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DRAG REDUCTION IN FIRE HOSE
TRIALS AT FIRE SERVICE TECHNICAL COLLEGE 1974
PART 2 ANALYSIS AND APPLICATION OF RESULTS

by

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SUMMARY

Results, previously reported, of trials with a proprietary drag reducing additive for fire fighting water are analysed.

The practical benefits of drag reduction in fire fighting operations are analysed and discussed. The potential applications are seen to be rather more limited under UK fire ground contitions than under US conditions.

Department of the Environment and Fire Offices' Committee
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INTRODUCTION

The results of trials with a proprietary drag reducing additive for water carried out at the Fire Service Technical College by the Fire Research Station in collaboration with the Home Office have been reported[1,2].

It was found that, overall, friction losses in fire hose could be reduced by about 70 per cent for 19 mm hose reel hose, 50 per cent for 44.5 mm and 70 mm hose and 20 to 25 per cent for 89 mm hose. This note analyses the results in more detail and suggests under what circumstances the deployment of drag reducing additives might prove beneficial.

RESULTS OF THE TRIALS

The trials are described in a previous note[1] which included tables showing the detailed results. Briefly, measurements were made of pressure losses along lengths of fire hose as a function of flow rate for water treated with a commercially available drag reducing additive based on polyethylene oxide (PEO) in slurry form, known as Rapid Water Additive (RWA). Trials were made with the additive injected either just downstream of the pump or into the suction inlet of the pump. Hose reel hose (19 mm), 44.5 mm, 70 mm and 89 mm diameter hose were used in lengths to 914 m. Trials were also made with plain water and the results of these, together with a discussion which includes an assessment of the pressure losses contributed by instantaneous hose couplings are published elsewhere[3].

Overall results, in the form of friction factor and Reynolds number have been calculated by non-linear regression analysis and are shown in figs 1 to 4.

DISCUSSION OF RESULTS

1. <u>19 mm hose-reel hose</u> (experiments 1 and 2)

The results for this hose are shown in fig 1 for plain water and RWA Dose 1. In experiment 2 the water flow rate was in the range 45 to 105 l/min (10 to 23 gpm). The RWA injector was operated at its lowest setting, dose 1, 0.19 l/min of RWA. The concentration of RWA was therefore in the range 1800 ppm to 4000 ppm and the concentration of PEO 360 ppm to 800 ppm. This was an unavoidably high concentration, being some ten times greater than the 'design' concentration. The results of experiment 2 should therefore be considered in this light.

For example, concentrations of PEO of this order would increase the viscosity of the water. In order to check this, measurements were subsequently made in the laboratory of the viscosity of solutions of Rapid Water Additive in distilled water using a Brookfield model LVT viscometer. The results are shown in fig 6 for 1800 ppm and 4000 ppm solutions. The viscosity is plotted as a function of shear rate (actually speed of rotation of spindle number 1). It can be seen that the solutions exhibit some non-Newtonian behaviour. It is also known that solutions of PEO exhibit visco-elastic behaviour.

Since the above concentrations would not be used operationally, an analysis of the effect of the non-Newtonian behaviour is not particularly relevant. Explanation of the unexpected shape of the curve correlating the Dose 1 results would involve the variation in viscosity of the treated water with flow rate. This variation is twofold -

a) there is a variation in concentration of additive due to the additive injection rate being constant and the water flow rate varying and

b) the variation of viscosity with shear (flow) rate. The Reynolds numbers used to correlate the results have been calculated (as is usual practice) on the basis of the viscosity of the solvent (water). Correction for the actual viscosity will displace the Reynolds number for each individual run towards lower values by an amount dependant on the particular conditions of each experimental run.

2. 44.5 mm hose (experiments 3 and 4)

The results for this hose are shown in fig 2, for plain water and RWA dose 1. In the dose 1 experiment, the water flow rate was in the range 250-600 l/min; the concentration of RWA varied between 317 and 760 ppm and the effective concentration of PEO from 63 to 152 ppm. This is up to five times the 'design' concentration but would not have seriously affected the results, in contrast to the 19 mm hose results.

Reductions in friction factor of 40 to 45 per cent were measured with the usual decrease in drag reduction effect at higher flow rates. The results do not show any identifiable effect of hose length on drag reduction.

3. 70 mm hose (experiments 5 to 13)

The overall results for this hose are shown in fig 3. In the dose 1 experiments the concentration of slurry ranged from 119 ppm at 1600 l/min to 380 ppm at 500 l/min. The effective concentration of PEO was in the range 24 ppm to 76 ppm. The PEO concentration in the dose 2 (injection rate 0.38 l/min) experiments was 48 to 58 ppm. The curve for dose 1 therefore includes the effect of a three fold increase in effective concentration of PEO. Although the concentration was never less than 24 ppm, a concentration normally regarded as adequate for drag reduction, a more meaningful correlation of the results is obtained if the dose 1 curve up to about 760 l/min is combined with the dose 2 curve. In this way results are seen for effective PEO concentrations in the narrower range of 50-76 ppm. This combination of the results is shown as a dotted line in Fig 3. Hence, if a means of injection were available which ensured a constant additive concentration independent of flow rate, a greater degree of drag reduction could be achieved. This is illustrated in fig 5, in which the percentage drag reduction is plotted against flow rate for the 70 mm hose results together, for comparison, with results obtained by Kresser[6] for 50 mm hose using an injector which is designed to produce a constant additive concentration of 100 ppm.

An experiment was made in which the slurry was injected directly into the suction inlet of a pump. In the other experiments the slurry had not been subjected to mechanical shearing in the pump. It had been claimed that the slurry formulation was more resistant to shear degradation than was a simple aqueous solution of the polymer. The results, figs 3, 5, show that there is a loss in effect (increase in fraction factor) of 5 to 10 per cent with dose 1 (effective PEO concentration 27 to 42 ppm). A smaller decrease in effect would be expected if dose 2 were employed.

Experiments 6, 9 and 11, show some evidence of a length effect, that is a change in pressure loss per unit length with hose length. The flow rates in the experiments did not overlap sufficiently for a detailed analysis to be made of any length effect with flow rate, but at a flow rate of 1000 l/min, the following average pressure losses are seen:

first	183 m (600 ft)	0.29 bar per 30 m
second	" "	0.33 " " "
third	" "	0.37 " " "
fourth	550 m (1800 ft)	0.37 " " "

The corresponding value for plain water is
0.71 bar per 30 m

4. <u>89 mm hose</u> (experiments 14 to 19)

The overall results for this hose are shown in fig 4, for plain water, dose 1 and dose 2. In the dose 1 experiments, the concentration of the slurry varied between 46 ppm at 1750 l/min and 160 ppm at 500 l/min. The corresponding effective concentration of PEO was 10 ppm to 32 ppm. In the dose 2 experiments it was 23 to 28 ppm. Experiments at higher injection rates were not made since preliminary analysis of the results with dose 1 and dose 2 immediately after the experiments showed that the drag reduction was lower than expected (due to the high contribution of the standard couplings to the overall pressure losses).

The concentration of PEO was somewhat marginal in some of the experiments (< 20 ppm). Amalgamation of the curve for dose 2 and the curve for dose 1 up to 10^3 l/min (Re $= 1.8 \times 10^5$) will produce an overall result for which the effective PEO concentration is in the range normally regarded as the minimum required (20 to 30 ppm). This combined result is shown as a dotted curve in fig 4, and indicates an average value for friction factor of 0.0052, or 25 per cent drag reduction compared with plain water.

Further detailed analysis of the results with 89 mm hose is of limited value in view of the relatively high pressure losses presented by the standard instantaneous couplings fitted to the hose. Losses due to turbulence produced by contractions in diameter are not susceptible to reduction by drag reducing additives in the same way as are losses due to skin friction.

A previous report[3] has discussed the contribution of couplings to the pressure losses in 70 mm and 89 mm hoses; in the case of the 89 mm hose contraction losses at standard couplings appear to be of the same order as the skin friction losses in the hose itself.

Large, non-standard instantaneous couplings are sometimes employed with 89 mm hose. These couplings have a straight-through bore and the only contraction is to the internal tail diameter. There is an advantage in the use of such couplings, and no convincing case for the use of drag reduction in water relaying can be made for the 89 mm hose incorporating the standard couplings.

GENERAL

One feature of the commercial system studied which may be a disadvantage under UK conditions, is the method of injection. The injector will deliver the slurry only at one of a number of pre-selectable rates, resulting in a variation of additive concentration with flow rate. With the range of flow rates currently available even at the minimum flow rate, gross overdosing with the 19 mm hose is unavoidable. An alternative type of injector, which ensures a constant concentration of additive would be an advantage. Such a system is being developed and results using it, for a 30 mm hose of German manufacture, have been discussed[2].

Apart from the results for the 19 mm hose reel hose, all the results consistently show a feature which is seen in all work on drag reduction in rough pipes. That is, the gradual reduction in drag reducing effect as Reynolds number (flow rate) is increased above a certain value.

It is generally thought that this is due to the thinning of the boundary layer as flow rate is increased resulting, eventually, in the thickness of the boundary layer being comparable to the height of the protrusions on the wall of the rough pipe. Thereafter, form drag will compete with, and eventually predominate over, the drag reducing processes[2]. In a fire hose, the resistance of the couplings will be an additional factor, particularly in those cases where there is a reduction in the diameter at the coupling[3]. Increasing the concentration of additive will reduce the above effect but not cancel it. The fact that, with a fixed rate of injection, additive concentration will decrease with increase in flow rate, tends to aggravate the situation. Of course, a higher injection rate can be selected above the relevant flow rate, but this would be operationally inconvenient.

The results do not show any consistent systematic hose length effect. Braun[5], using a similar system with a 38 mm hose found that with low flow rates and dose 1, the pressure loss per unit length was higher over the first 30 m than over subsequent lengths (up to 300 m) of hose by a factor of about 2. With 64 mm hose and 'dose 2', the pressure loss over the first 60 m was higher than over subsequent hose lengths (up to 600 m) by a factor of about 3.

The current experiments with 70 mm hose indicate an increase in pressure loss per unit length with length, but a detailed analysis is not possible with the available data.

Application to UK fire-fighting operations

When considering the possible application of Drag Reduction to UK fire-fighting operations, it is necessary to be aware that there are essential differences in fire-fighting styles and equipment between the UK Fire Services and others who are currently employing Drag Reduction, with claimed advantage, eg the Fire Department of New York (FDNY).

Because of their particular problems with manpower and tenement blocks, the FDNY need to use a small (eg 44.5 mm, 1¾ in) diameter hose, in order more easily to negotiate the geography of the buildings they deal with. They also favour relatively large bore nozzles, ie 25 mm (1 inch nominal) and upwards in order to apply large quantities of water quickly to a fire.

The UK fire service, on the other hand, normally uses 70 mm hose ($2\frac{3}{4}$ in) with nozzles of smaller bore, eg 15 mm ($\frac{5}{8}$ inch) to 22 mm ($\frac{7}{8}$ inch). Indeed, there is a tendency, among some brigades at least, to reduce the water application rate to domestic and other small fires by using the more convenient hose reel hose of 19 mm bore, fed from a water tender.

Thus the relative contribution of friction loss in the hose to the overall performance of the hose/nozzle system is generally smaller under UK conditions than under FDNY conditions. This will be illustrated mathematically later.

Generally, broad claims are often made for the use of a Drag Reduction system in fire fighting. For example, typical manufacturer's claims based on US practice might be:

a) Pressure drop in hose is halved, nozzle pressure and jet throw may be doubled.

b) Flow rate increase of 40 per cent for given hose length and pump pressure.

c) Pump pressure reduced by 50 per cent for a given flow rate.

d) Double the length of hose can be used and same flow rate achieved.

e) Use of smaller hose sizes possible, maintaining flow rate.

From a consideration of the hydraulics of a hose/nozzle system, it will be shown that only one of the above claims (d) is generally true. The other claims are valid only under certain specific circumstances, which may assume different relative importance in the UK or elsewhere.

The application of drag reduction to UK fire fighting operations will be assessed using the equations 1, 2, and 3, derived in the Appendix, together with the following values of friction factor.

Hose diameter	Friction factor	
	Plain water	Water treated with DRA
44.5 mm ($1\frac{3}{4}$ in)	0.0045	0.0024
70 mm ($2\frac{3}{4}$ in)	0.0045	0.0023
89 mm ($3\frac{1}{2}$ in)	0.007	0.0052

The assessment will be based on the claims made for the additive, as outlined above.

Equation 1 can be used to test claim a) which is essentially that $P_{N_2} \gg 2P_{N_1}$ when $P_{f_2} \leqslant 0.5\ P_{f_1}$. Simple algebra shows that this is true only if $P_{f_1} \gg \frac{2}{3}P_p$ or $P_N \leqslant \frac{1}{3}P_p$. This will be the case for large bore nozzles at the ends of long lengths of hose but for normal operations using 16 to 22 mm nozzles the advantage will be substantially less.

However, useful increases in nozzle pressure, 'throw' and 'height' of the jet can be achieved. This is illustrated in fig 7 where nozzle pressure, maximum throw and height of jet and flow rate are plotted against pump pressure for a 200 m length of 70 mm hose, terminating in a 25 mm nozzle for both plain water and water treated with PEO. Superimposed on the graph is part of a typical fire pump characteristic curve. In the example shown, with the pump working at full throttle, a throw of 41 m and a height of 33 m are achieved with plain water. In the presence of the additive, the pump performance can climb the characteristic curve and an increased throw of 48 m and height 41 m can be expected. Thus the range of the jet is increased by some 20 per cent: this could be equivalent to three storeys in a building. In addition, the coherence of the jet is somewhat enhanced and the 'fall out' reduced, on a subjective assessment, by some 30 to 50 per cent, due to the additive. These jet effects are incidental to the use of the additive for friction reduction and are not, in themselves, effects worth using the additive specifically to achieve. Better jet performance with plain water can be achieved by the use of modified nozzle profiles.

Equation (3) can be used to test claim b). It can be seen that if f_2 is reduced to 50 per cent of f_1, L_2 will only approach twice L_1 if in both numerator and denominator of the right-hand side of the equation, the term $4000\ f\ l\ d_N^{\ 4}$ is substantially larger than $d_H^{\ 5}$ This will be true for long lengths of hose (high l), small hose diameters (low d_H) - both of which result in large pressure losses in the hose, and large bore nozzles (high d_N) which will call for large flows relative to the capacity of the hose. It will also be true for relaying in which water issues from an open-ended hose, (d_N is effectively equal to d_H).

Similarly, equation (3) can be used to test claim c) and similar arguments to those above show that it will be true only for large l, low d_H, large d_N or relaying operations. Claim d) is however generally true, as seen by inspection of equation 3 for equal flow rates and pump pressures. The principle that the normal size of hose might be replaced by a smaller, lighter, and more manoeuvrable hose in some operations is important.

To illustrate this concept and its practical implications, equation 2 has been plotted in fig 8, for a specific set of conditions. It has been assumed that 70 mm hose, normally used with nozzles between 16 and 22 mm ($\frac{5}{8}$ in and $\frac{7}{8}$ in) might be replaced by 44.5 mm hose using nozzles up to 25 mm diameter. In the graph the pump parameter $L/\sqrt{P_p}$ has been plotted against hose length l, for 70 mm hose using the friction factor (f) for plain water and 44.5 mm hose using the friction factor (f) for treated water. In considering the graph, it is necessary to recall that the pump characteristic curve might well impose a limit on any considered combination of L and P_p. To illustrate the use of fig 8, consider a 180 m length of 70 mm hose terminated by a 16 mm ($\frac{5}{8}$ in) nozzle. The maximum pump parameter for this hose/nozzle combination is 159. This means, for example, that the hose/nozzle would pass 420 l/m at a pump pressure of 7 bar. Figure 8 indicates that the same length of 44.5 mm hose would pass the same flow of water treated with PEO at the same pressure using, instead of the 16 mm nozzle, a 19 mm nozzle. The throw of the water jet thus produced would, of course, be reduced. It is generally true that the 'throw' of a water jet is proportional to the exit velocity of the water (proportional to $\frac{L}{d_N}2$). In order to achieve the same throw with the larger nozzle, the flow rate (L) would have to be increased by $(^{19}/_{16})^2$ a factor of 1.41, to 590 l/min. To maintain the pump parameter at 159 at this higher flow rate the pump pressure should be raised by a factor of $\sqrt{1.41} = 1.19$, say 8.3 bar instead of 7 bar.

One of the real potential applications of drag reduction is in relaying. However, the full benefit can currently only be realised with 70 mm hose relaying. Normally relaying is carried out using 89 mm hose. However, the couplings in this hose when assembled in 23 m (75 ft) lengths represent a substantial portion of the total pressure losses (possibly about 50 per cent). The reduction in friction factor by the use of DRA is consequently only about 25 per cent since the couplings losses are substantially unaffected by the presence of polymer in the water. There seems little point therefore in using Drag Reduction for relaying with 89 mm hose; only a 12 per cent increase in delivery or a 30 per cent increase in length can be achieved.

Relaying with 70 mm hose will benefit however, and the use of Drag Reduction with 70 mm hose will enable about 96 per cent of the plain water flow rate in an equivalent length of 89 mm hose to be achieved. The use of 70 mm hose with only a four per cent reduction in delivery compared with 89 mm hose may be advantageous in some circumstances. In addition, the treated water can be passed through a second pump with a loss of only one-quarter of the normal drag reduction effect in the subsequent hose. The benefits are summarised in the following table and are based on relaying with 107 m of 70 mm hose at a flow of 1590 lm^{-1}.

Number of pumps	Relaying distance (m) with		The distance relayed with treated water would, with plain water, have required:
	Plain water	Treated water	
1	107	267	3 pumps
2, in series	214	366	4 pumps

Although experience in handling polyethylene oxide is its slurry formulation indicated this particular form of the additive was generally convenient to use, the injection equipment was found to have two disadvantages:

1) the lowest injection rate was too high for use with 19 mm hose-reel hose

2) at a given injection rate, the concentration of additive in the water varied with flow rate - this is an inconvenient but not insuperable feature of the system.

Injection equipment which provided a constant concentration of additive even at the lowest flow rates used would be more appropriate to UK conditions and its availability would be a prerequisite for any operational trials. A more realistic assessment of the effect of drag reducing additives in hose-reel hose could only be made with such equipment.

It should be noted that attention given to water relaying hose and its couplings could be beneficial.

If the pressure losses due to the present standard instantaneous couplings could be substantially reduced then water relaying performance could be improved with plain water even beyond that achieved by using drag reduction with 89 mm hose and the standard couplings.

REFERENCES

1. THORNE P F, THEOBALD C R, MAHENDRAN P. Drag Reduction in Fire Hose. Trials at Fire Service Technical College 1974. Part I Experiments and Results, Fire Research Note 1033, 1975.
2. THORNE P F. Drag Reduction in Fire Fighting. Proc. International Conference on Drag Reduction. Cambridge 1974. British Hydromechanics Research Association, 1975, BRE Current Paper CP 70/1975.
3. THORNE P F, THEOBALD C R, MAHENDRAN P. Pressure losses in fire hose, Fire Research Note 1036, 1975.
4. THORNE P F and JORDAN K. Preliminary experiments in the case of water additives for friction reduction in fire hose, Fire Research Note 959, 1973.
5. BRAUN D B. 'An analysis of the effect of UCAR Rapid water additive in Fire-fighting streams'. Union Carbide Corporation Report TSR-73-118.
6. KRESSER A. Private Communication 1974. AEG/Telefunken, Hamburg.

APPENDIX

Hose-nozzle system analysis

Apart from water relaying operations when the water may be discharged directly from an open-ended hose, water is normally discharged from fire hose through a nozzle. The nozzle, as well as the hose, presents a resistance to flow. The total pressure drop across the system comprises two elements:

1) the static pressure loss along the hose $= P_p - P_N$

2) the static pressure drop across the nozzle $= P_N$

where P_p is the pump pressure and P_N the nozzle pressure.

All pressures are, of course, gauge pressures. In the nozzle, the static pressure energy P_N is converted to a velocity head with an efficiency represented by the coefficient of discharge C_D, which for fire service nozzles of traditional design is typically 0.98.

The pressure loss along a length of hose is

$$P_f = \frac{9000\ f\ l\ L^2}{d_H^{\ 5}}$$

$$P_f = P_p - P_N$$

P_f is the pressure loss due to friction, bar

f is friction factor

l is length, m

L is flow rate l min^{-1}

d_H is hose diameter, mm

Therefore

$$P_N = P_p - \frac{9000\ f\ l\ L^2}{d_H^{\ 5}} \qquad (1)$$

The flow through a nozzle is

$$L = \frac{2}{3}\ d_N^{\ 2} . \sqrt{P_N} .$$

d_N is nozzle diameter, mm

The factor $^2/_3$ includes the discharge coefficient.

Combining these to eliminate P_N

$$\left[\frac{L}{\sqrt{P_p}}\right] = \sqrt{\frac{0.44 \quad d_H^5 \, d_N^4}{4000 \quad f \, l \, d_N^4 + d_H^5}} \qquad (2)$$

The left-hand side of this equation contains only pump performance parameters; the right-hand side contains only hose/nozzle system parameters.

For a given hose and nozzle combination, the effects of adding a drag reducing additive can be examined by writing

$$\left[\sqrt{\frac{P_{p_1}}{P_{p_2}}}\right]\left[\frac{L_2}{L_1}\right] = \sqrt{\frac{4000 \quad f_1 \, l_1 \, d_N^4 + d_H^5}{4000 \quad f_2 \, l_2 \, d_N^4 + d_H^5}} \qquad (3)$$

where condition 1 is with plain water
and condition 2 is with water treated with additive.

Equations 1, 2 and 3 enable a full analysis of the effects of adding a drag reducing additive to fire-fighting water to be made.

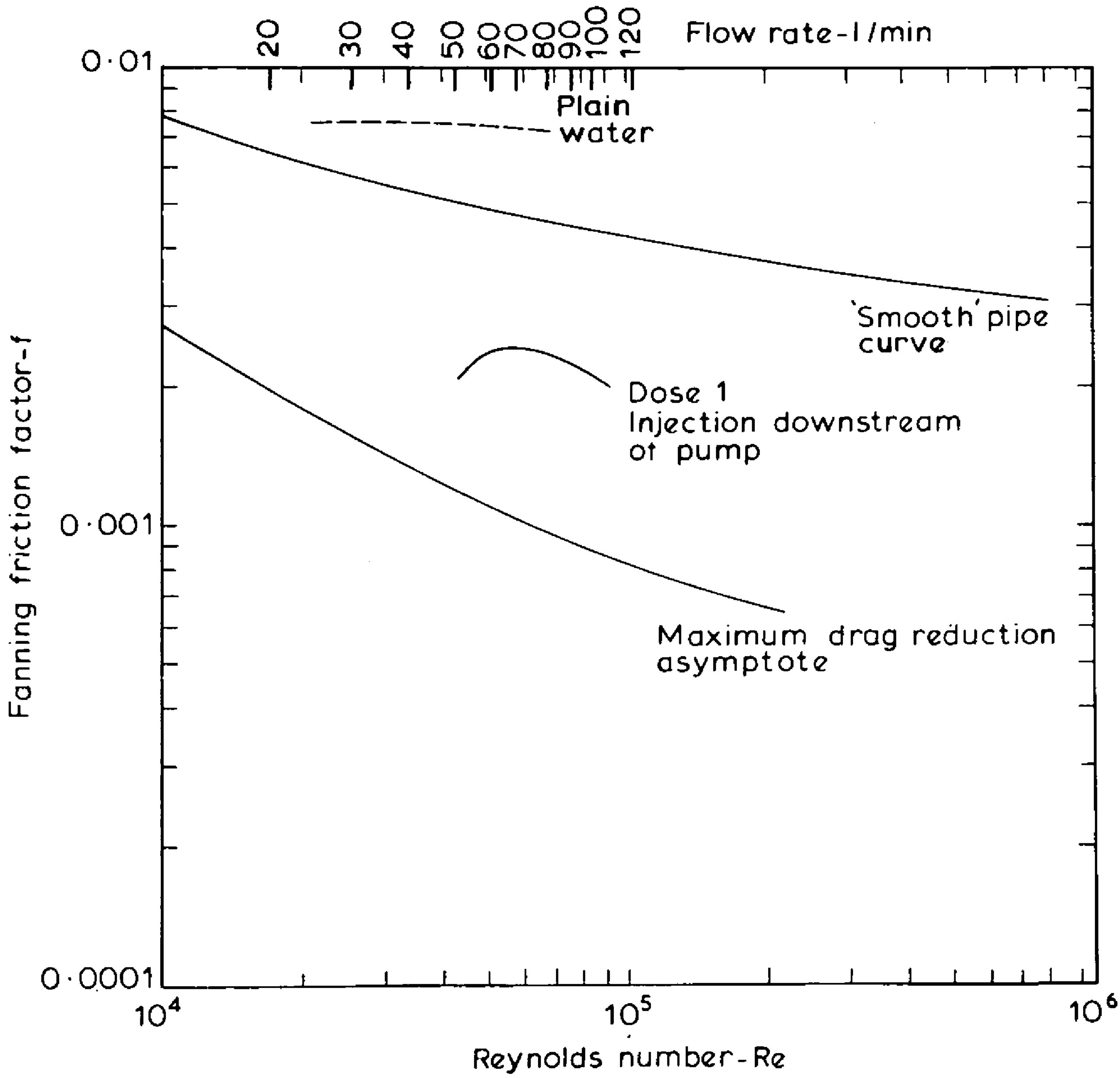


Figure 1 Results for 19mm hose

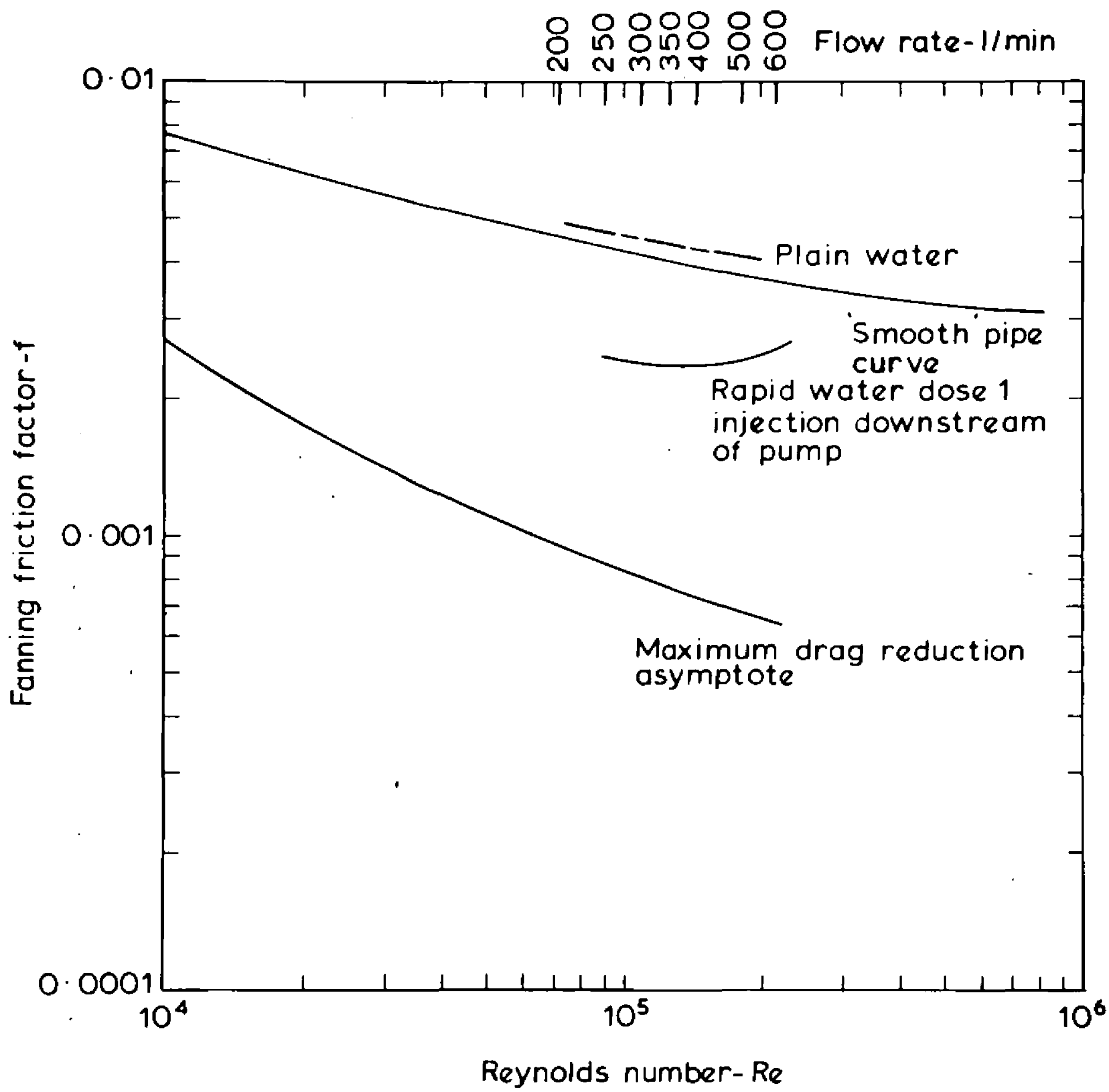
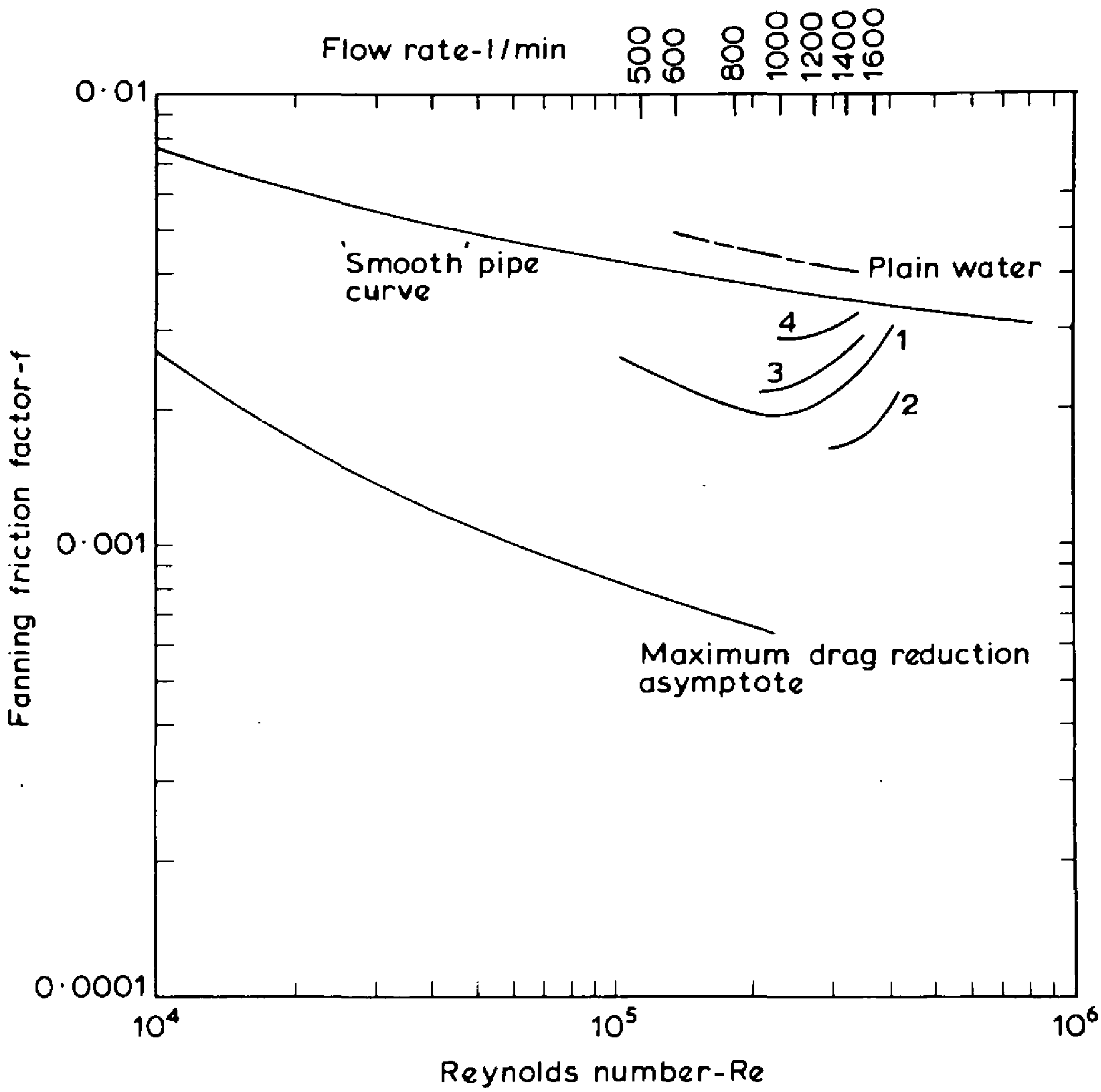


Figure 2 Results for 44·5mm hose



—— Rapid water

Curve 1 Dose 1
injection downstream of pump-hose lengths up to 1100m

Curve 2 Dose 2
injection downstream of pump-hose lengths up to 275m

Curve 3 Dose 1
injection into suction inlet-hose lengths up to 275m

Curve 4 Dose 1
injection into pump, through 275m hose, through second (relay) pump, measurements taken on a second 275m length of hose

Figure 3 Results for 70mm hose

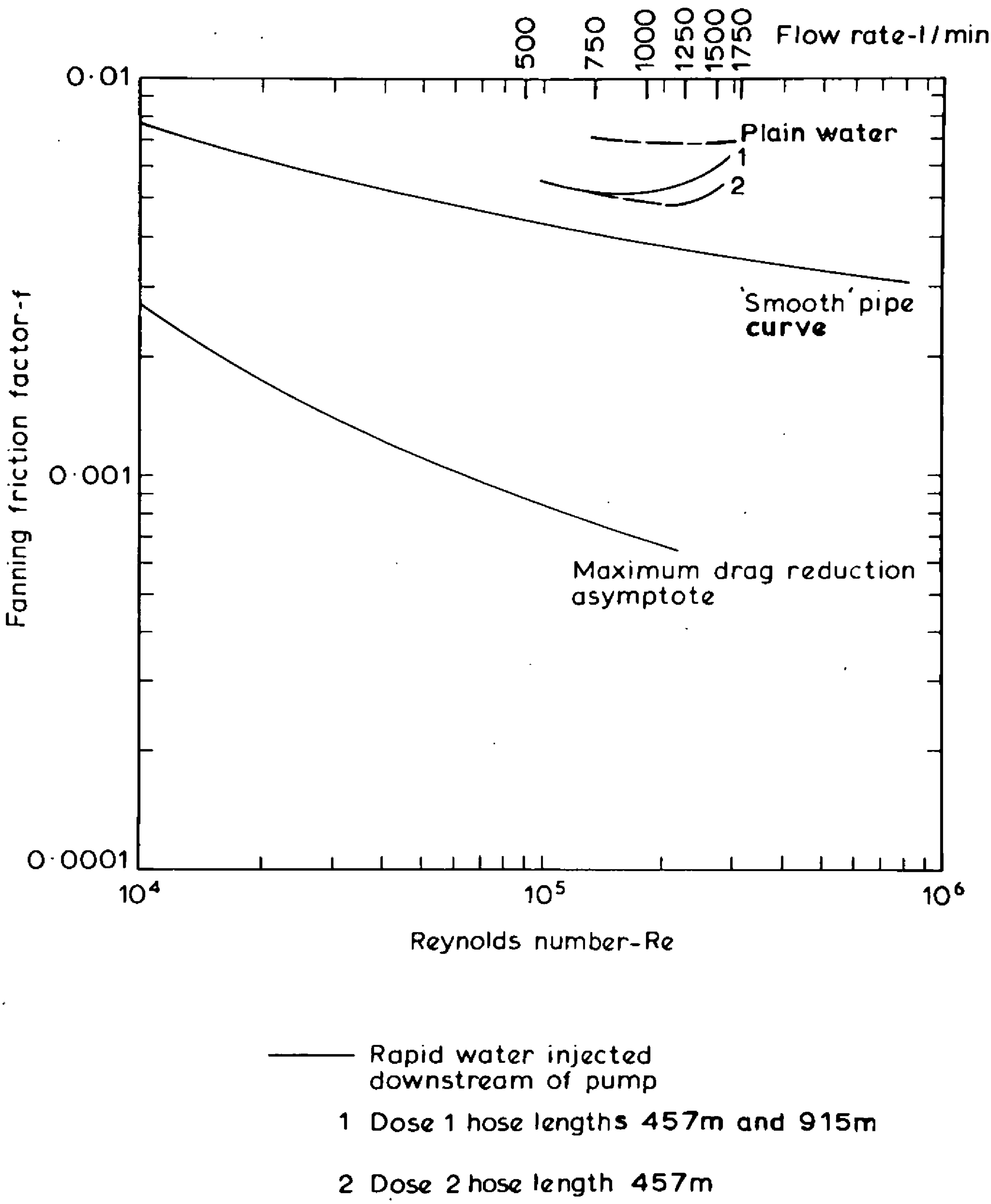
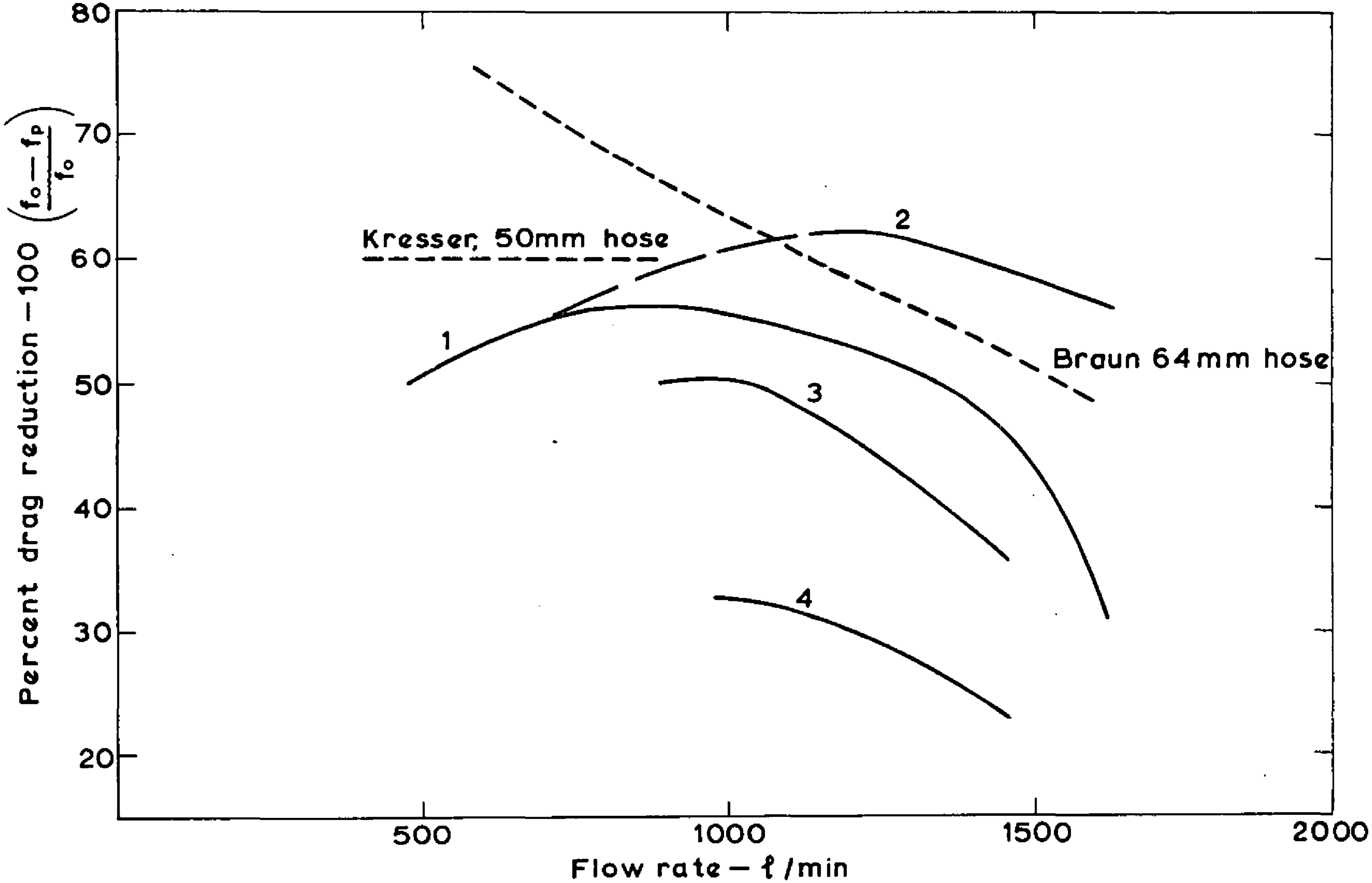


Figure 4 Results for 89mm hose



For identification of curves see figure 3

Figure 5 Summary of drag reduction results for 70mm hose

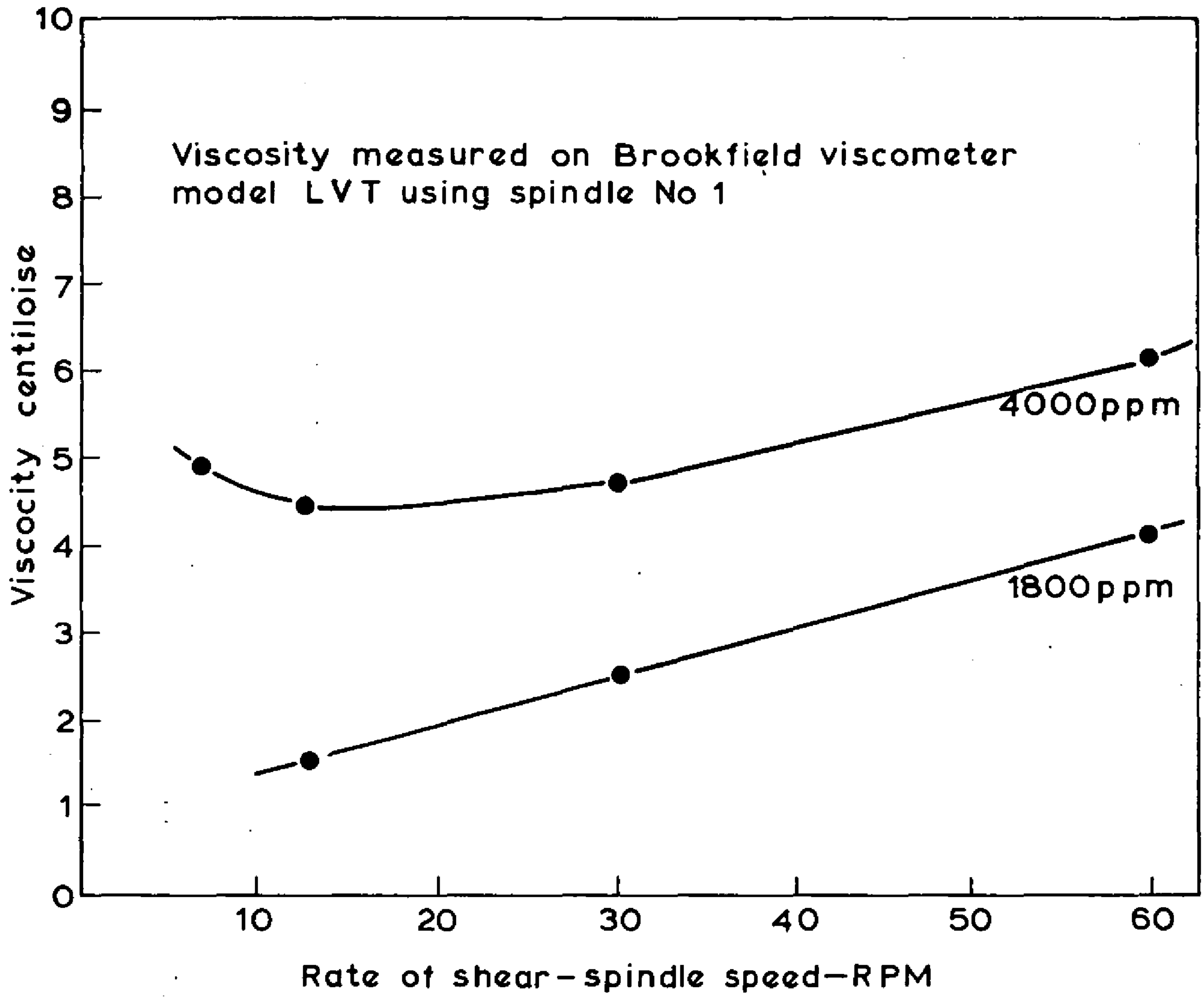
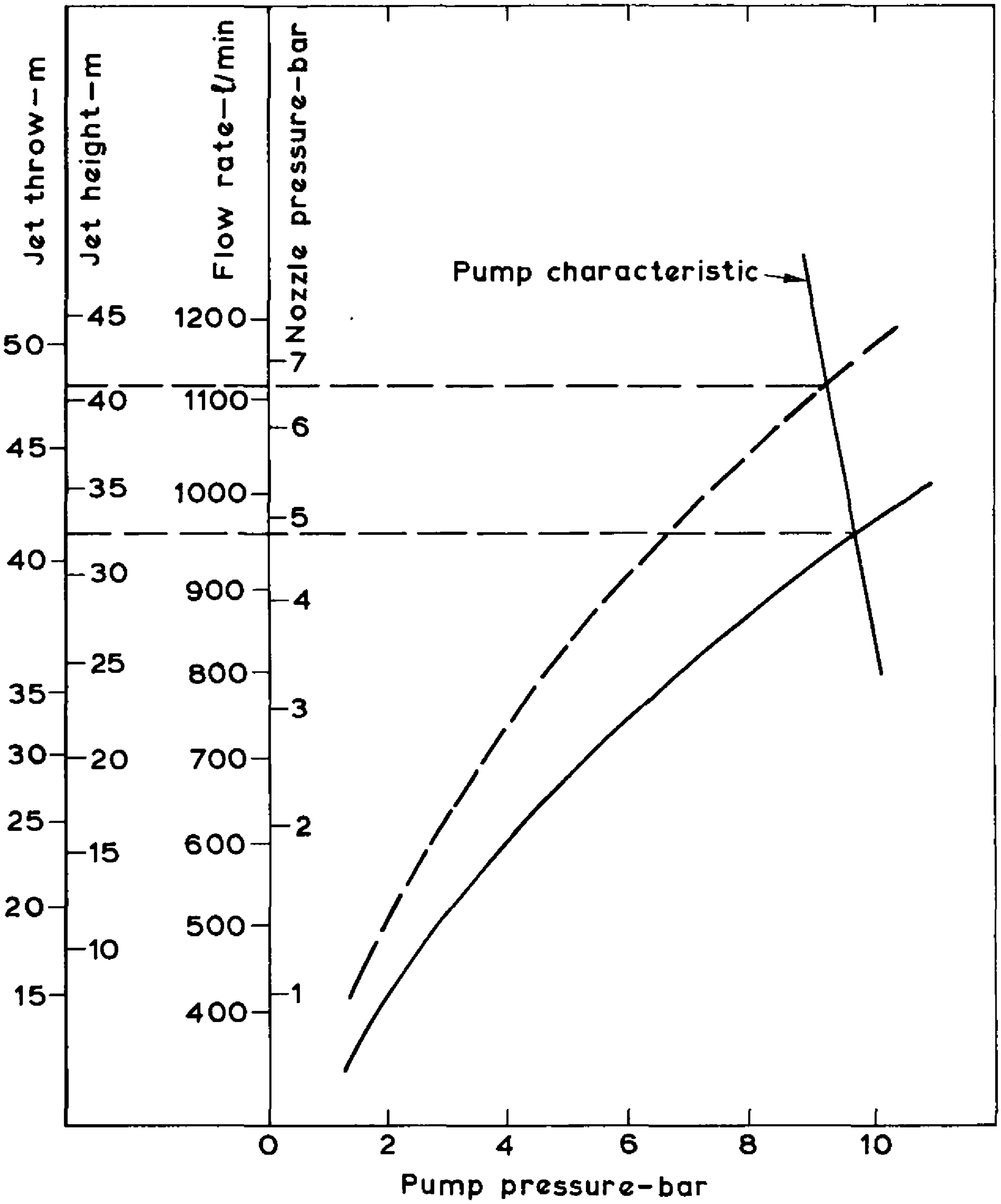


Figure 6 Viscosity of RWA solutions



– – – – Water treated with drag reducing additive f=0·002
——— Plain water f=0·005
Hose diameter 70mm
Hose length 200m

Figure 7 Height and throw of a 25mm jet

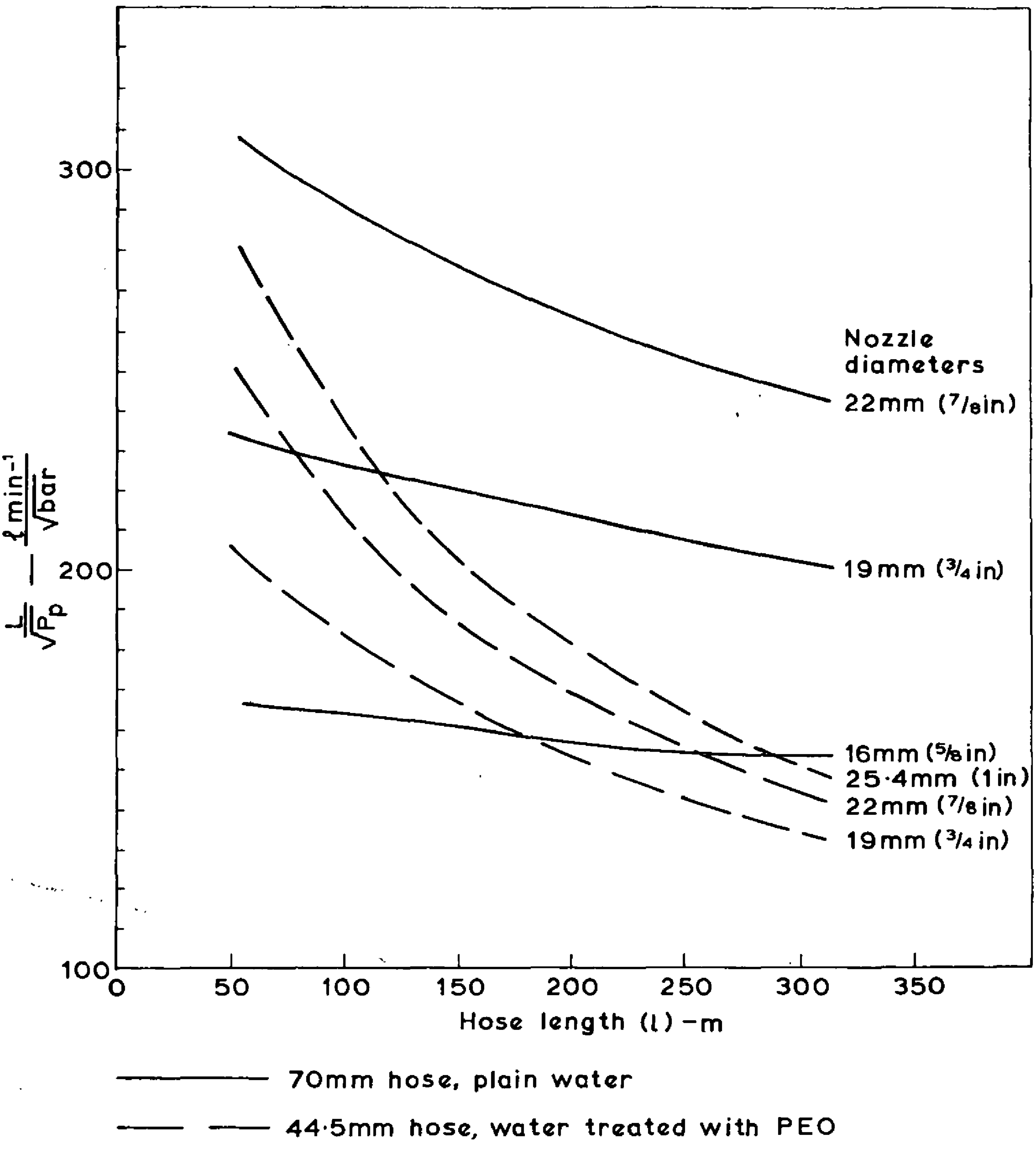


Figure 8 Pump parameter $\left(\frac{L}{\sqrt{P}}\right)$ v hose length (l) for 70mm hose (plain water) and 44·5mm hose (PEO) and various nozzle diameters

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