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# Inhibition of diffusion controlled corrosion in pipelines by drag reducing polymers under turbulent flow conditions

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The effect of adding carboxymethylcellulose drag reducing polymer on the rate of corrosion of aluminium tube through which sodium hydroxide solution flows, was studied by a weight loss technique. The variables studied were solution flow rate and polymer concentration. Reynolds number and polymer concentration were varied over the range 3500 to 30 000 and 10 to 500 ppm, respectively. Polymer addition was found to decrease the rate of corrosion by a maximum of 63% depending on polymer concentration and Reynolds number.

## Nomenclature

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|---|---|
| $Re$ | Reynolds number |
| $\rho$ | Solution density |
| $d$ | tube diameter |
| $u$ | solution viscosity |

## 1. Introduction

Recent studies [1, 2] on the effect of drag reducing polymers on the rate of turbulent flow mass transfer have shown that these polymers give rise to a dramatic decrease in the rate of mass transfer owing to the ability of these polymers to damp the small scale, high frequency eddies that prevail in the boundary layer [3]. This finding opens up the possibility of using drag reducing polymers as corrosion inhibitors in pipelines carrying oil or water where the rate of corrosion may be determined by the rate of oxygen diffusion to the pipe wall or the rate of diffusion of the corrosion products away from the pipewall. This would result in improving the economy of pipelines through: (i) cutting down the pumping power requirement as a result of drag reduction; (ii) prolongation of the lifetime of the pipeline as a result of corrosion inhibition.

Moreover drag reducing polymers pose no environmental hazard since they are nontoxic [4] and biodegradable [5].

In a previous study [6] the effect of polyethylene oxide (Polyox WSR-301) on the rate of corrosion of aluminium pipe in an acid solution was studied. The present work deals with testing the performance of carboxymethylcellulose (CMC-7H) as corrosion inhibitors for aluminium pipe carrying sodium hydroxide solution under turbulent flow conditions. Corrosion of aluminium in alkaline solutions is known to be diffusion controlled [7] and therefore can be inhibited by drag reducing polymers. CMC was chosen for the present study in view of its chemical stability in alkaline solutions.

## 2. Experimental technique

The apparatus used in the present study (Fig. 1); consisted of a 4 dm$^3$ thermostated, plexiglass storage tank, a centrifugal pump made of plastic and a pipe assembly. The pipe assembly consisted of a test section made of a 16.5 cm length of aluminium tube 1.2 cm in diameter preceded by an entrance section comprising an 85 cm length of plexiglass tube 1.2 cm in diameter, a length sufficient to obtain fully developed flow in the test section [8], the test section was followed by an outlet section comprising a 15 cm length of plexiglass tube 1.2 cm in diameter. The three sections were connected using a threaded plexiglass sleeve;

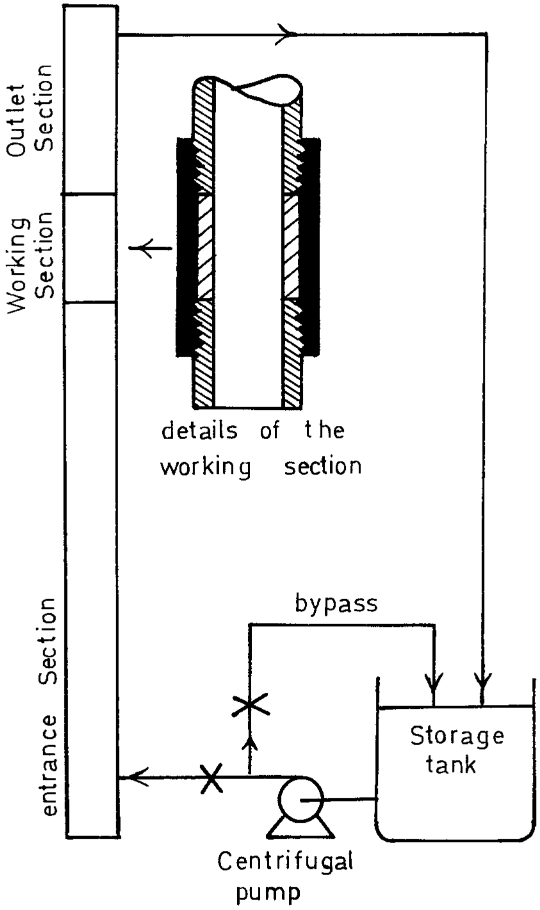

Fig. 1. Experimental apparatus.

soft rubber gaskets were used to prevent electrolyte leakage at the connections. Care was taken to avoid any discontinuity or roughness in connecting the three sections.

Before each run the internal surface of the test section was etched for 120 s with 35% HCl to remove the oxide film adhering to the aluminium surface; the flat ends of the test section were isolated with epoxy resin and weighed after drying. After the flow loop had been assembled 1 mol $dm^{-3}$ NaOH was circulated through the test section for a period of 30 min. The flow rate of the solution through the test section was regulated with a by-pass. After each run the working section was dismantled, washed with distilled water, dried and then reweighed. NaOH solution was prepared from AR grade materials.

CMC-7H [4] (a product of Hercules) was used in the present study. The polymer solution was prepared by dissolving the required weight in distilled water overnight. It was mixed with NaOH to obtain the required concentration of polymer and NaOH. Concentrations of up to 500 ppm CMC were prepared. Each run was carried out using fresh solution and a new test section to avoid the presence of any surface irregularity caused by corrosion. The temperature was 25° C. Rheological measurements showed that all CMC solutions used in the present work were Newtonian.

## 3. Results and discussions

Fig. 2 shows the effect of Reynolds number on the rate of aluminium corrosion in the polymer free solution (1 mol $dm^{-3}$ NaOH). The result can be represented by the equation:

$$\text{Rate of Corrosion} \propto Re^{0.35}.$$

The exponent 0.35 shows that under the present conditions, corrosion of aluminium in NaOH is partially controlled by the diffusion of $NaAlO_2$ away from the aluminium surface [9]. For fully diffusion controlled reactions inside tubes under turbulent flow conditions, the exponent in the above equation should be about 0.6 to 0.9 [7, 9]. Under the present conditions where diffusion affects the rate of aluminium corrosion in NaOH, the addition of CMC was found to have a dramatic effect on the rate of corrosion by increasing the diffusion layer thickness. Fig. 3 shows the effect of *Re* on the inhibition efficiency of CMC at different polymer concentrations, the % decrease in the rate of aluminium corrosion ranges from 3.5 to 63.8% depending on Reynolds number and polymer concentration. The inhibition efficiency of CMC increases with Reynolds number until it reaches a constant value at low CMC concentrations or decreases with a further increase in Reynolds number at high CMC concentrations. The initial increase in the inhibition efficiency of CMC with Reynolds number may be explained by the expansion (uncoiling) of CMC molecules by the high shear stress exerted on them; this improves the ability of CMC molecules to damp turbulent eddies in the buffer layer of the hydrodynamic boundary layer [10–12] with a consequent increase in the diffusion layer thickness. At a certain Reynolds number it seems that CMC molecules become fully stretched and accordingly their ability to damp turbulent eddies becomes

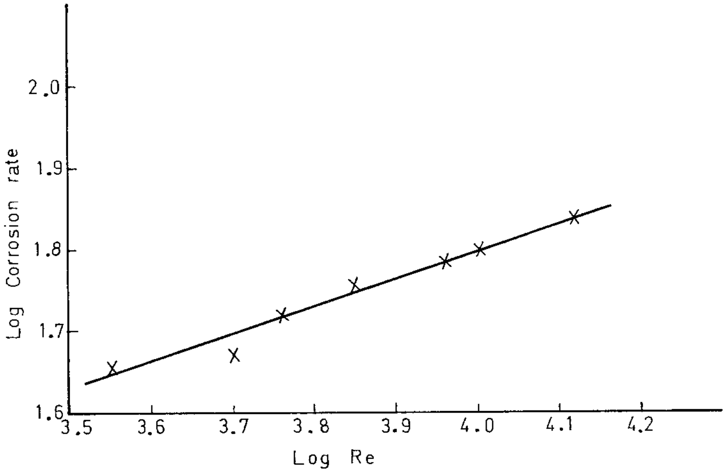

Fig. 2. Effect of Reynolds number on the rate of corrosion of aluminium tube in 1 mol dm$^{-3}$ NaOH.

independent of Reynolds number. With high CMC concentrations, e.g. 200 or 500 ppm, where the inhibition efficiency decreases at high Reynolds number after reaching a maximum it seems that the conformation of CMC is adversely affected by the high ionic strength resulting from the presence of high concentration of $NaAlO_2$ along with a relatively high concentration of CMC polyelectrolyte in the very limited volume of the hydrodynamic boundary layer existing at high *Re*.

Under these conditions, $NaAlO_2$ changes the CMC molecules from the stretched form to the less effective coiled form. This change takes place through the salting out effect of $NaAlO_2$ and its ionic interaction with the ionic segments of CMC which is a polyelectrolyte. This ionic interaction decreases the activity of the negatively charged segments of CMC molecules and decreases their ability to repel each other to produce stretched polymer molecules [13]. The decrease in the

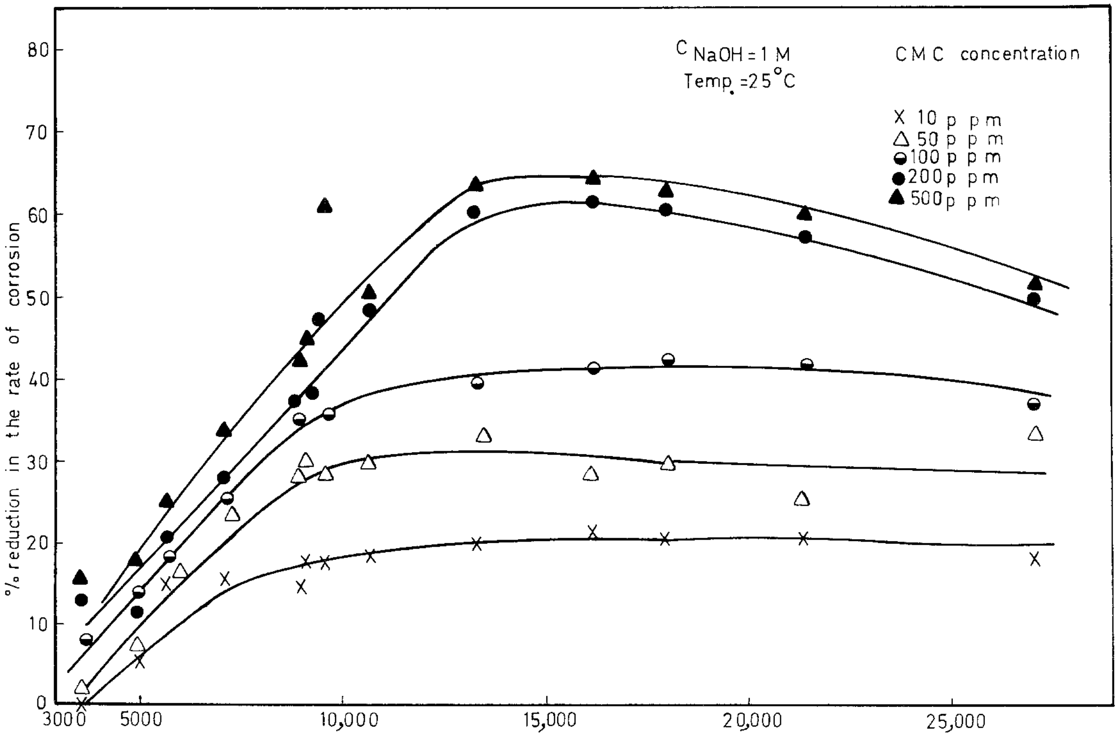

Fig. 3. Effect of CMC concentration on the percentage reduction in the rate of corrosion of aluminium in NaOH under turbulent conditions.

inhibition efficiency at high Reynolds number and high CMC concentration cannot be ascribed to shear degradation of the polymer molecules which is unlikely to take place under the present conditions [5]. In a previous investigation the effect of CMC on the rate of mass transfer between turbulently flowing fluid and a tube wall was studied by an electrochemical technique involving the cathodic reduction of potassium ferricyanide in a large excess of NaOH at a nickel cathode [1]. A comparison between this study and the present work shows that the % reduction in the rate of mass transfer measured by the electrochemical technique is less than the % reduction in the rate of corrosion obtained in the present work for a given CMC concentration and Reynolds number. This discrepancy may be attributed to the following:

(i) In the electrochemical study the solution used was 0.025 mol dm$^{-3}$ $K_3Fe(CN)_6$ + 0.025 mol dm$^{-3}$ $K_4Fe(CN)_6$ + 1 mol dm$^{-3}$ NaOH, i.e. the ionic strength of the solution used in the electrochemical study is higher than that used in the present work (1 mol dm$^{-3}$ NaOH); accordingly the adverse effects of interionic attraction and salting out on the conformation of CMC molecules are more drastic in the case of the electrochemical technique.

(ii) In the electrochemical study a tube diameter of 2.4 cm was used while in the present study a tube of diameter 1.4 cm was used; the ability of the drag reducing polymer to damp small scale high intensity eddies is known to decrease with increasing tube diameter for a given Reynolds number and a polymer concentration [3].

The implication of this comparison is that the efficiency of CMC as a corrosion inhibitor increases with decreasing the salt content of the fluid being pumped in the pipeline. This is consistent with the finding of Shah and Ecanow [14] that the drag reducing ability of CMC decreases with adding salts to the solution and agree also with the fact that salt addition reduces the drag reducing ability of other polyelectrolytes [12–15].

## References

[1] G. H. Sedahmed, M. Nagy Soliman and N. S. El-Kholy, *J. Appl. Electrochem.* 12 (1982) 479.

[2] G. H. Sedahmed, B. A. Abdel-Naby and A. Abdel-Khalik, *Corros. Sci.* 17 (1977) 865.

[3] J. W. Hoyt, *J. Basic Eng.* 94 (1972) 258.

[4] Hercules Bulletin, Sodium Carboxymethylcellulose, (1971).

[5] A. Abdel-Khalik, MSc thesis, Alexandria University (1974).

[6] G. H. Sedahmed, M. S. Abdo, H. A. Farag and S. G. Tantawy, *Surf. Technol.* 9 (1979) 359.

[7] B. T. Ellison and C. J. Wen, AICh E Symposium Series 77, No. 204 (1981) 161.

[8] J. G. Knudsen and D. L. Katz, 'Fluid Dynamic and Heat Transfer', McGraw-Hill Book Company, Inc, New York (1958).

[9] P. A. Lush and M. J. Carr, *Corros. Sci.* 19 (1979) 1079.

[10] F. E. Bailey, Jr and R. W. Callard, *J. Appl. Polym. Sci.* 1 (1959) 56.

[11] R. C. Little, R. J. Hansen, D. L. Hunston, O. K. K. Im, R. L. Patterson and R. V. Ting, *Ind. Eng. Chem.* 14 (1975) 283.

[12] M. A. Frommer, A. F. Lavy and M. A. Kraus, *J. Colloid Interface Sci.* 48 (1974) 165.

[13] Fumio Oosawa, 'Polyelectrolytes', Marcel Dekker Inc., New York (1971) p. 139.

[14] D. Shah and B. Ecanow, *J. Pharmaceutical Sci.* 63 (1974) 1164.

[15] R. L. Patterson, D. L. Hunston, R. Y. Ting and R. C. Little, *J. Chem. Eng. Data* 20 (1975) 381.