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RESEARCH NOTES

PRESSURE DROP OF PSEUDO-PLASTIC FLUIDS IN STATIC MIXERS

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1 INTRODUCTION

Use of static mixers to process non-Newtonian fluids is quite common. Data on the pressure drop of non-Newtonian fluids in Kenics static mixers are very useful in the design and engineering application of such mixers. However, only a few studies concerned with the pressure drop of non-Newtonian fluid flow in static mixers can be found in literature. Wilkinson and Cliff[1] presented pressure drop data for aqueous glycerine solutions (Newtonian fluids) and aqueous 1% polyacrylamide solution showing viscoelastic behavior. They found no difference between the friction factors of Newtonian and viscoelastic fluids. Recently, Chandra and Kale[2] presented a correlation for viscoelastic fluids. Shan and Kale[3] gave another correlation between the friction factor and the general Reynolds number covering different sizes of static mixers; however, their studies were limited to only two levels of concentrations for aqueous sodium salt solution of carboxymethylcellulose (CMC, sodium salt). Pressure drop data of non-Newtonian fluids are scarcely available in literature. The present paper aims at studying the pressure drop of pseudo-plastic fluid flows under different concentrations.

2 EXPERIMENTAL

A schematic diagram of the experimental assembly employed is given in Fig. 1. Two Kenics static mixers, one with 5 elements and the other 10 elements, and 20 mm i.d. were being studied. Each element is 1.5 times as long as the diameter of the mixer. Pressure-gauges were fitted at the inlet and outlet of the static mixer so that pressure drop could be measured. The volumetric flow rate was measured by a gear flow meter (Hefei Instrument General Factory, Anhui Province).

Twelve samples of CMC (Shanghai Shailulu Factory, Shanghai) aqueous solutions with varying concentrations were used as pseudo-plastic fluid test specimens. The concentrations of different samples of CMC aqueous solutions are shown in Table 1. Their rheological properties were measured with a HAAKE Rotoviscometer (Model RV

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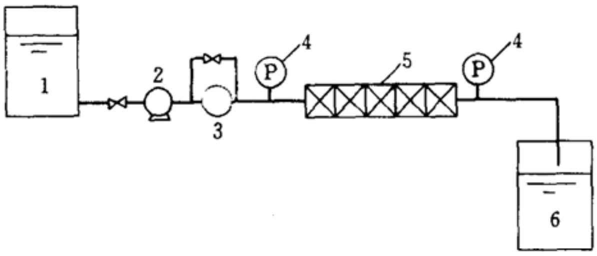

Figure 1 Schematic flow diagram

1—supply tank; 2—pump; 3—gear flow meter;
4—pressure-gauge; 5—static mixer; 6—receiving tank

20) over the shear rate range of 0 to 1340 s^{-1}. Table 1 lists the values of the rheological parameters of the test fluids. Flow rates were varied from 0 to 429×10^{-6} $m^3\cdot s^{-1}$. Shear stress, τ, and shear rate, $\dot{\gamma}$, data for the CMC solutions were fitted by the power-law model

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

Table 1 Rheological properties of CMC aqueous solutions

w_{CMC}, %	n	K, $Pa\cdot s^n$	w_{CMC}, %	n	K, $Pa\cdot s^n$
0.60	0.685	0.420	2.40	0.527	10.6
0.90	0.585	1.52	2.69	0.720	7.24
1.20	0.550	2.44	3.00	0.607	14.2
1.50	0.641	2.64	3.37	0.577	23.9
1.80	0.792	2.64	3.67	0.506	35.8
2.10	0.564	7.64	3.93	0.528	39.1

3 RESULTS AND DISCUSSION

For power-law fluids in empty pipes Reynolds number can be defined as[4]

$$Re=\frac{D^n u^{2-n}\rho}{K[(3n+1)/4n]^n 8^{n-1}} \tag{2}$$

Due to the porosity of the mixers, the mean velocity of fluid flow through the mixers would be higher than the superficial average velocity of the fluid in empty pipes. Therefore, the Reynolds number should be defined in the following manner through incorporating the porosity of the mixers

$$Re=\frac{D^n u^{2-n}\rho}{K\varepsilon^{2-n}[(3n+1)/4n]^n 8^{n-1}} \tag{3}$$

The results of pressure drops, Δp, for the different samples of CMC aqueous solutions are shown in Fig. 2 and Fig. 3 in static mixers of 10 elements and 5 elements, respectively. The data shown indicate that pressure drop is greater at higher Reynolds number and is almost directly proportional to the Reynolds number in the logarithmic coordinate with a certain concentration range of the CMC solution and a certain size of the static mixer. It is also found that pressure drop increases with any increases in the concentration of the aqueous CMC solution when measured in one and the same mixer. Figs.2 and 3 indicate that with a Reynolds number of 1 and above, the slopes of the logarithmic linear relationship at Δp *vs.* *Re* are slightly different. Such changes in the slope is due to the presence of secondary flow. Furthermore, it is observed that compared with 5 element mixers, the 10 element ones always exhibit higher pressure drops (Fig.4).

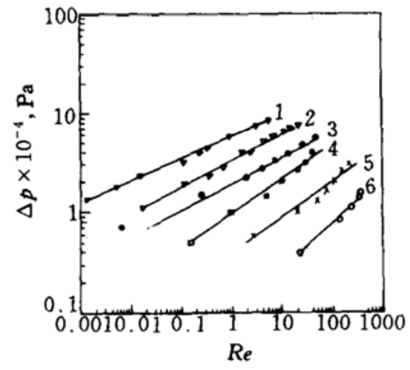

Figure 2 lgΔp *vs.* lg*Re* in a 5 element static mixer
w_{CMC}, %: 1−3.67; 2−3.00; 3−2.40; 4−1.80; 5−1.20; 6−0.60

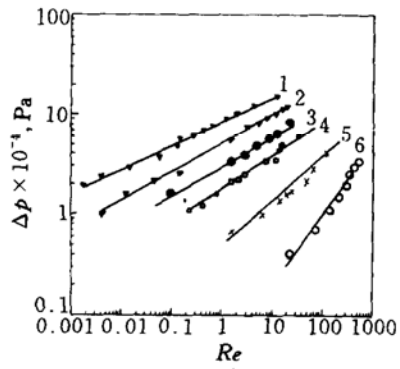

Figure 3 lgΔp *vs.* lg*Re* in a 10 element static mixer
w_{CMC}, %: 1−3.67; 2−3.00; 3−2.40; 4−1.80; 5−1.20; 6−0.60

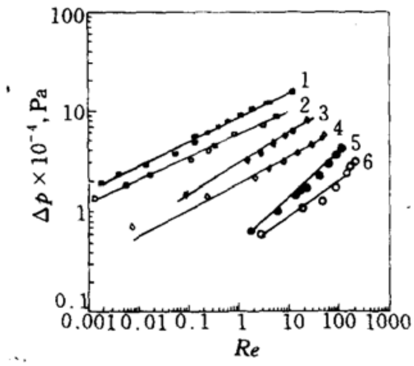

Figure 4 lgΔp *vs.* lg*Re* in static mixers with different elements
1, 3, 5−10 elements; 2, 4, 6−5 elements;
w_{CMC}, %: 1−3.67; 2−3.67; 3−2.40; 4−2.40; 5−1.20; 6−1.20

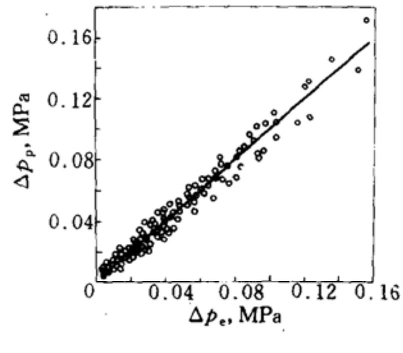

Figure 5 Comparison of experimental data with those predicted values

According to the experimental data of 12 samples of CMC aqueous solution, at varying concentrations, pressure drop is found to be influenced by the properties of the fluids, the geometry of the static mixers and the operating parameters.

These parameters can be expressed by the following dimensionless numbers: *Re*, *n*, *K* and L/D. A correlation of pressure drop in a Kenics static mixer can be obtained as follows

$$\Delta p = 1836 Re^{0.271} n^{1.03} K^{0.855} (L/D)^{0.559} \tag{4}$$

Validity of the correlation is subjected to the following conditions

$$0.506 \leqslant n \leqslant 0.792$$
$$0.420 \leqslant K \leqslant 39.2$$
$$0.00105 \leqslant Re \leqslant 560$$

Fig.5 shows the results. The thus obtained limits of ±10% are shown in Fig.5. The agreement is quite good.

4 CONCLUSIONS

The relationship between pressure drop and Reynolds number, with the porosity of the mixer assembly taken into consideration, (Eq.4) correlates satisfactorily the data for pseudo-plastic fluids over a wide range of Reynolds number. The agreement between the experimental data and those predicted is quite good. Though the correlation is empirical, it is very useful for the evaluation of pressure drop of pseudo-plastic fluids in static mixers with a greater range of power-law index n and K than those found in literature.

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NOMENCLATURE

D	inner diameter of mixer, m
K	parameter of power-law model, Pa·s^n
L	overall length of mixer, m
n	parameter of power-law model
Re	Reynolds number of non-Newtonian fluids
$u_.$	mean velocity in empty pipe, m·s^{-1}
w_{CMC}	mass percentage of CMC aqueous solution, %
Δp	pressure drop, Pa
Δp_e	experimental pressure drop, MPa
Δp_p	predicted pressure drop, MPa
γ	shear rate, s^{-1}
ε	porosity of mixer
ρ	fluid density, kg·m^{-3}
τ	shear stress, Pa·s

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