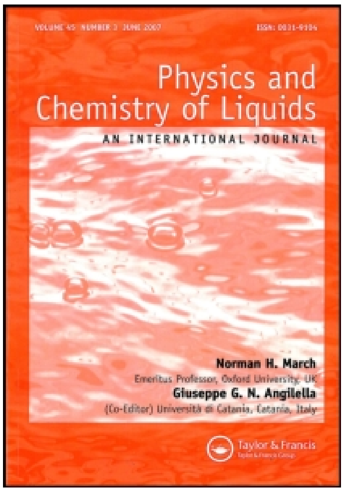

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# Determination of Hagenbach and Coutte Correction Factors for the Flow of Power Law Fluids

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# DETERMINATION OF HAGENBACH AND COUTTE CORRECTION FACTORS FOR THE FLOW OF POWER LAW FLUIDS

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Hagenbach and Couette correction factors ($K_H$ and $K_C$), constituents of the excess pressure drop resulting due to the flow of aqueous polymer solutions through a 2 : 1 pipe contraction have been determined. The data obtained in the present work, combined with those reported in the literature have been correlated in terms of the flow behaviour index($n$) and the diameter contraction ratio $\beta$. While $K_H$ could be correlated in terms of $n$ and $\beta$ with reasonable accuracy, $K_C$ could be represented with an overall deviation of 18.9% over a data set of 14 points.

*Keywords*: Fluid flow; aqueous polymer solutions

## 1. INTRODUCTION

Entrance losses in excess of the fully developed condition arising out of the fluid flow through abprut pipe contractions received adequate theoretical analyses including those by Bogue [1] and Collins and Schowalter [2]. However, the reports on the excess entrance loss ($\Delta P_{\text{ex}}$) data defined by

$$\frac{\Delta P_{\text{ex}}}{\rho V^2/2g_c} = K_H + \frac{K_C}{N_{\text{Re}}} \tag{1}$$

with $\rho$, $V$ and $N_{\text{Re}}$ denoting the fluid density, average velocity in the down stream pipe and Reynolds number respectively are scarce. The constants $K_H$ and $K_C$ are well known as the Hagenbach and Couette correction factors. $N_{\mathrm{Re}}$, in the case of power law fluid flow through a circular pipe is defined by

$$N_{\mathrm{Re}} = \frac{D^n V^{2-n} \rho}{g_c K 8^{n-1}} \tag{2}$$

$n$ and $K$ of Eqn. (2) are the flow behaviour index and consistency index. In this work, $K_H$ and $K_C$ - values determined from the measured entrance losses using the Eqns. (1) and (2) for the aqueous polymer solutions are reported. These data, along with those reported by others [3, 4] have been correlated in terms of the flow behaviour index $n$ and the diameter contraction ratio, $\beta$ (ratio of the diameters of the down stream pipe to the upstream pipe).

## 2. EXPERIMENTAL SETUP

The flow system consisting of a 1500 L storage tank, a surge tank, a 11 KW monopump and the test section was described in brief elsewhere [5]. The test section comprised of two 2.44 m long copper pipes of 5 cm and 2.5 cm diameters respectively, separated by a sudden contraction. Nineteen 3 mm diameter pressure taps were located along the test section. Each pressure tap was provided with two 6.4 m hose tail connections. Poly vinyl chloride tubing of about 5 mm dia. has been used as lead lines from pressure taps to the respective manometer manifold valves. Mercury was used as the manometer gauge field. Further details of the experimental set up were reported by Dutt [6].

Aqueous solutions of the polymers, Methocel (a cellulose manufactured by M/s. Dow Chemicals) and Carbopol (carboxy vinyl polymer manufactured by B.F. Goodrich Co.) have been used as test fluids. Because of the appreciable variation in the rheological parameters even with small variations in the concentrations of the solutions, the fluids were characterized in terms of the Power law indices, $n$ and $K$.

In all, 5 test samples comprising of 3 Methocel solutions and two Carbopol solutions were studied in the present work. Each of the test sample characterized on a R-16 Weissenberg Rhogoniometer before and after the test run carried out on the flow rig exhibited little change in the flow curves, implying the absence of shear degradation.

## 3. RESULTS AND DISCUSSION

The excess pressure drop at a particular flow rate was determined from the plot of pressure drop vs. distance from the first pressure tap. Excess pressure drop is the difference between the extrapolated values on the ordinate drawn to the position of the contraction from the upstream and down stream data pointsin the respective fully developed regions as illustrated in Figure 1. For any polymer solution, the excess pressure drop vs. flow rate (in the down stream pipe) data obtained from the flow rig has been cast in the form of the dimensionless excess pressure drop [first term of Eqn. (1)] vs. inverse of Reynolds number [defined by Eqn. (2)] to determine $K_H$ and $K_C$. The data obtained on $K_H$ from the present work are reported in Table I

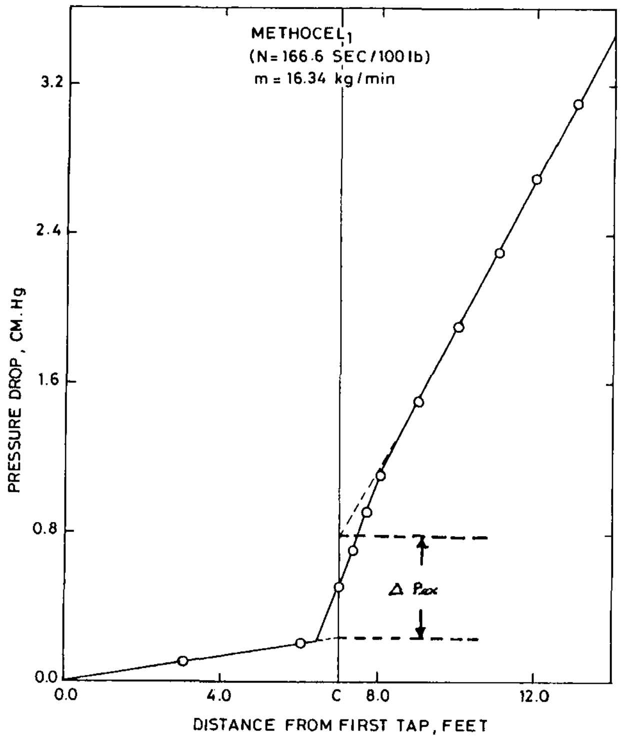

FIGURE 1 Pressure Drop versus Distance from First Pressure Tap for Methocel$_1$ Solution.

TABLE I Data on $K_H$ and their representation by Eqn. (3)

| *Polymer* | $\beta$ | $n$ | $K_H$ | *% Dev. on $K_H$ Eqn. (3)* | *Reference* |
|---|---|---|---|---|---|
| Methocel | 0.468 | 0.656 | 1.41 | −14.5 | This work |
| Methocel | 0.468 | 0.756 | 2.05 | 17.1 | This work |
| Methocel | 0.468 | 0.636 | 1.38 | −15.9 | This work |
| Carbopol | 0.468 | 0.670 | 1.46 | −11.7 | This work |
| Carbopol | 0.468 | 0.734 | 1.79 | 6.0 | This work |
| Theory | 0.0 | 0.400 | 1.52 | −11.6 | 2 |
| Theory | 0.0 | 0.500 | 1.70 | −7.9 | 2 |
| Theory | 0.0 | 1.000 | 2.32 | −0.9 | 2 |
| Polyox | 0.1249 | 0.400 | 2.10 | 22.9 | 4 |
| Polyox | 0.1249 | 1.000 | 2.40 | 7.1 | 4 |
| Over all | 0–0.468 | 0.4–1.0 |  | 11.5% |  |

along with the data of Sylvester [4] and the $K_H$-values calculated by the analysis of Collins and Scholwalter [2].

Following the reasoning of Sylvester [4] that both $K_H$ and $K_C$ should be the functions of $n$ and $\beta$, the equation

$$K_H = 2.3387\left[n(1-\beta)\right]^{0.3506} \tag{3}$$

has been developed and tested with the data reported in Table I. The data also includes the $K_H$ - values calculated for the analysis of Collins and Schowalter [2], corresponding to the values of $n$ (all at $\beta=0$). The % deviations (e) between the reported and calculated values of $K_H$ [from Eqn. (3)] and the average absolute deviation (e) of 11.5 % at 10 data points suggest reasonable fit of the data by Eqn.(3). Eqn. (3) was further tested by means of the data on Newtonian fluids at $\beta=0$ reported by several investigators and % deviations calculated for each reference are reported in Table II.

TABLE II Testing the Eqn. (3) by the data on Newtonians at $\beta=0.0$

| *Investigator (s)* | $K_H$ | *% Dev. on $K_H$(Eqn.3)* | *Reference* |
|---|---|---|---|
| Boussinesq | 2.24 | −4.5 | 7 |
| Knibbs | 2.27 | −3.1 | 8 |
| Schiller | 2.16 | −8.3 | 9 |
| Rieman | 2.25 | −4.0 | 10 |
| Langhaar | 2.28 | −2.6 | 11 |
| Swindells | 2.30 | −1.7 | 12 |
| Lundgren *et al.* | 2.34 | 0.0 | 13 |
| Sparrow & Lin | 2.24 | −4.5 | 14 |

Astarita *et al.* [3], while reporting the data on $K_C$, pointed out the absence of any conspicuous effects of elasticity on $K_C$. Increase in the concentration of the polymers has been found to decrease the value of the flow behaviour index, $n$. Since the concentration of the polymer increases the excess pressure drop and there by the values of $K_C$, an inverse relationship between $K_C$ and $n$ could be expected. Besides, $K_C$ should increase with $\beta$. Hence, an equation of the type

$$K_C = A\left[\frac{1-\beta}{n}\right]^B \tag{4}$$

has been conceived for testing the data on $K_C$.

In Table III, the data on $K_C$ reported by several authors including the present one are reported. The data reported could be represented with an overall deviation of 17.8 % by the equation

$$K_C = 591.3\left[\frac{1-\beta}{n}\right]^{-1.74} \tag{5}$$

As can be seen from the contents of Table III, reasonably wide ranges of variables were studied (being 0.4–0.89 for $n$, 0.125–0.468 for $\beta$ and 185–1648 for $K_C$). The average absolute deviation ($e$) at 14 data points reported in the Table, is 18.9 %. The somewhat higher value of $e$, implies the usage of Eqn. (5) for first estimates.

TABLE III Testing of Eqn. (5) with the data on Couette correction factor

| *Polymer* | $\beta$ | $n$ | $K_C$ | *% dev. On $K_C$, Eqn. (5)* | *Reference* |
|---|---|---|---|---|---|
| Methocel | 0.468 | 0.636 | 931 | 15.7 | This work |
| Methocel | 0.468 | 0.656 | 554 | - 48.9 | This work |
| Methocel | 0.468 | 0.756 | 1280 | 19.3 | This work |
| Carbopol | 0.468 | 0.670 | 1325 | 35.7 | This work |
| Carbopol | 0.468 | 0.734 | 1648 | 40.2 | This work |
| Polyox | 0.1249 | 0.400 | 185 | 7.7 | Sylvester |
| ET 597 | 0.402 | 0.530 | 400 | −22.1 | Astarita |
| ET 597 | 0.402 | 0.540 | 500 | −0.6 | Astarita |
| ET 597 | 0.402 | 0.590 | 720 | 19.6 | Astarita |
| ET 597 | 0.402 | 0.745 | 920 | 8.9 | Astarita |
| ET 597 | 0.402 | 0.875 | 1120 | 3.4 | Astarita |
| Carbopol | 0.402 | 0.790 | 1170 | 21.4 | Astarita |
| Carbopol | 0.402 | 0.860 | 1230 | 14.5 | Astarita |
| Carbopol | 0.402 | 0.890 | 1130 | 6.1 | Astarita |

It can hence be concluded that further experimentation is required for arriving at more meaningful correlations on $K_H$ and $K_C$.

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