A STUDY OF THE FLOW PROPERTIES OF NEW ZEALAND WOOD PULP SUSPENSIONS

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Happy is the man who finds wisdom,
and the man who gets understanding,
for the gain from it is better than
gain from silver and its profit
better than gold.

Proverbs 3; 13,14

ABSTRACT

One of the most important process operations in the pulp and paper industry is the transport of pulp in pipe lines. Because pipe friction losses are much higher than with water under comparable conditions, accurate design correlations for each pulp are important to the industry. The purpose of this investigation was to design and build a flow rig suitable for investigating a wide range of pulp conditions, to obtain pipe friction loss data for New Zealand pulps, and to produce design correlations and procedures for the industry.

This thesis is therefore concerned primarily with describing the experimental equipment and procedures, presenting pipe friction loss data for a variety of New Zealand pulps, including a design correlation for them, and developing design methods for computing friction losses. It includes, in addition, data on drag reduction observed at high velocities of flow, and a discussion of flow mechanisms in each regime of flow.

The equipment was designed to produce friction loss data from three pipe diameters simultaneously for each consistency of pulp. Flow rate was controlled without throttling the flow. Pipe friction loss data are presented for five Kraft pulps and one neutral sulphite semi-chemical pulp. Data were obtained from 1, 2, 3 and 4 in. diameter PVC pipes for a wide range of consistencies and flow rates up to 0.8 ft^3/sec. Standard Lampen mill evaluations on hand sheets made from the pulps are presented, as well as data on the characteristics of the fibres.

The Kraft pulps exhibited the characteristic maxima and minima but the semi-chemical pulp did not exhibit these turning points.

For Kraft pulps head losses before the respective maxima were increased by refining the pulp and using rough pipe; and decreased by adding short-fibre Tawa and by drying and reslushing the pulp. In comparison with maxima for the unbeaten Kraft pulp, the maxima of the head loss curves for all Kraft pulps were shifted to lower velocities by the above-mentioned operations. This would reduce the friction loss in many practical cases. In particular, rough pipe lowers the magnitude of friction loss in this regime, and can therefore yield a considerable economic advantage.

A single design correlation for Kraft pulps is presented for the regime of flow before the maxima in the head loss curves. The limits of the correlation are given. Friction losses of New Zealand pulps were found to be lower than those previously reported in the literature.

Two methods of design are presented for the regimes at velocities above the maxima in the head loss curves. A procedure is suggested for pulp and paper mills to obtain their own limits for the design correlation and to verify the correlation proposed in this investigation for their own pulps.

A design correlation for the Tawa NSSC pulp is also presented.

Mechanisms of flow are discussed for Kraft pulps and a semi-chemical pulp. Visual observations in an artificially roughened pipe for the regime of flow before the maxima of the head loss curves have confirmed fibre-wall contact in this regime. Data obtained at the first sign of permanent plug disruption have been correlated with data at the onset of drag reduction. Fully developed turbulence was found to occur at the maximum level of drag reduction. Some velocity profiles are reported for the transition regime using a modified annular-purge probe.

In addition the disruptive shear stress of fibre networks has been correlated by three different methods.

Data for the onset of drag reduction are presented and compared with data previously obtained from large diameter pipes from other investigations. This correlation is used as a method for designing piping systems at high flow rates.

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NOTATIONS

A	The fibre length-to-diameter ratio A.
A'	Annulus thickness at distance y from the pipe wall.
C	Oven-dry or moisture-free consistency; a constant in equations [2.17], [2.38].
c	The weight concentration of fibres.
c_O	The upper critical fibre concentration for unimpeded rotation.
c_S	The sedimentation weight concentration.
c_V	The minimum concentration below which continuous networks could not exist.
c'	Constant defined in equation [2.16].
D	Diameter of pipe.
D_R	Drag ratio defined in equation [2.36].
F	Empirical constant.
F_1, F_2, F_3	Empirical constants in equation [2.33].
f	Fanning friction factor.
f'	Modified friction factor defined by equation [2.24].
$f(\tau_y)$	Function defined by equation [2.22].
G	Shear modulus of visco-elastic networks.
G'	Empirical constant in equations [2.3], [2.7].
$\frac{\Delta H}{L}$	Friction head loss per unit length.
ΔH	Friction head.
K	Empirical constant; von Kármán constant for Newtonian fluids.
K'	Consistency index for a power law fluid; empirical constant in equation [6.11].
K''	Empirical constant in equation [6.12].
K'''	Empirical constant in equation [6.13].
k_G	Empirical constant in equation [2.3].
k_τ	Empirical constant in equation [2.4].
L	Length.
ℓ	Fibre length.
N	Dimensionless flow number defined by equation [2.26].
n	Power law fluid constant in equation [2.9]; exponent defined in equation [5.1].
n'	Flow behaviour index in a power law fluid.
$\left(\frac{\partial P}{\partial \ell}\right)$	Longitudinal pressure gradient in pipe.

Q	Volumetric flow rate.
R	Pipe radius.
Re	Newtonian Reynoldsnumber; water Reynolds number for pulp flow.
Re_t	Annulus Reynolds number.
Re'	Pseudo-Reynolds number in equation [2.31].
R_L'	Generalised Reynolds number defined by equation [2.15].
r	Radial distance from pipe axis.
S	Dimensionless shear parameter.
s	Time; yield shear stress after Head (45).
T	Temperature.
t	Annulus thickness.
u	Local mean velocity.
V	Mean velocity in a pipe.
V_p	Mean velocity of the pulp plug.
V_R	Slip velocity at the wall.
v	Local mean velocity at distance y from pipe wall.
v_s	Effective slip velocity at the wall.
v^+	Dimensionless velocity defined in equation [2.40].
y	Distance from the pipe wall.
y^+	Dimensionless distance defined in equation [2.41].
α	Constants in equation [2.28]; Hydrodynamic specific volume.
β	Constants in equation [2.28].
γ	Constants in equation [2.28]; Kinematic viscosity.
δ'	Thickness of the laminar sublayer.
τ	Shear stress at a distance r from pipe axis.
τ_d	Disruptive yield stress of a fibre network.
τ_0	Empirical constant in equation [2.4].
τ_u	Ultimate shear stress of fibre networks.
τ_W	Shear stress at pipe wall.
τ_y	Shear yield stress of a material.
τ'	Empirical constant in equation [2.5].
ρ	Newtonian fluid density; density of pulp suspension in equation [2.26].
σ	Hydrodynamic specific surface.

μ	Newtonian fluid viscosity.
μ_s	Slope viscosity in equation [2.12].
ϕ	Friction factor used in this investigation and defined by equation [3.1].
$\zeta_{(\tau_w)}$	The effective slip coefficient.

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