\right)\cdot\rho}{\eta}\ ;Ta_{\mathrm{Re}}=\frac{\Omega\cdot r_i\cdot(r_o-r_i)\cdot\rho}{\eta} \qquad \text{(1-a,b,c)}$$

The effect of deformation forces of concentric liquid layers, moving at different velocities, leads to the friction forces appearance that are in direct correlation with the nature of the substance (its viscosity). Determination of

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flow regime, particularly the transient one, has special importance on these forces; their reduction (Toms effect) through the addition of small quantities (ppm) of specific substances (surfactants [3], linear polymers [4-6], fibers), leads to energy consumption decreasing.

The liquids rotational motion is specific to rotational viscometers (Couette, Rheotest and modified Couette) that, alongside rheological characterization, assure the detailed study of the transient regime and the turbulence, defining the Taylor-Couette flow.

The rheometer that was made and tested (modified Couette type) contains two concentric glass cylinders; the inner cylinder is rotated around its axis by an asyncronous electric motor with adjustable rotation speed using a transmission; the outer cylinder is elastically fixed with a rubber tube which allows a partially rotation with a central angle $\Delta\theta$; this angle is the measure of the torsion moment M_t [4]. The rubber tube provides the hydraulic closure of the ring-shaped space where the liquid is introduced to study its rheological behavior. This cylinder is suspended to the upper side through a torsionable thread which assures the centering and controlled straining of the elastic tube-cylinder-thread system [3, 4]. The viscometer's Duran glass cylinders have the following characteristics: height H= 290mm; inner radius r_i= 40mm, outer radius r_o= 42mm, ring-shaped thickness $\Delta r= r_o - r_i$= 2mm; r_o/r_i=1.05.

The driving shaft is provided with a sealing system and a disk for measuring the rotation speed; the entire cylinder system is placed in a controlled temperature environment.

RESULTS AND DISCUSSION

The measurement of the inner cylinder rotation speed

The rotor rotation speed n_r is calculated using equations (2a, b, c) as a function of its slide s as compared with the synchronism rotation n_s determined by the triphasic currents system (p- the number of winding pole pairs):

$$n_r = n_s \cdot (1-s); \qquad s = \frac{n_s - n_r}{n_r}; \qquad n_s = 60 \cdot \frac{\nu}{p}; \qquad \text{(2-a,b,c)}$$

At synchronism, the shaft will have the rotation speed n_{Ax-s} (eq.3a):

$$n_{Ax-s} = n_s \cdot R_t = 60 \cdot \frac{\nu}{2} \cdot \frac{1}{3} = 10 \cdot \nu \; ; \qquad \text{(3a)}$$

The real rotation speed of the device shaft n_{Ax} (eq. 3b):

$$n_{Ax} = (1-s) \cdot n_{Ax-s} = 10 \cdot (1-s) \cdot \nu \; ; \qquad \text{(3b)}$$

The factor f represents the ratio between these two rotation speeds (eq. 4):

$$f = \frac{n_{Ax}}{n_{Ax-s}} = \frac{(1-s)\cdot n_{Ax}}{n_{Ax-s}} = (1-s); \qquad (4)$$

By modifying the electric current frequency, the values of the f factor (the ratio between the real and the synchronism rotations) have been experimentally determined, which is shown in Figure 1, both for the no-load situation (without friction to the sealing system) and for the loaded situation. This factor tends to 0.97 (in no-load situation) and 0.9, respectively. The rotation speeds actually used are between 30 and 200 rpm and can be reached for frequencies between 5 and 20Hz (0.65 < f < 0.9).

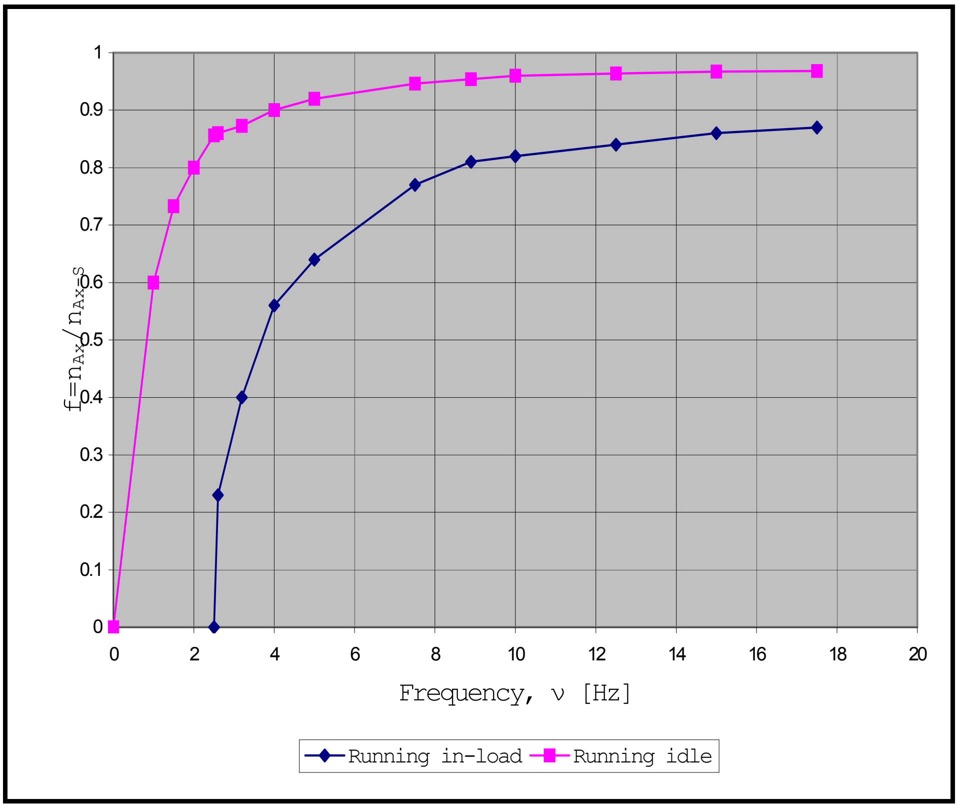

Figure 1. The influence of feed current frequency on the rotation ratio.

Depending on the inner cylinder rotation speed and the geometrical dimensions of the two cylinders, the functional sizes which define the rheological behavior can be calculated (Table 1).

Table 1. Rheometer functional sizes.

Size	General relation	Characteristic relation**
Shear rate, γ [s^{-1}]	$\gamma = \frac{2\cdot\pi\cdot r_o^2}{r_o^2 - r_i^2}\cdot n$	$\gamma = 67.5\cdot n$
Shear stress*, τ [Pa]	$\tau = \eta\cdot\gamma$	$\tau = 67.5\cdot\eta\cdot n$
Friction force, F_f [N]	$F_f = 2\cdot\pi\cdot H\cdot r_o\cdot\tau$	$F_f = 5.17\cdot\eta\cdot n$
Torsion moment, M_t [N.m]	$M_t = F_f\cdot r_o$	$M_t = 0.22\cdot\eta\cdot n$

* For Newtonian fluids: η - dynamic viscosity, $Pa\cdot s$; n - rotation speed, s^{-1}.

** For rheometer dimensions, m : $r_i = 0.04$, $r_o = 0.042$, $H = 0.29$.

The measurement of muff elongation force

The outer glass cylinder is attached to the gasket body by means of a rubber muff with the following characteristics: material – natural rubber/ butadiene-styrene; hardness 40±5 Shore A; inner diameter 90mm; wall thickness 0.5, 1.0 and 1.5mm, muff length 180mm, Figure 2.

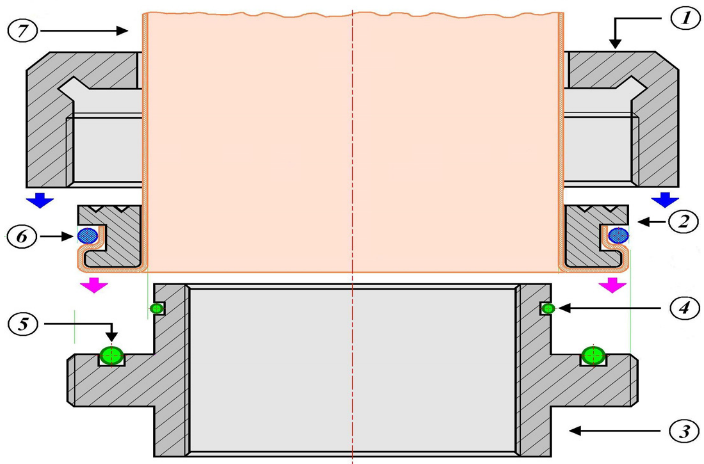

Figure 2. The fitting of rubber elastic muff
1- nut; **2**- aluminium ring; **3**- fixing socket; **4**, **5, 6**- fittings O-Ring; **7**- rubber muff.

The cylinder is suspended to the upper side by means of a torsionable thread which assures the cylinders centering and the control of system straining. The elongation is achieved either using an electric system (stepper motor) or through a screw system.

The measurement of the elongation force is assured by a bimetal force sensor (KD24S type); the obtained results can be locally displayed (digital size) or transmitted to a computer.

The torsion measurement of the outer cylinder

The torsion measurement of the outer cylinder is achieved by using a linear measure magnetic system, without contact, composed of a magnetic belt fixed on the outer surface of an aluminium disk, solidary fitted with the outer cylinder and a magnetic sensor fixed on the viscometer body to a distance between 0.1 and 2mm in comparison with the magnetic tape.

The magnetic belt moving in front of the sensor generates impulses that can be counted (experimentally was obtained 224.4 impulses/rotation or 0.028 radian/impulse). The correlation between the torsion angle of the outer cylinder $\Delta\theta$ and the torsion moment M_t was achieved using two torsion balances (Figure 3a, b) for different elongation forces and thicknesses of the elastic muff. The results are shown in Figure 4a, b, c.

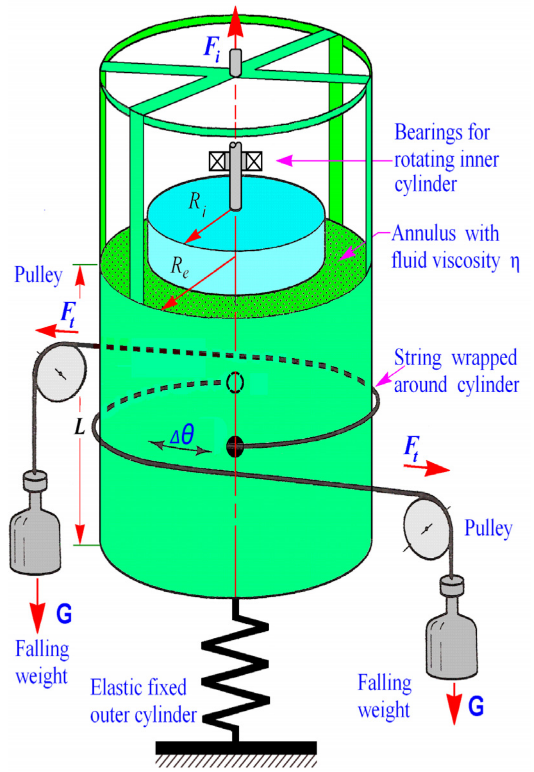

Figure 3a, b. The torsion measurement of the outer cylinder.

From these pictures presented it is found that an increase of muff thickness assures a better stability against the elongation force modification (Figure 4a and 4b), as well as a good linearity (Figure 4c).

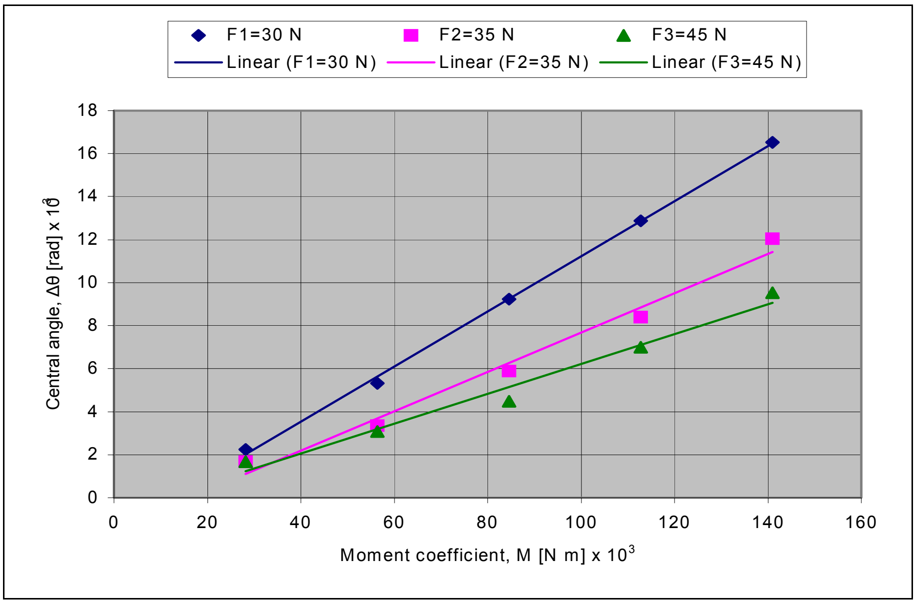

Figure 4a. Δθ= f(M_t) dependence, at different elongation forces, for δ_m= 1mm.

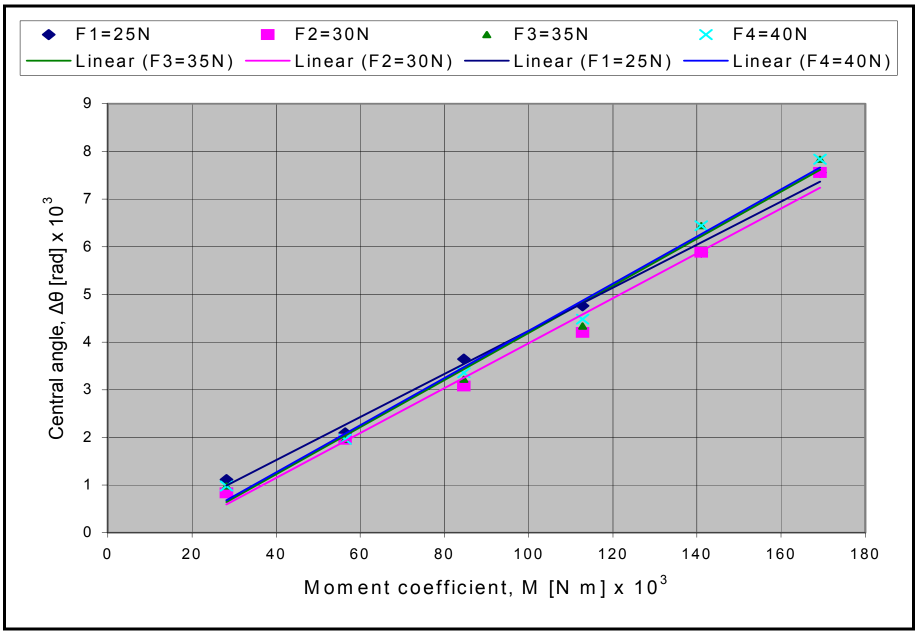

Figure 4b. Δθ= f(M_t) dependence, at different elongation forces, for δ_m= 1.5mm.

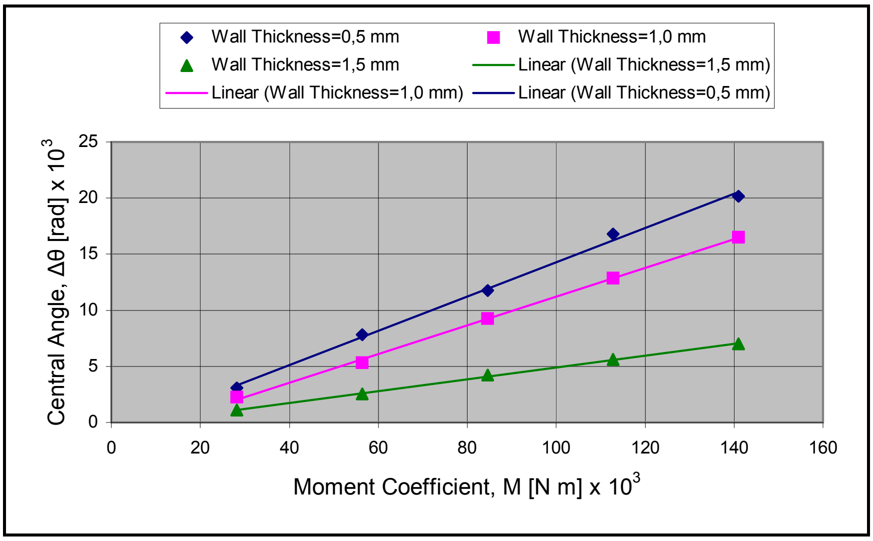

Figure 4c. $\Delta\theta = f(M_t)$ dependence, at different elastic muff thicknesses, for elongation force F= 30N.

CONCLUSIONS

A modified Couette type rotational viscometer with two glass concentric cylinders has been designed and realised.

The rotation speed adjustment is obtained through the electric current frequency modulation; the standardization curve frequency-revolution was experimentally traced;

It was experimentally established the effect of the torsion moment caused by the viscous friction force on the rotation angle of the outer cylinder assembled using an elastic muff.

The correlation between the torsion moment and the rotation angle was determined for different elongation force values and elastic muff thicknesses so as to determine the domain which is nearest to linearity.

EXPERIMENTAL

The rheometer constructive-functional scheme is presented in Figure 5.

The shaft is driven by using an asincron motor with power P= 180W and rotation speed n= 1360 rpm (at 50Hz); the transmission ratio $R_t = 1/3$, frequency domain 1< ν <120Hz, frequency step $\Delta\nu = 0.1Hz$. It is thus possible to achieve rotation speeds of the inner cylinder 6 < n_{Ax} < 1080 rpm.

The inner cylinder revolution is measured using an inductive proximity detector; the data are digitally indicated and it is possible to transfer them to a computer.

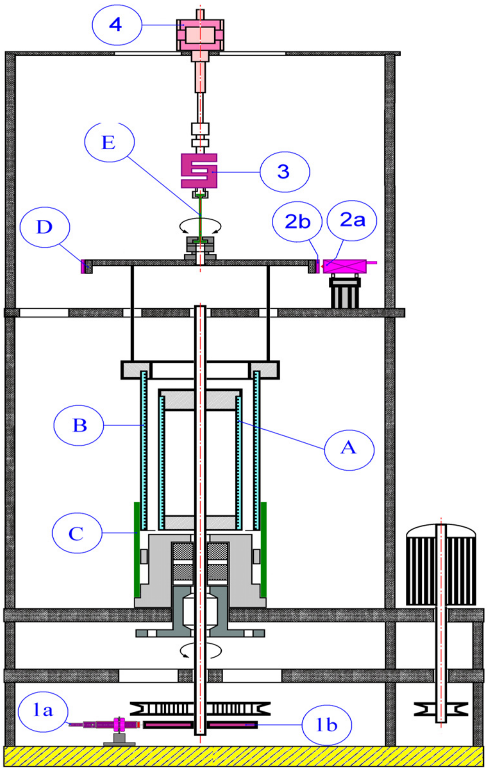

Figure 5. The scheme of experimental device
A- inner cylinder; **B**- outer cylinder; **C**- elastic tube; **D**- device for the free height regulation of the elastic tube; **E**- elongation thread; **1a**- inductive proximity detector IE 5260 (rotation sensor); **1b**- camp late E89010 (accessory to 1a); **2a**- magnetic measurement system for cylinder torsion; **2b**- magnetic tape; **3**- force detector KD24S; **4**- elongation system driven by a stepper motor.

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