SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series A
Faculty of Chemical Technology
15 (2009)

FLOW OF PURELY VISCOUS FLUIDS THROUGH FILTER SCREENS

Alexandr SURÝ and Ivan MACHAČ[1]
Department of Environmental and Chemical Engineering,
The University of Pardubice, CZ–532 10 Pardubice

Received September 30, 2008

Fluid flow through woven metal screens is employed in various branches of technology and process engineering, in particular in filtering operations. Metal filter screens are widely used as filter medium due to their good resistance to chemical and mechanical attacks and relatively narrow distribution of pore size. In this contribution, experiments were carried out with six filter screens differing in wire diameter, aperture dimension, and type of weaving. The dependence of the pressure drop on the volume flow rate was measured in the flow of purely viscous power-law aqueous solutions of different polymers. The pressure drop measurements were performed in a device consisting of a plastic pressure drop measuring cell of 50 mm inner diameter with a calming tube of 40 mm length. It has been verified that the pressure drop can be expressed in the form of dependence of drag coefficient f on power-law Reynolds number Re_n.

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[1] To whom correspondence should be addressed.

Introduction

Fluid flow through woven metal screens is employed in various branches of technology and process engineering, in particular in filtering operations. Metal filter screens are widely used as filter medium due to their good resistance to chemical and mechanical attacks and relatively narrow distribution of pore size. Information on the hydraulic resistance associated with the fluid flow is usually of main interest here.

Fluid flow of Newtonian liquids through screens has been experimentally studied, for example, see Refs [1-3]. Lu *et al.* [4] and Tung *et al.* [5] conducted numerical studies of fluid flow through woven structures. However, their findings on the pressure loss contradict the experimental results. There are only a few studies of the flow of non-Newtonian liquids through screens. Chhabra and Richardson [6] studied experimentally the flow of shear thinning carboxymethyl cellulose solutions through a screen. The relationship between drag coefficient and Reynolds number was suggested. Kiljanski and Dziubinski [7] extended the study using shear thinning molten polyethylene and provided a correlation of the drag coefficient with Reynolds number also for multiple screens. Ting *et al.* [8,9] investigated the effect of weave pattern, aperture/diameter ratio and non-Newtonian fluid behaviour on pressure drop using mathematical modelling. Their observations were found to be in good agreement with the existing experimental data.

This contribution reports the results of our measurements of the pressure drop in the creeping flow of purely viscous power-law aqueous solutions of polymers through six different types of metal filter screens.

Fundamentals

Pressure drop in the flow of a liquid through a filter screen depends on the liquid rheological behaviour, its velocity, and the screen geometry.

It is generally accepted that the flow through a screen could be represented in a similar way to that used for the flow through porous media, for example, in the form of a dependence of the drag coefficient f on the Reynolds number Re.

In this case, the simple power law model

$$\tau = K\dot{\gamma}^n \tag{1}$$

with parameters K and n, is sufficient for the approximation of the flow curve of a purely viscous liquid.

The drag coefficient for a screen was defined by Weighart [1] as

$$f = \frac{2\Delta p}{\rho\left(\frac{u}{\beta}\right)^2}\frac{1}{1-\beta} \tag{2}$$

where *b* is the fraction of total screen area available for flow. The Reynolds number can be defined, like that for pipe flow, as [6]

$$Re_n = \frac{\rho\left(\frac{u}{\beta}\right)^{2-n} d^n}{K} \tag{3}$$

where *d* is the wire diameter.

Evaluating their experimental data, Chhabra & Richardson [6], and Kiljanski & Dziubinski [7] found that the dependence of the drag coefficient on Reynolds number can be in the creeping flow region expressed as

$$f = \frac{C}{Re_n} \tag{4}$$

Ting *et al.* [8,9] argued that a more appropriate expression for Re_n is that including the screen hydraulic diameter d_h instead of the wire diameter *d*, i.e.

$$Re_n = \frac{\rho\left(\frac{u}{\beta}\right)^{2-n} d_h^n}{K} \tag{5}$$

Experiments

Dependences of the pressure drop on the volume flow rate were measured in the flow of aqueous solutions of polyalkylene glycol Emkarox (Newtonian fluid) and aqueous solutions of different polymers, exhibiting various measure of shear thinning (non-Newtonian purely viscous fluids), through six different mesh woven metal screens. The polymeric liquids used were solutions of hydroxyethyl cellulose Natrosol 250 HHR, carboxymethyl cellulose (BDH high viscosity), and polysaccharide Xanthane CX 12. Their characteristics are given in Table I. Rheological properties of the liquids were measured on the rotational rheometer MARS. Additional measurements of capillary thinning and break-up process of liquids were performed using rheometer CABER 1.

Basic characteristics of the filter screens used, differing in wire diameter,

Table I Characteristics of test liquids

Liquid	ρ kg m^{-3}	$\Delta\dot{\gamma}$ s^{-1}	K Pa s	n	δ %	λ_N s	λ_E s
Em 20 %	1028	10-2000	0.062	1.000	1.8	-	-
Em 30 %	1046	10-2000	0.214	1.000	2.5	-	0.008
Na 0.8 %	1002	10-2000	2.000	0.514	9.7	0.0037-0.0003	0.018
CMC 0.8 %	1002	10-2000	2.062	0.492	9.2	0.0059-0.0008	0.035
Xa 0.3 %	999	20-2000	1.651	0.360	6.1	0.0003-0.0001	0.005

aperture dimension, and type of weaving, are summarized in Table II. The screens dimensions were determined using a micrometer and an image analysis of microscopic photographs. The scheme of knitting of screens and their enlarged pictures are shown in Fig. 1. The hydraulic diameter d_h of the screens I and II was evaluated from pressure drop measurements in the flow of Newtonian solution of Emkarox.

Table II Characteristics of filter screens

Symbol	Type of weaving	d_s mm	d_w mm	d_{app} mm	ε	L mm	d_h mm
I	plain twilled	0.037	0.037	0.051	0.796	0.091	0.051
II	Dutch	0.036	0.053	-	0.418	0.136	0.016
III	twilled Dutch	0.150	0.215	-	0.543	0.650	0.055
IV	plain square	0.025	0.025	0.040	0.758	0.062	0.040
V	plain square	0.045	0.045	0.080	0.809	0.109	0.080
VI	plain square	0.095	0.095	0.160	0.859	0.228	0.160

The pressure drop measurements were performed in a device consisting of a plastic pressure drop measuring cell of 50 mm inner diameter with a calming tube of 40 mm length. The scheme of the device is shown in Fig. 2. The liquid volume flow rate was determined by weighing on a digital balance. The pressure drop and flow rate data were recorded by a personal computer.

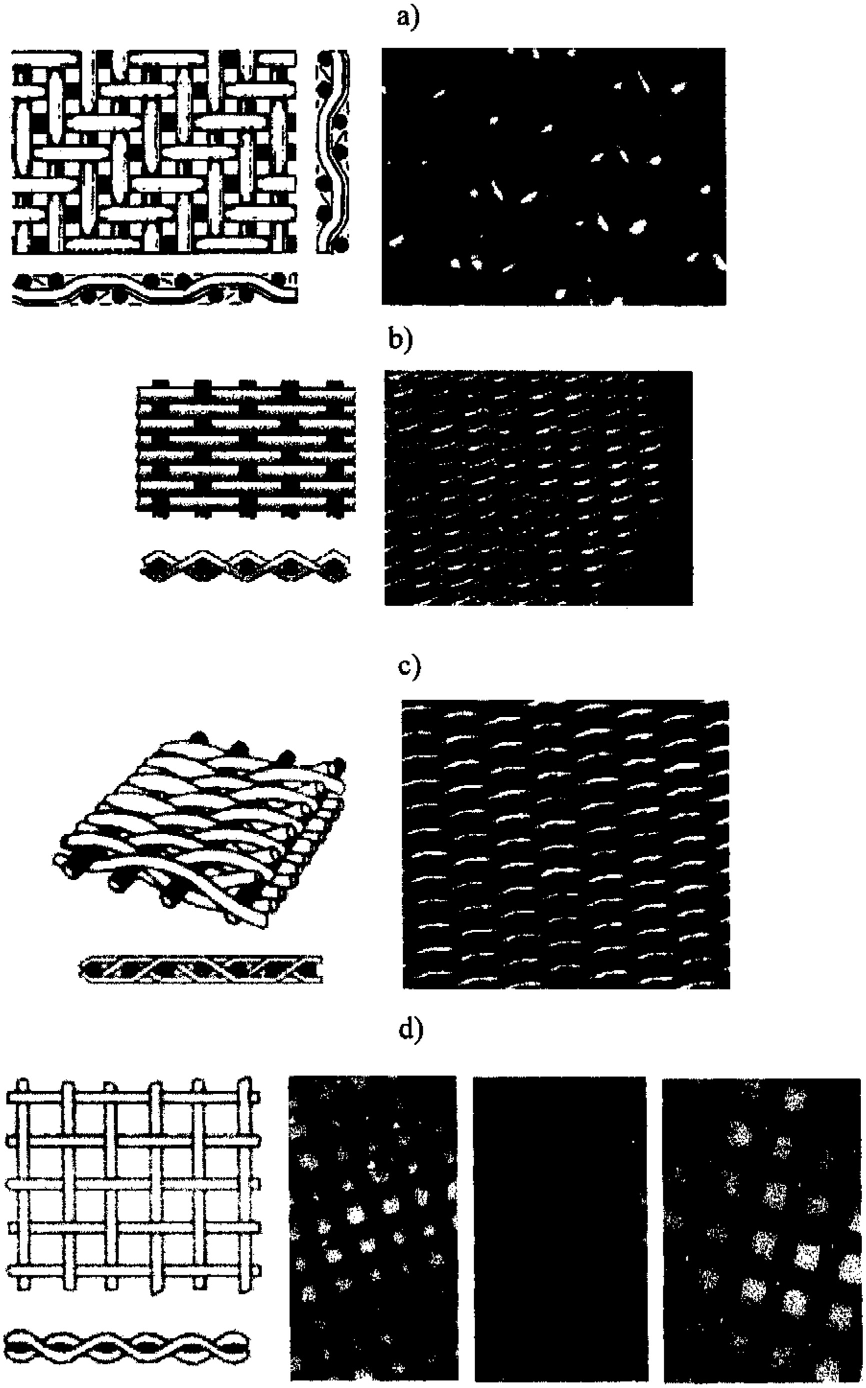

Fig.1 Mesh filter screens (a) I - plain twilled weave, (b) II - Betamesh Dutch weave, (c) III - twilled Dutch weave, (d) IV-VI - plain square weave

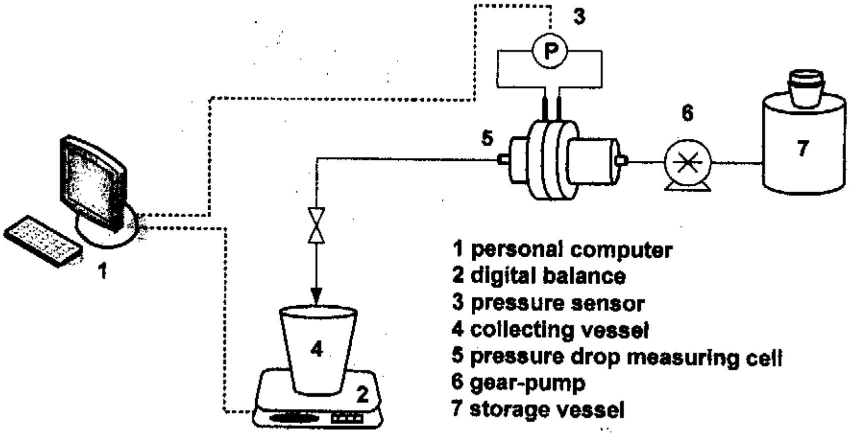

Fig. 2 Measuring device

Results and Discussion

Rheological Characteristics of Liquids

From the shear rate-shear stress rheometric data, parameters n and K of the power law model (1) were determined. Their values, evaluated in the shear rate interval $\Delta\dot{\gamma}$, are summarized in Table I. Examples of viscosity function courses of some test liquids are shown in Fig. 3. It is evident that the solutions of Emkarox are Newtonian fluids; the other polymer solutions are shear thinning.

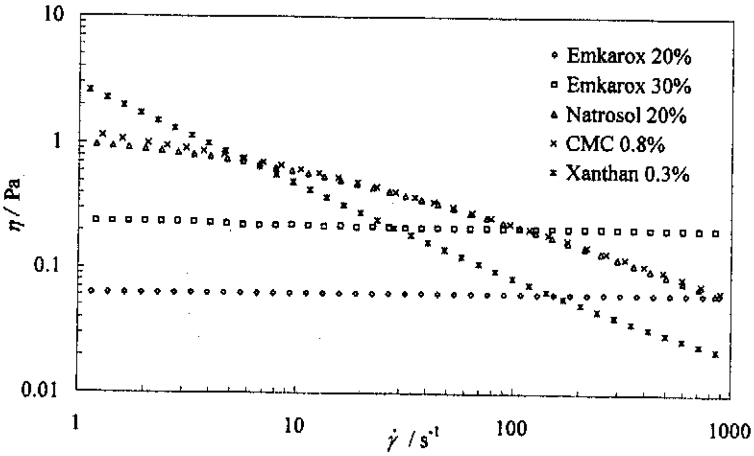

Fig. 3 Test liquids viscosity functions

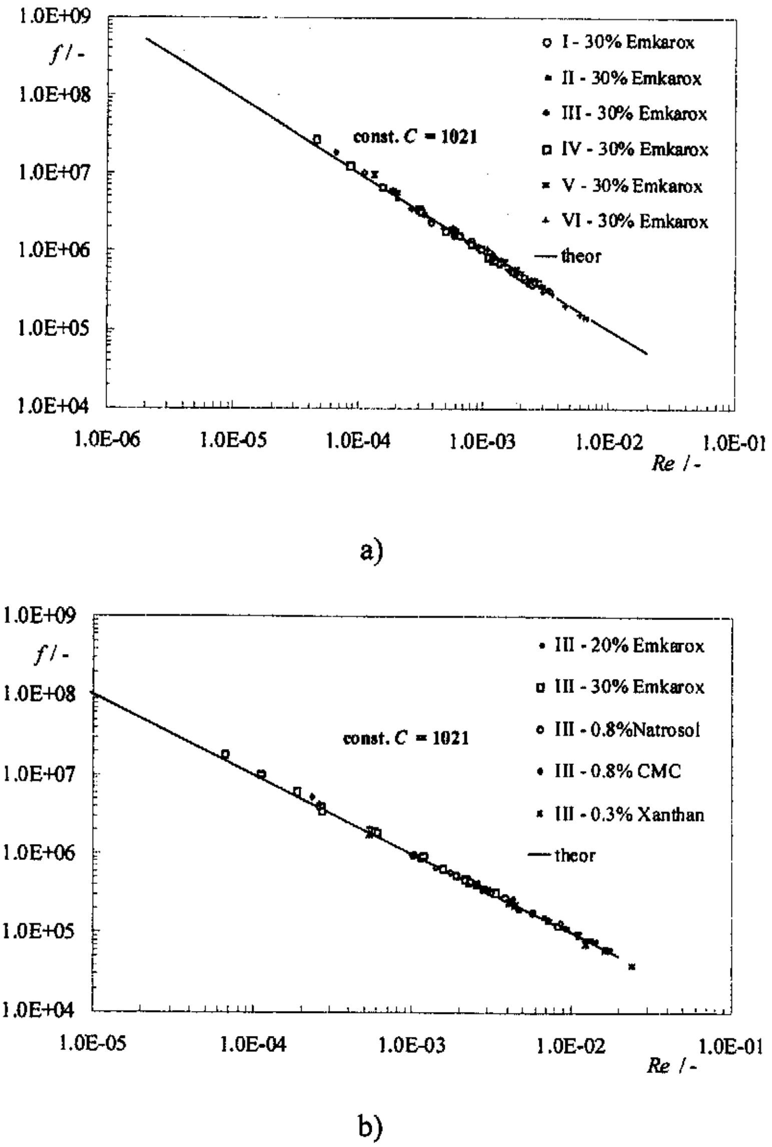

Fig. 4 Dependence of drag coefficient f on Reynolds number Re_n. (a) filter screens / Emkarox 30%; (b) liquids / filter screen III

From the measurements of primary normal stress differences N_1, the values of the Maxwellian characteristic liquid time

$$\lambda_N(\dot{\gamma}) = \frac{N_1(\dot{\gamma})}{2\tau_{12}\dot{\gamma}} \tag{6}$$

were evaluated. Furthermore, the values of the characteristic time λ_E, referred to as characteristic time scale for viscoelastic stress growth in a uniaxial elongation flow [10], were determined from the capillary thinning experiments. The obtained values of both the characteristic times λ_N and λ_E are given in Table I as well. Low values of λ_N and λ_E, belonging to the solutions of Emkarox, CMC, Natrosol, and Xanthane, indicate a very weak non-linear elasticity of these solutions and their purely viscous behaviour.

Pressure Drop

From the experimental data obtained for the flow of test liquids through the screens, the dependences of drag coefficient f on Reynolds number Re_n, whose examples are shown in Fig. 4, were evaluated. In the calculation of f according to Eq. (2) and Re_n according to Eq. (5), the fraction β was substituted by the screen porosity ε (Table II). Figure 4 shows that experimental data of f satisfy Eq. (4). Using a linear regression, we found that the best value of parameter C is 1021. Therefore, the pressure drop in the flow of purely viscous non-Newtonian liquids through filter screen tested can be predicted according to relationship

$$f = \frac{1021}{Re_n} \tag{7}$$

Mean relative deviations δ and maximum relative deviations δ_{max} between experimental pressure drop data and those calculated from Eq. (7) are given in Table III.

Table III Mean and maximum relative deviations between experimental and calculated pressure drop data for filter screens I-VI

Filter screen	Liquid	δ %	δ_{max} %
I	20 % Emkarox	13.9	33.9
I	30 % Emkarox	4.0	12.4
I	0.8 % Natrosol	6.4	25.4
I	0.8 % CMC	6.0	11.5
I	0.3 % Xantan	15.9	20.0
II	20 % Emkarox	2.3	2.3
II	30 % Emkarox	2.7	2.7

Table III – Continued

Filter screen	Liquid	δ %	δ_{max} %
II	0.8 % Natrosol	10.1	10.1
II	0.8 % CMC	8.3	8.3
II	0.3 % Xantan	5.5	5.5
III	20 % Emkarox	9.4	15.8
III	30 % Emkarox	11.5	22.3
III	0.8 % Natrosol	6.1	11.2
III	0.8 % CMC	11.9	23.3
III	0.3 % Xantan	4.6	9.7
IV	20 % Emkarox	6.2	20.2
IV	30 % Emkarox	5.9	25.8
IV	0.8 % Natrosol	7.9	24.0
IV	0.8 % CMC	14.7	33.9
IV	0.3 % Xantan	7.5	15.0
V	20 % Emkarox	8.0	19.0
V	30 % Emkarox	9.5	31.0
V	0.8 % Natrosol	6.5	12.4
V	0.8 % CMC	11.0	27.8
V	0.3 % Xantan	7.5	19.6
VI	20 % Emkarox	10.0	14.6
VI	30 % Emkarox	7.1	16.9
VI	0.8 % Natrosol	5.3	13.8
VI	0.8 % CMC	3.1	6.3
VI	0.3 % Xantan	9.1	23.9

Conclusion

The pressure drop measurements in the creeping flow of Newtonian and inelastic non-Newtonian polymer solutions through six metal filter screens have been performed.

It has been verified that the pressure drop in the flow of a purely viscous liquid can be satisfactorily predicted from relationship (7) with the Reynolds number based on the hydraulic diameter of the screen.

Acknowledgements

The authors thank the Grant Agency of the Czech Republic for financial support of this work (Grant project No. 104/08/H055).

Symbols

C	parameter in Eq. (4)
d	wire diameter, m
d_{ap}	aperture diameter, m
d_h	screen hydraulic diameter, m
d_s	shute wire diameter, m
d_w	warp wire diameter, m
f	drag coefficient, Eq. (4)
K	power law parameter (consistency), Pa s^n
n	power law parameter (flow index)
N_1	primary normal stress difference, Pa
Δp	pressure drop of purely viscous fluid, Pa
Re_n	Reynolds number, Eqs (3) and (5)
u	superficial velocity of liquid, m s^{-1}
β	fraction of total screen area available for flow
	shear rate, s^{-1}
δ	relative deviation, %
ε	porouse media voidage
ρ	density of liquid, kg.m^{-3}
λ_E	characteristic time for viscoelastic stress growth, s
λ_N	Maxwellian characteristic time, Eq. (6), s

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