A DRAG REDUCTION IN CWM TRANSPORTATION WITH POLYMER ADDITIVES

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Experimental investigations have been carried out to determine the drag reduction produced by polymer additives in coal water mixture(CWM) and hydraulic tranports. Different values of flow velocities, polymer concentrations and different temperatures were adopted to obtain a clear picture about the process involved. The additives are polyox WSR-301 and separan AP-273 in coal and deionized water mixtures. The experiments were undertaken with a test section pipe diameter 9.8mm and length 3500mm in a closed loop. The criteria used is to produce the amount of drag reduction and have the stability against degradation with reliable polymer additives. It is found that the drag reduction on CWM containing polymer is greater at higher flow velocities and in "pure" polymer solutions than CWM containing polymer. Furthermore, polymer concentrations at which drag reduction reached a maximum have been investigated.

Key Words : Drag Reduction, CWM, Polymer Additives, Hydraulic Transport.

NOMENCLATURE

c_c	: Coal weight concentration [%]
c_p	: Polymer weight concentration [wppm]
D	: Inside diameter of pipe [m]
DR	: Percent of drag reduction [%]
f	: Friction factor
f_p	: Friction factor of the polymer solution
f_s	: Friction factor of the solvent alone
L	: Pipe length [m]
L_e	: Entrance length [m]
$PAAM$	: Polyacrylamide
PEO	: Polyethylene oxides
ΔP_p	: Pressure loss due to friction in unit length of the pipe for solvent alone [kgf/cm^2]
ΔP_s	: Pressure loss due to friction in unit length of the pipe for the solution containing the polymer additive [kgf/cm^2]
Re	: Reynolds number
V	: Flow velocity [m/sec]
ρ	: Density [kg/m^3]
τ_w	: Wall shear stress [kgf/m^2]

1. INTRODCUTION

Toms(1948) reported that under conditions of turbulent flow through a circular pipe, very dilute solution of polyethyl methacrylate in monochlorobenzene could cause drastic drag redction relative to the pure solvent at the same flow rate. This phenomenon is commonly refered to as "the Toms phenomenon". The Toms phenomenon; its most striking feature is that the polymeric additives often reduce skin friction relative to pure solvent. Under condition of turbulent pipe flow, dilute polymer solutions require a smaller specific energy expedition than the pure solvent: thus with the polymer solutions, a lower pressure gradient is needed to maintain the same flow rate, or higher flow rate can be attained for the same pressure gradient as solvent. Such a drag reduction was found to be associated with the suppression of fluctuating eddies by long-chain molecules.

The friction factor of polymer solutions is much lower than that of Newtonian fluids. This is due to the viscoelastic properties of polymer solutions and in the turbulent flow region the friction factor of viscoelastic fluids is much smaller than that of Newtonian or pure viscous fluids(Cho and Hartnett, 1985). However, Virk(1970) rerported that the drag reductions in turbulent flow are ultimately limited by unique asymtotes which are independent of the polymer concentration, solvent chemistry, and the degree of degradation. The asymtotes are solely dependent on the Reynolds number and dimensionless L/D. For hydrodynamically fully developed turbulent flow, the maximum drag reduction asymtotes are a function of only Reynolds number based on apparent viscosity. In general, the friction factor of polymer solutions lies between the line of friction factors on Newtonian fluids and the maximum drag reduction asymtotes.

Qualitatively, drag reduction appears to increase with increasing flow rate, polymer concentration, polymer molecular weight, and with decreasing pipe diameter(Virk, 1967). The friction factor of polymer solution circulating in the closed system breaks away from the ultimate asymtotes and increases gradually owing to the degradation of polymer substances.

Recently the Belovo-Novosibirsk Coal Slurry system (256km long, 20 in pipeline)(Ercolani, 1986), which represents the first industrial application of the whole CWM technology in the world, is being constructed in USSR, and it is expected that polymer additives injected into the coal slurry system will be able to contribute to the elevation of largely pumping power. Specially, Golda(1985) performed experiments on transportation of pulverized coal slurries.

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The sizes of coal particles used in his experiments were in the range of 2mm and 63mm. The experiments were carried out on two different pipe diameters of 40mm and 250mm. Through the experiments he suggested the possible drag reduction phenomenon up to 60% by adding various types of polymers to coal water slurries.

The present work is to determine the proposed drag reduction rates of much smaller CWM coal particles with the average size of 40μm through experimental investigations. It is performed by addition of polyethylene oxides(PEO) and polyacrylamides($PAAM$) to coal water mixture and hydraulic system to examine the effects of transport time, polymer and coal concentrations on drag reductions.

2. THEORETICAL CONSIDERATIONS

2.1 Friction Factor

In the pipe flow of a newtonian or non-Newtonian, the commonly used relationship between the pressure drop and the mean velocity is expressed in terms of the Fanning friction factor, defined as

$$f=\frac{\tau_w}{1/2\rho V^2}=\frac{D}{2\rho V^2}\frac{\Delta P}{L} \qquad (1)$$

where ΔP is the pressure difference between the ends of the test section, L is length of the test section, D is the pipe diameter, ρ is the density of the fluid, and V is the mean velocity. The friction factor is essentially a dimensionless pressure gradient, and it is a function of the Reynolds number for fully developed flow of Newtonian fluids.

In order to obtain fully established friction factors it is essential to measure the pressure drop between two pressure taps in the fully developed flow region. The entrance length L_e for laminar flw of Newtonian fluids is given by kays (1980) as

$$\frac{L_e}{D}=\frac{Re}{20} \qquad (2)$$

The maximum value of L_e would be about 100 diameters for the case of laminar flow. The hydrodynamic entrance region for turbulent flows of Newtonian fluids is fairly short, and 20 diameters are usually sufficient. However, for non-Newtonian fluids, L_e is approximately 100 diameters (Cho and Hartnett, 1982). For this reason, the pressure drop was measured at $x/d>100$ in the present study.

For fully developed turbulent flows, the von Karman relation for Newtonian fluids is used, i.e.,

$$f^{-1/2}=1.74\ln(Ref^{1/2})-0.40 \qquad (3)$$

for $3\times10^3<Re<3\times10^6$.

The Blasius equation is also used:

$$f=0.079Re^{-0.25} \qquad (4)$$

The blasius friction formula is as accurate as the logarithmic formula, Eq. (1), and is within 2% of the experimental data for $Re<10^5$.

In turbulent flow, the friction factor for a viscoelastic fluid may be significantly smaller than that of Newtonian fluid. In the limiting case of Virk's maximum friction reduction asymtote, the friction factor is given as

$$f^{-1/2}=19.0\log(Re\,f^{1/2})-32.4 \qquad (5)$$

Cho and Hartnett proposed the following empirical correlation, which is easier to use than Eq. (5) :

$$f=0.20Re^{-0.48} \qquad (6)$$

for $6000<Re<60000$.

2.2 Difinition of Equations Used to Describe Drag Reduction

A generally and widely accepted definition of drag reduction was as follows:

$$DR(\%)=\frac{(\Delta P_s-\Delta P_p)}{\Delta P_s}\times100 \qquad (7)$$

DR = Percent of drag reduction
ΔP_s = Pressure loss due to friction in unit length of the pipe for solvent alone
ΔP_p = Pressure loss due to friction in unit length of the pipe for the solution containg the polymer additive

Drag reduction can also be computed by using the following relationship:

$$DR(\%)=\left(1-\frac{f_p}{f_s}\right)\times100 \qquad (8)$$

f_s = Friction factor of the solvent alone in unit length of pipe
f_p = Friction factor of the polymer solution in unit length of pipe

3. EXPERIMENTAL METHODS

3.1 Materials in the Experiment

Polyethylene oxides, average molecular weights of about 4-5,000,000, obtained from Aldrich Chemical Company, and polyacrylamides, molecular weights about 5-6,000,000, from Aldrich Chemical Company were utilized in the present study. a stock solution for every sample was prepared by dissolving the dry polymer in water. Complete dissolution occured after gently stirring with a screw mixer at room temperature. The stock solution was then diluted to the appropriate concentration.

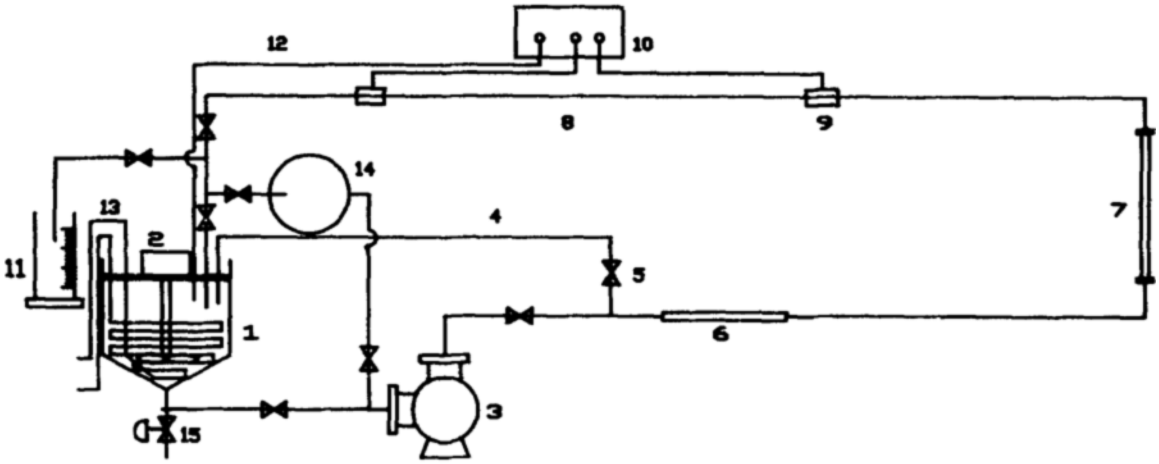
The present experiments were conducted using coal with a density of 1.417g/cm^3, average particle size of 40μm and the coal concentration used were 5 and 10 weight percent.

3.2 Experimental Conditions

—Reynolds number : within 50,000
—Temperatures of fluids : about 25℃
—Testing time : within 60 min
—Length of test section pipe : 3500mm
—Diameter of test section pipe : 9.8mm

3.3 Experimental Apparatus

The laboratory facility used in the experiments is shown schemetically in Fig. 1. It is a closed system with a total pipe length of about 16.0m. Water, Coal, and polymer additives can be added to the system at the storage tank ①. CWM and polymer solution in the storage tank are stirred by a screw



1. Storage Tank
2. Screw Mixer
3. Wesco Pump
4. By-Pass Line
5. Ball Valve
6. Flexible Pipe
7. Acryl Tube
8. Test Section (L=3500mm, I.D.=9.8mm)
9. Pressure Transducer
10. Data Logger FLUKE 2280B
11. Flow Meter
12. Thermocouple
13. Tube Heat Exchanger
14. Water Tank
15. Gate Valve

Fig. 1 Schametic diagram of experimental apparatus

mixer ②. The mixture is circulated by a Wesco pump ③ dirven by a variable-speed electric motor. To compensate the irregularity of pumping power and to bleed any entrapped air bubbles, by-pass line ④ and ball-valve ⑤ are established. In order ot prevent the vibration of the pipe line caused by the pump, a flexible pipe ⑥ is adopted. And an acryl transparent tube ⑦, I.D. of 20mm and a length of 1m was installed to observe the flow conditions before the test section.

Pressure drop measurements were carried out in the horizontal stainless steel pipe test section ⑧, which has an inside diameter of 9.8mm and a length of 3500mm(i.e., $L/D=357$). Two pressure transmitters(with ranges of $0\sim 2\mathrm{kgf/cm^2}$) ⑨ measuring the pressures at both ends of the test section were installed along the pipe axial direction and connected to a FLUKE model 2280B Data Logger ⑩. The flow rates were measured by reading the height of CWM in the flow meter ⑪.

The experiments were carried out at a room temperature (about 25℃), and the temperature of CWM is monitored using a Chromel-Alumel thermocouple(K-type) ⑫, which is also connected to the Data Logger. The temperatures of CWM are regulated by means of a tube heat exchanger ⑬. And water tank ⑭ contains the fresh water to wash out CWM remaining in the pipe.

This experiments were performed at the laboratory of Department of Mechanical Engineering, Inha University.

4. EXPERIMENTAL RESULTS

Figure 2 shows the friction factors for water solution of Polyacrylamides(*PAAM*) at concentration of 200wppm (weight parts per million) in comparison with the Virk's maximum drag reduction asymtotes. The dashed line is the friction factor of Newtonian fluids(pure water without polymer additives) derived from blasius' equation, the solid line shows the virk's maximum drag reduction asymtotes, and the chain line indicated the friction factor for distilled water solution of polyacrly amides obtained in the present study. This figure shows that the friction factors for water solution of *PAAM* are considerably lower than that of pure water and slightly higher than Virk's maximum asymtotes.

Figure 3 indicates the drag reduction for water solution for 200 wppm *PAAM* as a function of Reynolds number. In the beginnig, the drag redction at velocity of 4.36m/sec showed the highest value of 72% but as time passes polymer additives degraded considerably. And after 60 minutes the drag reduction was reduced to 34% which was 49% of the initial drag

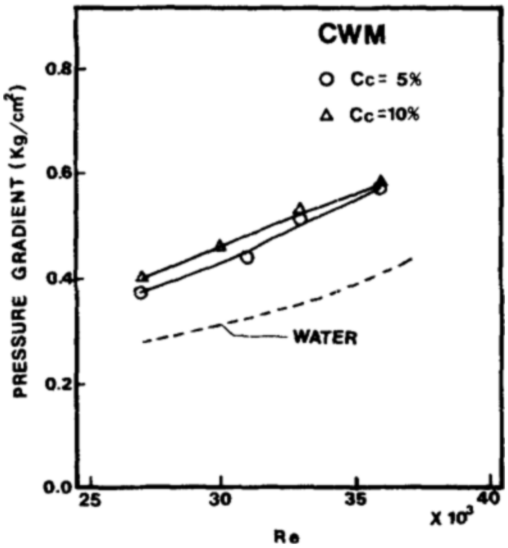


Fig. 2 Friction factor versus reynolds number for water solution of *PAAM* : $c_p=200\mathrm{ppm}$, for a pipe flow

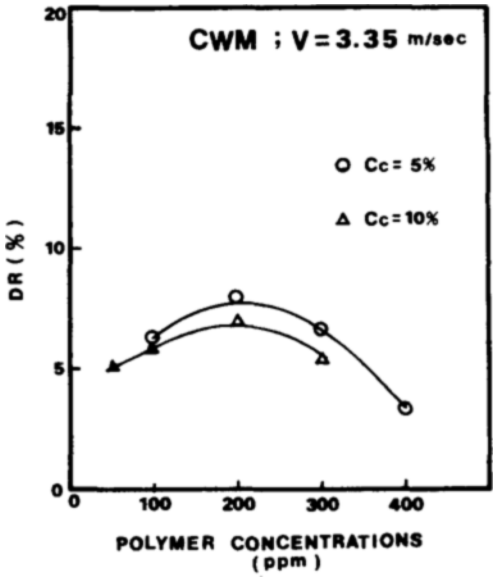


Fig. 3 Drag reduction for water solution of *PAAM* versus trandport time : c_p=200ppm, for a pipe flow

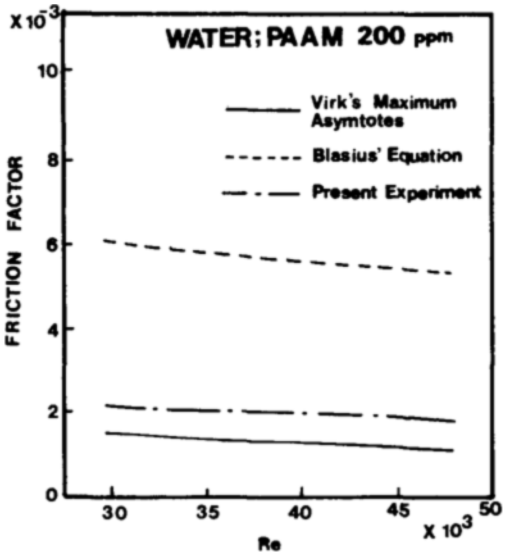


Fig. 4 Pressure gradient versus reynolds number for water and CWM c_c=5% and 10%, for a pipe flow

reduction. However, it was shown that the polyacrlyamides degraded gradually at velocity of 2.72m/sec. Through this experimentation, it was found that the drag reduction increases with increasing Reynolds number and polymer additives degraded faster at higher Reynolds numbers.

Figure 4 shows the pressure drop within the test section for 5% and 10% CWM without polymer in comparison with pure water. The pressure drops of CWM show higher values compared with pure water of dashed line. The pressure drop of c_c=10%, 0.401kgf/cm^2, is 44% higher than that of pure water, 0.279kgf/cm^2, at Reynolds number of 27,000, and for all Reynolds numbers, the pressure drop increased with larger coal concentrations.

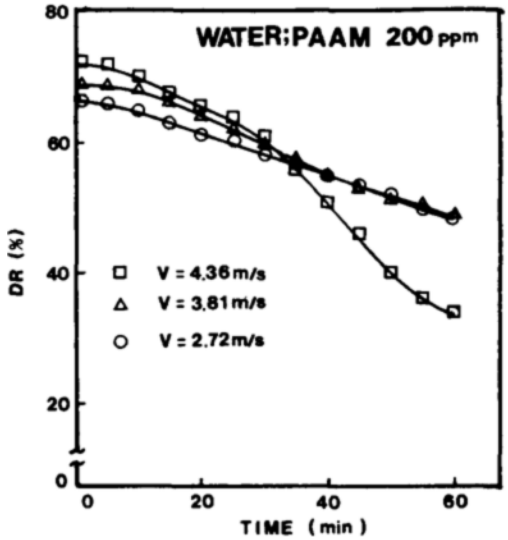


Fig. 5 Influence of coal and polymer concentrations on drag Reduction for CWM at V=3.35m/sec, for a pipe flow

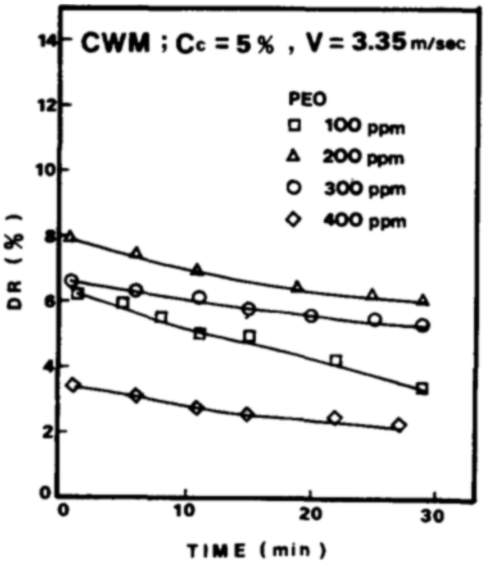


Fig. 6 Drag reduction for various polymer concentrations versus transport time : c_c=5%, V=3.35m/sec, for a pipe flow

The results of the experiments investigating the effect of the polymer and coal concentration on drag reduction for a flow velocity of 3.35m/sec, are shown in Fig. 5. This experiment was carried out by using 5% and 10% CWM with *PEO* additives. The drag reduction increases with increasing polymer concentrations, but at some value it reaches a maximum and with further increases in polymer concentrations only lead to less value of drag reduction. In the present study the maximum drag reduction occurs at 200 wppm. The drag reduction of 10% CWM appears to be lower than that of 5% CWM in the entire range of polymer concentrations.

The decrease in drag reduction of coal water mixture compared with pure water suggests that since the polymer

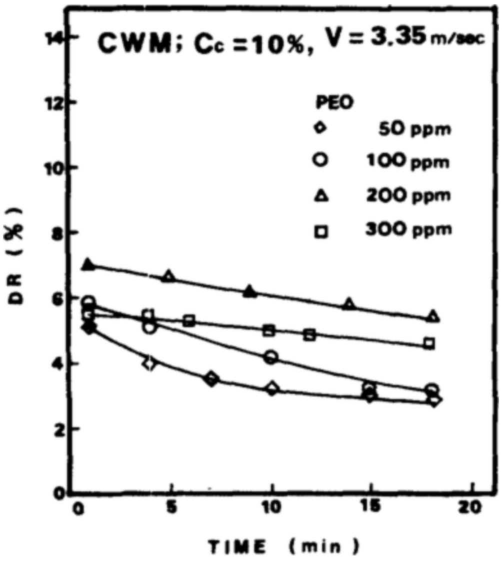


Fig. 7 Drag reduction for various polymer concentrations versus transport time : $c_c=10\%$, $V=3.35$m/sec, for a pipe flow

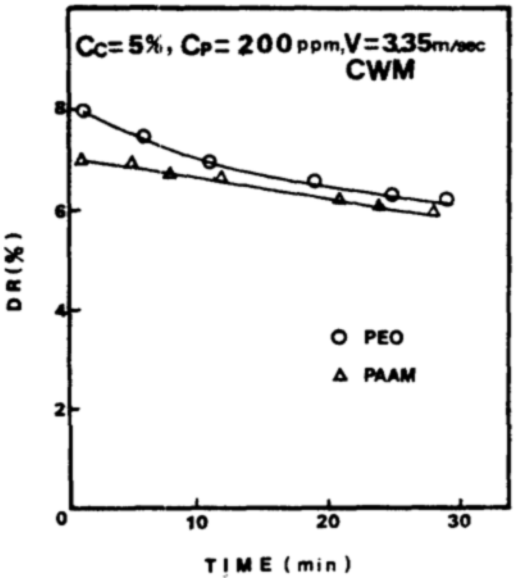


Fig. 8 Drag reduction for *PEO* and *PAAM* versus transport time : $c_p=200$ppm, $c_c=5\%$, and $V=3.35$m/sec, for a pipe flow

additives are flocculants, it is explained that they are adsorbed onto the surface of solids. This adsorption leads to a decrease in the effective concentration of polymer in the pipe and resulting decrease in drag reductions.

Figures 6 and 7 indicate the effect of transport time on drag reduction for four polymer concentrations at 5% CWM and 10% CWM repectively. It was found that the decrease in drag reduction as a result of polymer degradation was more likely at lower polymer concentrations. For a coal concentration of 5% with polymer concentrations of 100wppm and 200wppm, the initial values of drag reduction were 6.3% and 7.9% respectively. After 30 minutes the drag reduction was reduced to 3.5% and 6.1m respectively, i.e. about 56% and 77% of the initial values. Figure 8 shows that in the case of 50wppm polymer concentration the flow was more rapidly degraded than for other values of concentration. It may be due to the polymer degradation caused by a pump blade and pipe connecting parts.

In order to determine the stability of the polymer types, Fig. 8 shows that in the beginning the drag reduction of *PEO* is 13.9% higher than that of *PAAM*. However, *PAAM* appears to be more stable substance than *PEO* in practical applications.

5. CONCLUSIONS

The results of the present investigation to determine the effects of Drag Reduction by polymer additives injected into a coal water Mixture and hydraulic system can be briefly summarized as follows :

(1) As the polymer concentration increases, the drag reduction in a pipe first appears to increasing, and it reaches maximum value where there is no increase in drag reduction. For 5% CWM and 10% CWM, the drag reduction gives maximum values at polymer concentration of 200wppm and further increase in polymer concentration shows even less values of drag reduction.

(2) The drag reducing effect depends not only on the polymer concentration as well as concentration of coal. An increase in coal concentration gives less value of drag reduction. It is shown that the *DR* for 10% CWM is 11.3% lower than that of 5% CWM.

(3) Drag reduction decreases with longer transport time as a result of polymer degradation. It becomes more significant at low polymer concentration and high reynolds numbers. The degradation of the polymer solution is considered to be affected by pump, valves, bends, and pipe connecting parts in the flow system. It was found that *PEO* degraded faster than *PAAM*. *PAAM* is considered to be a more effective additive for trasnportation purpose.

(4) Under the conditions utilized in the present investigation, it is found that the drag reduction of the Coal Water Mixture is considerably lower than that of pure water solution with polymer additives. The effect of drag reduction becomes more apparent with higher polymer molecular weight.

Sufficient drag reduction in much higher rates as demonstrated in other literatures for larger coal particles were not observed in the present investigation. It is considered to be due to the limitations of the pumping power utilized in the present experimentations, which gives Reynolds number approximately up to nly 40,000. In order to see much higher drag reductions in coal water mixture system, it is recommended the Reynolds numbers should be increased for further investigations.

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