MILITARY TECHNICAL COLLEGE
CAIRO - EGYPT

EXPERIMENTAL INVESTIGATION OF FLOW EQUATION OF SCMC AQUEOUS SOLUTION IN PIPELINES

M.T.HARIDI* Ibrahim SALEH*
M.M.HAMZA§

ABSTRACT

Frictional pressure loss for flow of Sodium Carboxymethyl Cellulose (SCMC) aqueous solutions in piping system has been experimentally, investigated. Pipes of inner diameters range from 6 to 17.5 mm, were used. SCMC aqueous solutions have been found to behave as pseudoplastic fluids. Smooth and rough pipes have been used for SCMC concentration ranges from 0.03 to 1.1 wt.%.

It has been found that the pressure drop-flow rate diagram for pipes was similar to that of Newtonian fluids, with different consistency equation and transient Reynolds number. As concentration increases, the pressure loss increases, apperciably in the laminar region than in the turbulent one.

INTRODUCTION

Due to the importance of non-Newtonian fluids, considerable work has been undertaken to develop methods, by which the frictional head losses may be predicted. Bench scale viscometric data or pilot scale piping may be used, /1/.§§ Herein, pilot scale friction apparatus was used to investigate :

1. Effect of varying (SCMC) concentration on the flow

* Ph.D., Military Technical College, Kobry el Kobba, Cairo.
§ Eng., Armament Authority, Kobry el Kobba, Cairo.
§§ Reference number.

behaviour and consistency indices.

2. Pressure drop in smooth and rough pipes.

The practical choice, and importance of the SCMC aqueous solutions, lie in the fact that they are widely used in industry, /2/.

FLUID FLOW BEHAVIOUR

Newton's law of viscosity states that, for a streamline flow the shear stress (τ) is proportional to the velocity gradient ($\dot{\gamma}$) in the fluid. The constant of proportionality is known as the coefficient of dynamic viscosity (μ). Thus, Newton's law can be written as,

$$\tau = \mu \dot{\gamma} \qquad (1)$$

Fluids which obey this law are called Newtonian fluids. Otherwise, they are called non-Newtonian fluids. For non-Newtonian fluids, the term "viscosity" has no meaning unless it is related to a particular shear rate. This is the reason of using the term "apparent viscosity", (μ_a), /3/. The change of apparent viscosity with the change of time, and shear rate ($\dot{\gamma}$), determine the type of fluid.

For non-Newtonian fluids, the relationship between (τ & $\dot{\gamma}$) is more complex, and for time independent fluids, Eq.(1) may be written as,

$$\tau = \varphi(\dot{\gamma}) \quad , \qquad (2)$$

where φ means "function of." Attempts have been made to define this function by formulating mathematical models, to represent the rheological behaviour of non-Newtonian fluids, /4/. The simplest and most commonly used relationship is the power law equation defined as, /5/,

$$\tau = K \dot{\gamma}^n \quad , \qquad (3)$$

where K is called the consistency coefficient, and n is the power law index.

Fluids which obey the above equation are called power law fluids. For pseudoplastic fluids, ($n<1$), and for dilatant fluids, ($n>1$). In the case of Newtonian fluids, ($n = 1$), and K becomes the coefficient of dynamic viscosity.

PRESSURE LOSS IN PIPELINE

The relationship between pressure drop (Δp), and volumetric flow rate (Q), may be obtained by integrating the chosen flow equation relating the shear stress, (τ), and shear rate ($\dot{\gamma}$). The pressure drop in a pipe of radius (r), and length (L), is related to the wall shear stress (τ_w) by,

$$\frac{\Delta p}{L} = \tau_w \cdot \frac{2}{r} \quad . \qquad (4)$$

These losses can be investigated over laminar, transitional and turbulent flow regions, if the consistency equation, (3) is known.

Different flow equations, relating the pressure loss and flow rates, may be found in Ref. /2 & 3/. It is of practical interest to relate the pressure loss by Fanning friction coefficient (f), defined as ,

$$f = \tau_w / \frac{\rho v^2}{2} \quad , \qquad (5)$$

where (v) is the flow mean velocity in the pipe. This friction factor may be related to the generalized Reynolds number (R_e') .

Generalized Reynolds number (R_e'), is defined so that, in laminar flow, the same relation for the friction factor is valid for both Newtonian and non-Newtonian fluids, /5/.

For laminar flow in a pipe of inner diameter (D= 2r), Metzner-Reed equation, relating the shear stress and shear rate, may be written as, /7/,

$$\tau_w = K' \left(\frac{8\,v}{D} \right)^{n'} \quad , \qquad (6)$$

where K' and n' are constants, depend on the fluid properties. The Fanning-coeffecient (f) is, then,

$$f = \tau_w / \frac{\rho v^2}{2} = K' \left(\frac{8v}{D}\right)^{n'} / \frac{\rho v^2}{2} \quad , \qquad (7)$$

Knowing that the factor (f), for Newtonian fluids is,

$$f = 16/R'_e \quad ,$$

Eq.(7), yields to,

$$R'_e = \frac{\rho \, D^{n'} \, v^{2-n'}}{K'.8.^{n'-1}} \tag{8}$$

In case of power law fluids, n' = n , and $K' = K.(\frac{3n+1}{4n})^n$, the generalized Reynolds number is,

$$R'_e = \frac{\rho \, D^n . \, v^{2-n}}{\frac{K}{8} .(\frac{6n + 2}{n})^n} \quad . \tag{9}$$

EXPERIMENTAL INVESTIGATION

Experimental investigation of the flow behaviour of SCMC solutions, as well as the friction losses in pipes of different sizes and roughness, has been carried out according to the following sceme,

1. Preparation of SCMC solutions of differnt concentrations from 300 to 11000 ppm.
2. Measurement of the rheological properties of the prepared solutions.
3. Measurement of the pressure drop-flow rate data for water, as a Newtonian fluid, and for the prepared solutions for pipes having the diameters of 6, 10, 17.5 smooth and 17.5 mm rough of relative roughness 1/450.

The properties of Sodium Carboxymethyl Cellulose (SCMC) aqueous solutons are given in the British Pharmacobia 20, /4/. The SCMC solutions have been prepared in a motor driven, five blades cylinderical mixer of 40 cm outer diameter, and 100 cm depth. To allow complete solubility, the solution was mixed for 30 minutes, then lefted for 24 hours and then mixed for another 30 minutes, /4/.

The shear rate, shear stress and apparent viscosity of the prepared SCMC solutions have been measured using the Brook-field viscometer, described in Ref./4/. The effect of the mechanical degradation on the fluid apparent viscosity has been tested by measuring the rheometric properties of the solution before and after two hours pumping.

The experiment was carried out, in the laboratory of Fluid Mechanics of the M.T.C., by using a fluid friction apparatus C6-00, manufactured by Armfield Technical Education Co. Ltd. in England, /4/.

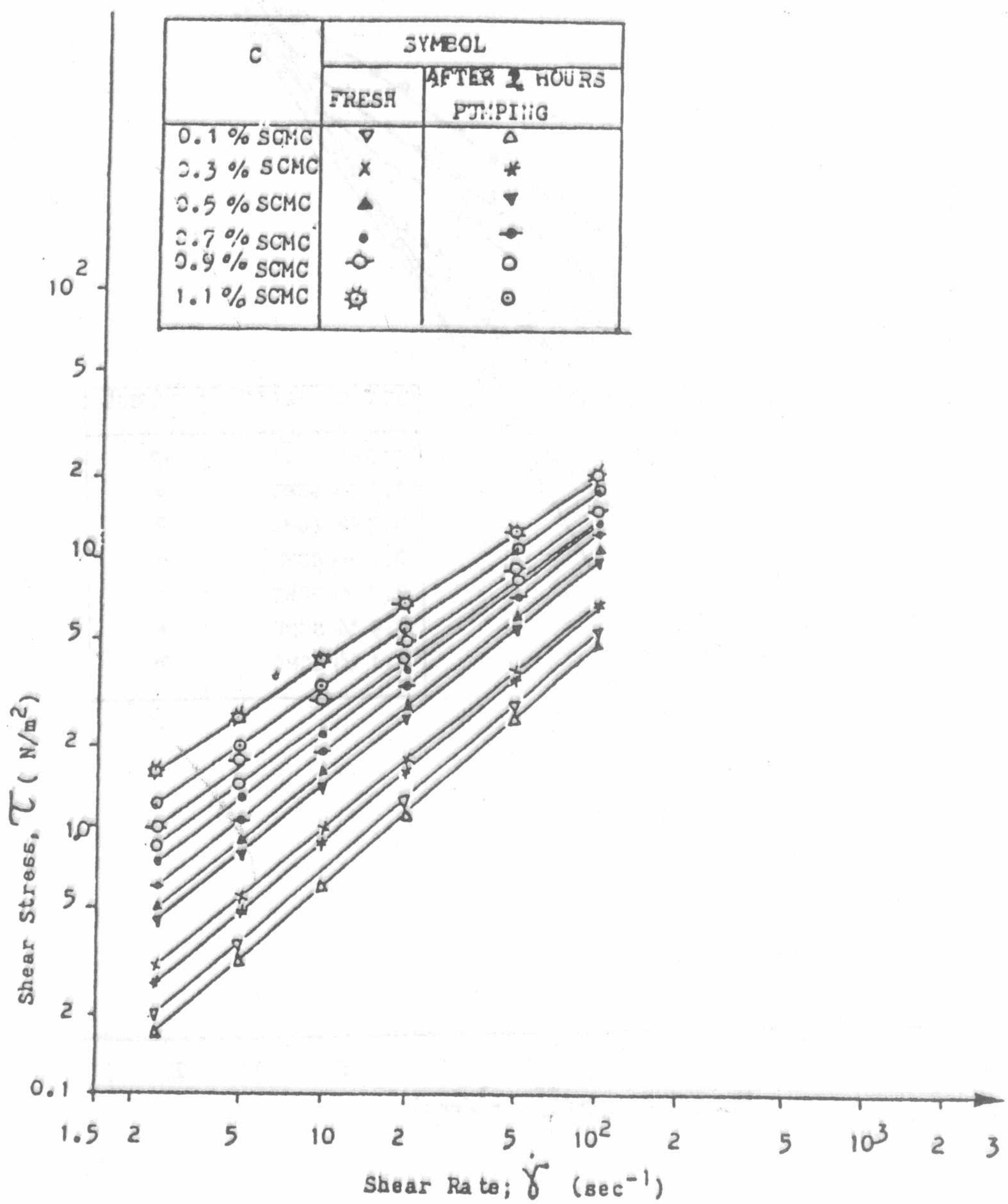

Fig.(1), Rheograms for SCMC Solutions

Experiment has been carried out for water flow and nine test-solutions of concentrations, 300, 450, 700, 1000, 3000, 5000, 7000, 9000 and 11000ppm. Fig.(1) shows the rheometric chart for these solutions. For each solution the flow rate (Q), and pressure drop (Δp) were measured.

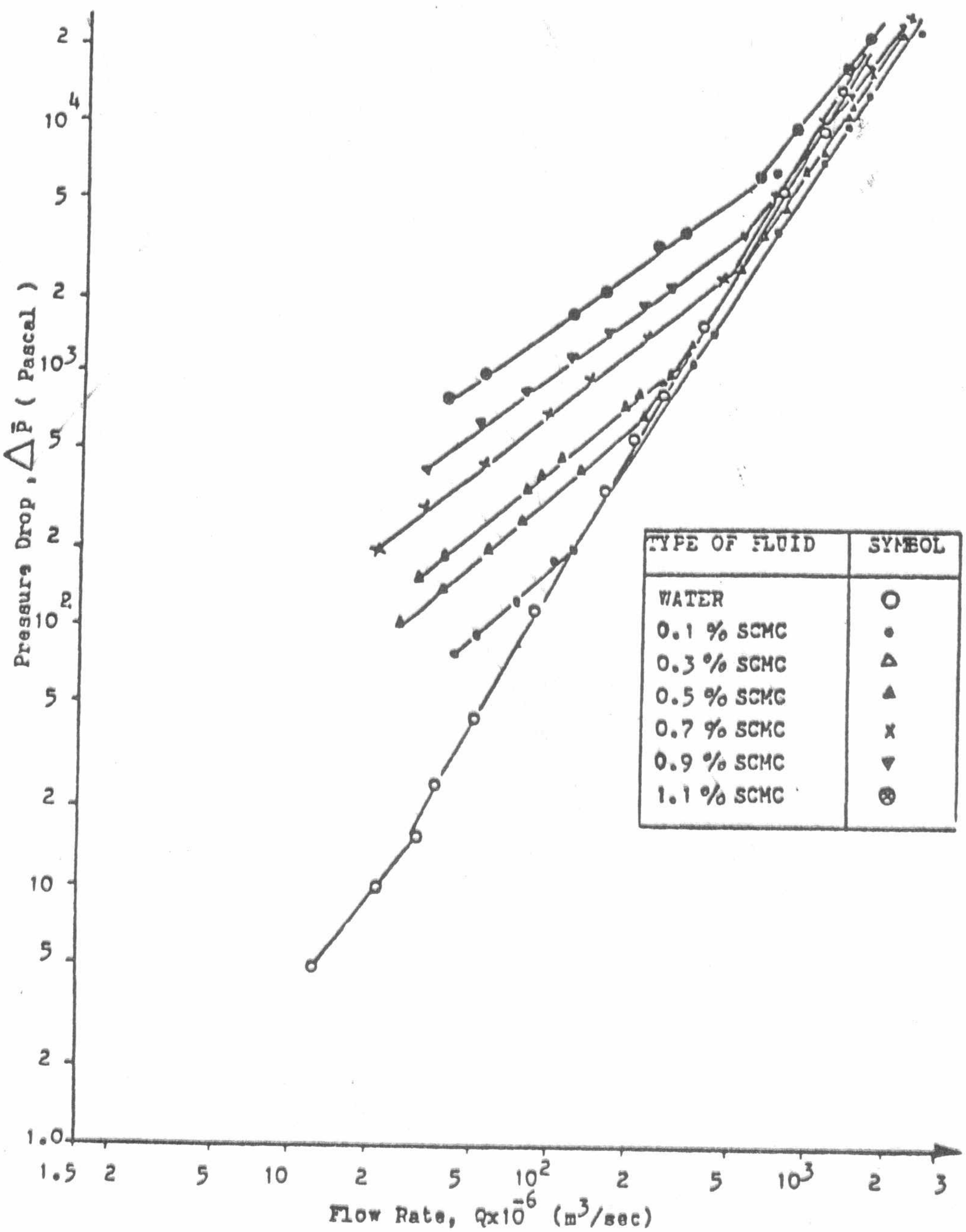

Fig.(2), Pressure drop in 17.5 mm smooth pipe.

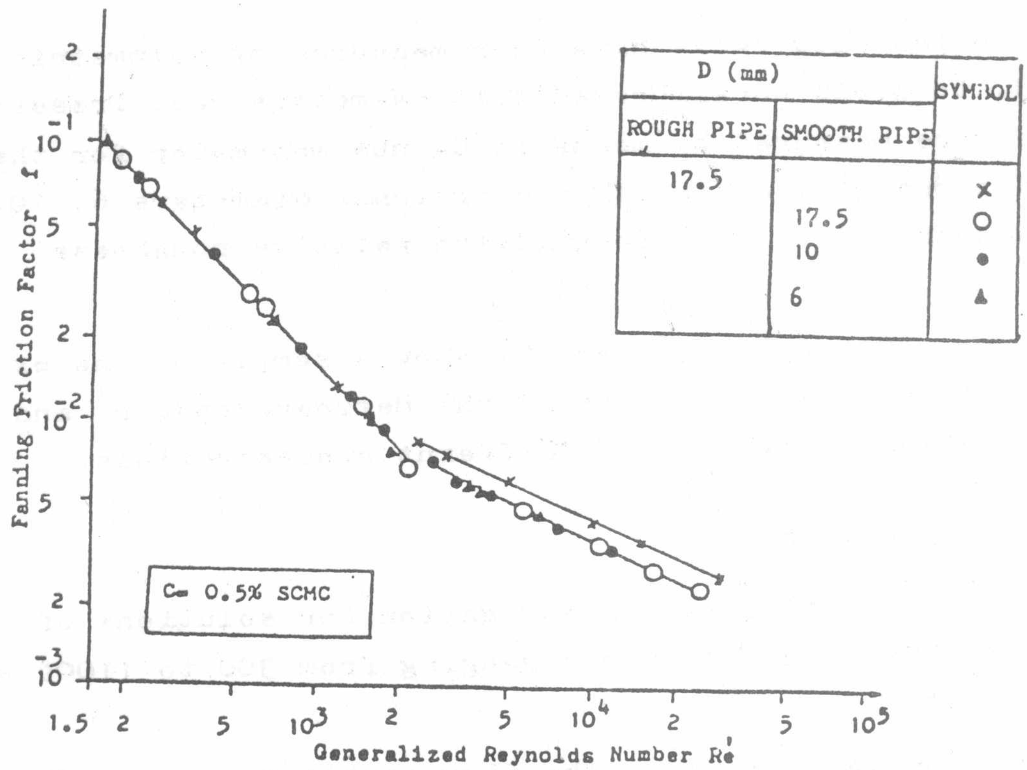

Fig.(3), Fanning Friction Factor, for 0.5% SCMC

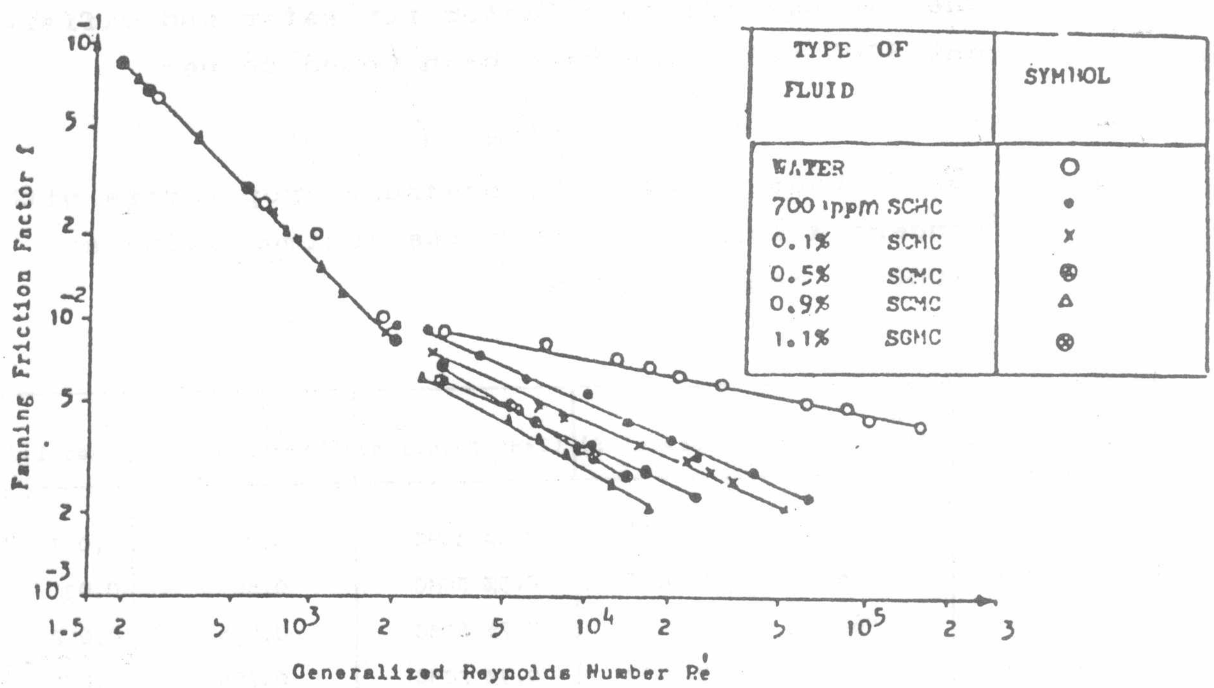

Fig.(4), Fanning Friction Factor for 17.5 mm pipe.

The solution flow rates have been measured by volumetric method, to avoid uncalibrated orifice-meters use. Pressure losses were measured by means of U-tube manometer for the tested pipes of 1 m. length and of inner diameters 6, 10 mm 17.5 smooth and 17.5 mm rough, with relative roughness 1/450.

Fig.(2), (3) and (4) show a sample of the experimental results. Constants of the Metzner-Reed, n' and K', are given in Tab.(1) for differnt concentrations.

CONCLUSIONS

Experimental investigation for solutions of different SCMC concentrations ranging from 300 to 11000ppm, showed that :

- For laminar flow, the flow constants n' and K', of Metzner-Reed equation vary with concentration. As polymer concenration increases, the constant n' decreases, while K' increases.
- The laminar friction factor for water and different SCMC solutions have been found to be:

$$f = 16/R_e' \quad .$$

- For Turbulent flow, the pressure drop varies with concentration. It reaches its maximum value at 11000ppm concentration.

Test Solution	n' (Dimensionless)	k' (pascal.S)	(Test Solution)	n' (Dimensionless)	k' (pascal.S)
Water	1	9×10^{44}	0.3% SCMC	0.9	0.013
0.03% SCMC	0.968	0.0015	0.5% SCMC	0.86	0.021
0.045% SCMC	0.960	0.0025	0.7% SCMC	0.825	0.042
0.07% SCMC	0.945	0.0032	0.9% SCMC	0.785	0.075
0.1% SCMC	0.925	0.006	1.1% SCMC	0.74	0.139

Tab.(1), Metzner-Reed Constants.

. . .

REFERENCES

1. Heywood,N.I., "Pipeline Design for non-Newtonian Fluids", Ins. Chem. Eng. Symp. Ser., Vol. 60, Interflow 80, pp. 33 to 52, 1980.

2. Gupta,A.K., Bhatia,Y.S., "Degredation Study of a Drag Reduction Polymeric Solution", J. Inst. Eng., India, Vol. 61, pp. 9 to 12, 1980.

3. Holland,F.A., "Fluid Flow for Chem. Eng.", Edward Publishers Ltd., 1973.

4. Hamza,M.M., "Flow of mon-Newtonian Fluids in Pipes", MSc. Thesis, F.of Eng., Cairo Univ.1985.

5. Andreas,A., "Modern Chemical Engineering", Vol. 1, Reinhold Publishing Corporation, 1963.

6. Kirk-Othmer, Encyclopedia of Chemical Technology , Vol.4, 2nd. Ed., " Hercules Cellulose Gum Properties and Uses", Hercules Powder Co., Wilmington, Del., 1960.

7. Coulson,J.M., and Pichard,J.F., "Chemical Engineering", Vol. 3, 2nd Ed., Richardson & Peacock, 1982.