Wall investigations of pulp of paper flow in pipes
New model of behaviour or pulp of paper flow
Salaheddine Skali Lami

1. LEMTA - Lorraine University, 2 Avenue de la Forêt de Haye - 54518 Vandoeuvre-lès-Nancy cedex France
2. salaheddine.skali-lami@univ-lorraine.fr

Résumé (12 gras)

In papermaking the pulp and paper treatment processes needs the optimization of various unit operations which require a better knowledge of the pulp of paper behaviour. The Pulp of paper, which is a suspension of cellulose fibers in water, shows several regimes when flowing in pipes. These regimes are experimentally and qualitatively well described in the literature, they are related to the evolution of fibre flocculation characterizing different regimes (called: plug flow, mixed regime and turbulent flow). By against a quantitative descriptions of these regimes are limited and we don't find a model in the literature that describes entirety the behaviour of the pulp of paper flow from a plug flow (high shear friction at low velocities) to identical behaviour that of water at high velocities (turbulent Newtonian flow) going through drag reduction in intermediate velocities.

We propose an experimental analysis of the flow of pulp of paper for several concentrations of fibers in two diameters of pipes (evaluation of confinement effects). These results are compared to a model describing the behaviour of paper in any regimes. The proposed model is based on calculating an average shear stress which takes into account both the elastic moduli of the flocs and the network of fibres (floc agglomerates) and secondly the viscosity of the fluid (water) modified with dispersed fibres..

Mots clefs : pulp of paper, model, flocculation-turbulence – drag reduction

1. Introduction (12 gras)

The investigations of the pulp of paper flow in pipes have been the subject of numerous studies since the 50s (Masson [1], Takeuchi [2], Kerekes [3] Duffy [4]) to understand the various regimes of paper pulp including drag reduction regime resulting from interactions flocculation-turbulence. Other objectives are the description of the friction coefficients of the flow of the pulp of paper. Moller [5], on the basis of an elastic behaviour of the network of fibres and a Newtonian behaviour of the liquid film which surrounds, showed that the evolution of the wall shear stress changes with the bulk velocity to power1/3. Current investigations are moving towards determining the rheological characteristics of the pulp of paper as the apparent viscosity, the yield stress and the elastic moduli (see summary of different works B. Derakhshandeh [6]). Despite the difficulties of measurements (non-homogeneous suspensions, containment ...) the authors give orders of magnitudes of these properties and their evolution as a function of the concentration and nature of the fibres. In these rheological measurements, the constitutive law is given by the measuring device where the torque is linked the wall shear stress and the shear rate is linked the velocity and gap. This is valid for a homogeneous fluid but for pulp of paper we encounter many problems due to the heterogeneity of the suspension.

In the case of pipe flow the wall shear stress can be deducted from the pressure loss against the determination of the wall shear rate must use electrochemical techniques (Skali-Lami [7] and Ogawa [8]). The measurements obtained by these authors show that the behaviour of the paper pulp close to the wall is Newtonian whatever the flow rate and whatever the concentration. In fact the two variables vary non-linearly with the flow rate, but remain a constant ratio in average over time. This suggests that in the modelling approaches must, in a zone near the wall, consider the viscosity of water modified by dispersed fibres.pouvoir assurer une bonne présentation des recueils des communications qui seront remis aux participants à l'ouverture du congrès, il est impératif de respecter les normes de présentation définies ci-après.… (10) Interligne (1.15)

2. Materials and methods

2.1 Materials

The experimental setup (fig.1) is composed of a tank, pump, flow meters, and two vertical pipes 7m in length and 80mm and 44mm diameters. Each of the pipes is

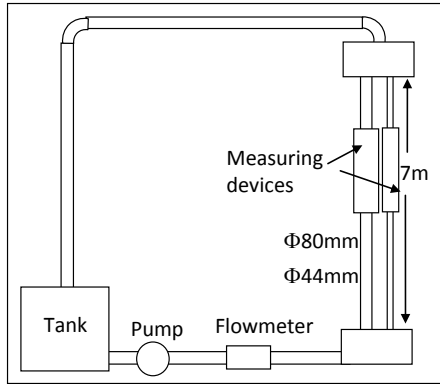equipped with an instrumented element by wall platinum electrochemical probes ($\square$ 0.5mm).

Fig.1 experimental setup

2.2 Methods

The fibre suspension is realized in an electrochemical solution of water, potassium ferricyanide (Co = 210^{-3} M/l), potassium ferrocyanide (2 * Co) and potassium chloride 1/3 M/l.

Determining the wall shear rate is obtained from the mass transfer equation of a potassium ferricyanide on the parietal microelectrode:

$$\frac{\partial C}{\partial t} + \vec{U}.\vec{\nabla} C = D\,\Delta C$$

With
$\begin{cases} * \ C \text{ is the concentration of potassium ferricyanide} \\ * \ U \text{ volocity : } Ux = \gamma\,y \text{ ; and } Uy = -\frac{y^2}{2}\frac{\partial\gamma}{\partial x} \\ * \ \frac{\partial^2 C}{\partial x^2} \ll \frac{\partial^2 C}{\partial y^2} \\ * \ x \text{ is the flow direction and } y \text{ is the normale to the wall} \\ * \ \gamma \text{ is the local wall shear rate} \end{cases}$

This equation was solved by Hanratty [9] to determine the mass flux and therefore the electrical current collected at a microelectrode in the case of a high Schmidt number. $I \approx \gamma^{\frac{1}{3}}$
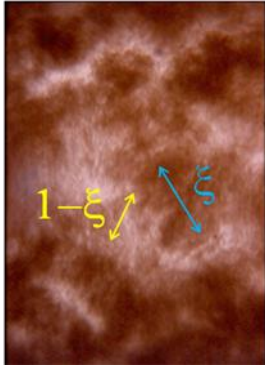
The measurement of current gives the instantaneous value of the local wall shear rate.

2.3 Theoretical analysis

We use theoretical approach to the calculation of the average stress resulting from that of a Newtonian fluid σ_{ij}^{w} in the liquid film of thickness δ and an elastic stress σ_{ij}^{f} in the radius of fibers of network (R-δ):

$$\sigma_{ij} = -\frac{\delta_{ij}}{V}\int_{V-\Sigma Vo} p\,dV + \sigma_{ij}^{f}\left(1-\frac{\delta}{R}\right)^2 + \sigma_{ij}^{w}\left(2-\frac{\delta}{R}\right)\frac{\delta}{R}$$

Fig. 2 Network

The elastic stress in the network can be described by a portion due to the splats and another portion surrounding floc because the elasticises are not the same:

$$\sigma_{ij}^{f} = \sigma_{ij}^{f1}(1-\xi) + \sigma_{ij}^{f2}\xi$$

We can deduce from this equation the mean shear elasticity modulus:

$$G = G_{\propto} + (G_0 - G_{\propto})\xi$$

This expression is similar to the Zener elasticity model, where ξ can be modelled by a kinetic 1 order according to the Reynolds number and a critical Reynolds number

Also at the interface of the network of fibres we can write the continuity of the tangential stresses where the network is assumed as a viscoelastic behaviour:

$$\tau = \tau_0 + \mu(c)\frac{V}{\Delta} = \tau_0 + \mu(c)\frac{V}{R\frac{\Delta}{R}}$$

And $\tau_0 = \tau\left(1-\frac{\Delta}{R}\right)$ and $N = E\frac{\Delta}{R} = 2\left(\frac{\tau}{G}\right)^2$

Where τ_o: yield stress, N:normal stress E : elastic modulus $\approx$ G and Δ: mean thickness of liquid film (large deformation of the network $\frac{\Delta}{R} = \int_0^{\frac{\delta}{R}}\frac{d\left(\frac{\delta}{R}\right)}{\left(1-\frac{\delta}{R}\right)}$)

$\mu(c)$ is the shear viscosity in liquid film, we use theoretical approach given by Dinh&Amstrong [10]:

$$\mu(c) = \mu_w\left(1 + \frac{4C\left(\frac{l}{d}\right)^2}{90\,Ln\sqrt{\frac{\pi}{c}}}\right)$$

Where μ_w: viscosity of water l/d: aspect ratio of fibre ($\approx$ 100) and C the concentration of fibres (0.3%$\leq$C$\leq$2%).

2.4 Results and discussions

Solving all these equations allows establishing the evolution of wall shear stress as a function of the mean velocity for various concentrations of fibres and for the two pipe diameters. The comparison between experimental results and this model is given in Figure 3:
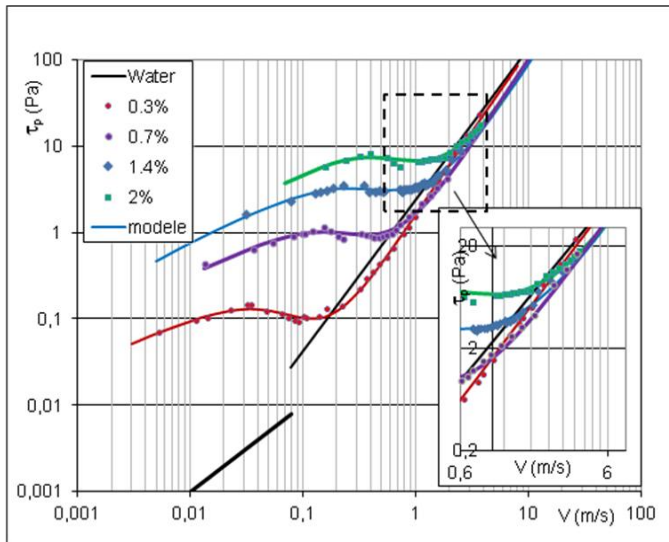
Fig.3 Wall shear stress vs mean velocity (pipe ϕ 80mm)

(■● ▲ experimental data – theoretical curves)

In Table 1, we postponed, versus the fibre concentration, the values of elasticities obtained by identification and those viscosities calculated by Dinh&Amstrong [10] equation. The critical Reynolds number is taken equal to 5000 and the values of G_∞ and G_o are obtained by identification to the experimental values. These elasticities values change with the concentration to the power 3.

C %	0,3	0,5	0,6	0,7	1,1	1,4	1,7	2
G_∞ (Pa)	1,4	2,2	6,1	13	16	45	82	178
G_o(Pa)	0,2	0,3	0,9	2,2	3	9,5	16	19
$\mu(C)*10^3$ (Pa.s)	1,3	1,6	1,7	1,9	2,5	3	3,5	4,1

Tab. 1 Elasticities G_∞ and G_o and viscosities used

3. Conclusions

The proposed model is highly nonlinear but allows describing all the behaviour of the flow of pulp with three adjustable parameters which are the thickness of the liquid film at rest, the elasticity of flocs and the elasticity in the inter-floc space. The viscosity in the liquid film is taken equal to that water modified by dispersed fibres.

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