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May 1975

DRAG REDUCTION IN FIRE HOSE

TRIALS AT FIRE SERVICE TECHNICAL COLLEGE 1974

PART I EXPERIMENTS AND RESULTS

by

P F Thorne, C R Theobald P Mahendran*

SUMMARY

This note describes trials of a commercially-available system for injecting drag reducing additives into fire-fighting water and presents measurements of the friction factors of a range of UK fire hose made using the system.

Reductions were found in friction factor of 70 per cent for $\frac{3}{4}$ inch hose reel hose, 50 per cent for $1\frac{3}{4}$ inch and $2\frac{3}{4}$ inch hose and of 20 per cent for $3\frac{1}{2}$ inch hose.

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Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

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1. INTRODUCTION

Pressure losses caused by friction during the turbulent flow of liquids in pipes can be reduced by the addition to the liquid of trace amounts ($<$ 30 ppm, 0.003 per cent) of 'Drag Reducing Additives'. These additives can be, for example, long chain, high molecular weight, water soluble polymers. One of the most effective and readily available DRA polymers is Polyethylene Oxide (PEO).

The application of the Drag Reduction phenomenon to fire fighting operations has been developed in the US by the Union Carbide Corporation working in conjunction with the Fire Department of New York[1,2]. The application to UK fire fighting operations has been studied and some preliminary measurements of friction factor of fire hose are published[3].

This note described practical trials of a commercially available system for injecting a Drag Reducing Additive based on PEO into fire fighting water, and presents the results of measurements of friction factors of UK fire hose under a wide range of operating conditions. The trials were carried out as a joint venture between the Fire Research Station and the Home Office Fire Department at the Fire Service Technical College Moreton-in-Marsh during April 1974.

A further note is being prepared which will analyse and discuss the results in detail.

2. PRACTICAL SYSTEMS FOR INJECTION OF DRAG REDUCING ADDITIVES INTO FIRE FIGHTING WATER

The first practical system adopted in the US[1] and the system investigated in the UK[3] was based on a premixed solution (ca 1.5 per cent) of PEO in water. This was injected into a hose system just downstream of the pump to give a final c concentration of about 30 to 50 ppm. In the US this type of system was known as 'Slippery Water'.

The 'Slippery Water' system had several practical disadvantages. Dilute solutions of PEO are shear sensitive and pumping can degrade the polymers to such an extent that all Drag Reduction is lost[3]. The additive had to be injected downstream of the pump to avoid shear degradation. The additive had a low concentration, 1 volume being sufficient to treat only 300 volumes of water. Concentrations of PEO in the premix higher than abour 1.5 per cent are impracticab since the viscosity of such solutions is very high ($> 10^4$ cP). A more practical system has recently been developed and has been adopted by the Fire Department of New York. A suspension or slurry of powdered PEO in a water-soluble carrier liquid is injected into the suction inlet of a pump. This system, known as 'Rapid Water', will be described in more detail below.

3. TRIALS AT FIRE SERVICE TECHNICAL COLLEGE

3.1. Objectives

Trials were organised at the FSTC in order to assess the performance of a commercially-available system for injecting a Drag Reducing Additive into water over a wide range of operating conditions. The main result of the trials was to be measurements of the friction factor for UK fire hose in common use as a function of hose diameter ($\frac{3}{4}$ inch to $3\frac{1}{2}$ inch), hose length (up to 3600 ft), additive concentration and point of injection (upstream or downstream of a fire pump). The effect of repumping water treated with the particular additive used, as in water relaying operations, was also investigated.

Details of the particular experiments carried out are listed in Table 1 and described below. In most experiments, the additive was injected downstream of the pump so as to remove the effect of shear degradation in the pump. Some experiments were also made to measure the effect of injection into a pump and the effect of subsequent relaying of treated water by a second pump since it was claimed that the Rapid Water Additive was less susceptable to shear degradation.

3.2. Equipment and experimental arrangements

Static pressure readings were usually taken at each end of the test length of hose and at a number of intermediate points. Flow rates were also measured. From these readings, and knowing the hose lengths involved, friction factors could be calculated. The equipment used and its arrangement is described in detail below, viz:

Hose and its arrangement
Flow measurement
Pressure measurement
Injection equipment and Drag Reducing Additive
Appliances used.

The above arrangements were modified in some experiments. Inspection of figs 1, 2 and 3 will indicate these modifications.

Due to the sloping nature of the test site, before each different experimental arrangement was used, a check was made of the pressure gauge readings with no flow in the hose. The four gauges were read simultaneously at each of two pressure levels, and corrections were calculated.

The normal procedure in an experiment involving injection downstream of the main pump was for a main pump pressure to be set and a number of flow rates set up by controlling the terminating valve, pressures P_1 to P_4 being read, when steady, at each flow rate. This procedure was repeated at a number of main pump pressures. The procedure during other experiments was similar but varied in detail. For example the support pump was not required when injecting into the pump. In the relaying experiment it was important to ensure that the relaying pump inlet pressure (P_R) was always positive to prevent collapse of the first stretch of hose.

3.2.1. Hoses and their arrangement

New 'Duraline' brand $1\frac{3}{4}$ in (44.5 mm), $2\frac{3}{4}$ in (70 mm) and $3\frac{1}{2}$ in (89 mm) hose was used in the trials. BTR brand hose reel hose $\frac{3}{4}$ in (19 mm) diameter was taken from appliances available at the F.S.T.C.

The general arrangement of the hose and equipment is shown in figs 2, 3 and 4.

Normally, the main pump was adjacent to the reservoir. The injector and flowmeter head were about one hose length away, adjacent to a control unit van which served as a base and within which the recorder and digital flow readout connected to the flowmeter were situated. The injector adaptor was connected directly upstream of the flowmeter head. The hose arrangement between the main pump and this equipment was such as to minimise the pressure loss and varied according to the main pump used. When an EP (Emergency pump) was used, a 6 inch hose was connected to the 6 inch outlet ('victaulic' coupling) on the pump. This was terminated by a six way dividing box into one outlet of which the injector/flowmeter pressure tapping was connected.

With other pumps six $3\frac{1}{2}$ inch hoses were fed from the pump to a six way collecting box which was directly coupled to a 6-way dividing box and the injector/flowmeter/pressure tapping assembly connected as before. A secondary pump (normally a water tender) was supplied with water under pressure from the main pump and fed the injector with mixing water at a pressure not less than 20 lb/i (1.3 bar) above P_1.

The test length of hose was laid out along the runway in straig lines or gentle curve as convenient. The test length of hose was terminated by a gate valve coupled directly into the P_4 pressure tapping. It was necessary to immobilise this end of the hose to prevent 'whiplashing' at high flow rates. This was done by securi the pressure tapping to the underside of a wooden pallet and parki a 'minibus' with one wheel resting on the pallet.

3.2.2. Flow measurement

Flow rates were measured by electromagnetic flow meters (Kent Veriflux meters using 3 in and $1\frac{1}{2}$ in detector heads, as appropriate The mA output from these devices could either be passed through a resistance box and the voltage drop displayed directly on a digital voltmeter or recorded on a 0-10mA chart recorder. Both methods were used during the trials. The error in flow rate measurements was typically one per cent.

3.2.3. Pressure measurement

Static pressures were measured on Bourdon tube gauges connected by flexible nylon tubing to piezometer adaptors inserted in the hos line. Generally 0-160 lb/in^2 gauges were used which could be read within 1 lbf/in^2. Two test gauges were also available for use wher appropriate. One 0-60 lbf/in^2, could be read to 0.35 lb/in^2 and the other, 0-120 lbf(in^2), could be read to 0.5 lbf/in^2. The gauge calibrations were checked by 'dead weight' test equipment. The flexible connections were throttled to reduce needle vibration and care was taken to ensure that the flexible tubes were always full of water. The piezometer adaptors were in two sizes. The larger size, fitted with $2\frac{3}{4}$ in instantaneous couplings, was used with $\frac{3}{4}$ in hose. The tappings have notable features; the actual tapping consisted of four $\frac{1}{8}$ in holes drilled all in the same plane of cross section, 90 degrees apart. They were connected together by an exterior channel encircling the pipe and welded to it. The pressure gauge was connected to this channel via the length of nylo tube. In addition, the length of the adaptor was such that the tapping was not less than five diameters downstream of the entry.

3.2.4. Injection equipment and Drag Reducing Additive

The injection equipment developed for the Union Carbide Corporation by the Bendix Corporation is shown schematically in fig.4. A positive displacement pump driven by a variable speed motor can be preset at one of six speeds giving injection rates which are multiples of 0.19 l/min. Each injection rate is held constant, independent of backpressure, by an electronic feedback control system. The slurry is fed to the pump into a small mixing chamber via an electrically-operated valve which opens when the unit is switched on. Mixing water is fed into the mixing chamber and the diluted, partially dissolved slurry flows to the appropriate injection point, which in USA practice is the suction inlet of the pump. Dissolution of the slurry proceeds during passage to the injection pump, during passage through the pump and depending upon conditions, may be completed early in the delivery hose.

The additive

The Rapid Water Additive (RWA) is said by the manufacturer to consist of a suspension of Polyethylene Oxide (molecular weight unspecified) powder in a carrier liquid. The concentration of PEO in this slurry and the composition of the carrier liquid are not stated. The density of the slurry is stated to be 1.23 g/cm^3 and its viscosity 6000 cP, both at $25^{\circ}C$.

3.2.5. Appliances used and water supply

A range of pumping appliances was used, as convenient and as available. They included:

Emergency pump	(EP)
Pump Escape	(PE)
Turntable Ladder	(TL)
Water tender	(WrT)

Generally two appliances were used; one as a main supply pump, the other supplied from the main pump to provide a secondary supply of water at a suitable pressure for the 'Bendix' injector.

Water was drawn by suction from a 100,000 gal tank supplied with freshwater at $10^{\circ}C$.

3.3. Trials procedure

Generally five observers were involved, maintaining contact by personal radio. The duties involved were distributed as follows:

Observer 1 Operate main and secondary pumps and injector as required

Observer 2 Read flowmeter, P. Co-ordinate experiment. Record readings from Observers 3, 4, 5.

Observer 3 Read P_2

Observer 4 Read P_3

Observer 5 Read P_4 , operate control valve at end of hose length.

4. RESULTS

Detailed readings (corrected) are shown in Tables 2 to 20 and the overall results for friction factor are shown plotted against Reynolds number and flow rate in figs. 5 to 8. Also shown on the graphs, for comparison, are correlation of friction factor and Reynolds number for hydraulically 'smooth' pipe for plain water and the 'Maximum Drag Reduction Asymptote' (MDRA) which represents the lowest experimental values of friction factor which have ever been obtained under any conditions, normally with short, small ($<$10 mm) diameter, smooth pipes. There is some variation of friction factor with flow rate and this aspect of the results will be discussed in greater detail in a subsequent publication. The following general results can be stated for the injection of the additive downstream of the pump.

Hose diameter	Friction factor with plain water	Friction factor with Drag Reducing Additive
$\frac{3}{4}$ in, 19 mm	0.0074	0.0022
$1\frac{3}{4}$ in, 44.5 mm	0.0045	0.0024
$2\frac{3}{4}$ in, 70 mm	0.0045	0.0023
$3\frac{1}{2}$ in, 89 mm	0.007	0.0055

The amount of Drag Reduction seen is of the order of 50 per cent for the $1\frac{3}{4}$ in and $2\frac{3}{4}$ in hoses. For $\frac{3}{4}$ in hose it is about 70 per cent but for $3\frac{1}{2}$ in hose the result is disappointing, at about 20 per cent.

Injection of the additive into the suction inlet of the pump results in a reduction of the effect by about five per cent. The passage of treated water through a second (relay) pump reduces subsequent Drag Reduction by about one quarter.

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The trials would not have been possible without the enthusiastic co-operation and assistance of Mr R M Simpson (Inspector) and ADO D W Howard (Assistant Inspector) of the Home Office Fire Department.

REFERENCES

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and BRODY M 'A report on Rapid Water' Fire Chief Magazine pp 19-21 (Feb) 1971.

2. BRAUN D B 'An analysis of the effectiveness of UCAR Rapid Water Additive in fire fighting streams' Union Carbide Report TSR-73-118

3. THORNE P F and JORDAN K 'Preliminary experiments on the use of water additives for friction reduction in fire hose'. Fire Research Note 959 (1973).

TABLE 1

DETAILS OF EXPERIMENTS

Experiment Number	Hose Diameter		Hose Length		RWA Dose	Injection*
	in	mm	ft	m		
1	$\frac{3}{4}$	19	180	54.9	0	
2	$\frac{3}{4}$	19	180	54.9	1	D
3	$1\frac{3}{4}$	44.5	600	182.9	0	
4	$1\frac{3}{4}$	44.5	600	182.9	1	D
5	$2\frac{3}{4}$	70	900	273.4	0	
6	$2\frac{3}{4}$	70	900	273.4	1	D
7	$2\frac{3}{4}$	70	900	273.4	2	D
8	$2\frac{3}{4}$	70	1800	548.8	0	
9	$2\frac{3}{4}$	70	1800	548.8	1	D
10	$2\frac{3}{4}$	70	1800	548.8	2	D
11	$2\frac{3}{4}$	70	3600	109.8	1	D
12	$2\frac{3}{4}$	70	975	297.3	1	P
13	$2\frac{3}{4}$	70	900	274.4	1	P(2)^x
14	$3\frac{1}{2}$	89	1125	343	1(0,2)	D
15	$3\frac{1}{2}$	89	1500	457.3	0	
16	$3\frac{1}{2}$	89	1500	457.3	1	D
17	$3\frac{1}{2}$	89	1500	457.3	2	D
18	$3\frac{1}{2}$	89	3000	914.6	0	
19	$3\frac{1}{2}$	89			1	D

* In this column D denotes injection downstream of the pump, P injection into the pump

x Relaying experiment

TABLE 2

Hose length between gauges 1 and 4 180 ft, 54.9 m

Total hose length 180 ft, 54.9 m

Experiment No 1
Hose dia $\frac{3}{4}$ in, 19 mm
Injection

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	P_{2-1}	P_{3-2}	P_{4-3}	P_{4-1} Overall		
1.1		11.4	51.82	87			30.9				2.12		
1.2		12.5	56.82	104			37.3				2.52		
1.3		14.2	64.55	132			47.9				3.17		
1.4		13.5	61.37	83			3.4				3.00		
1.5		14.7	66.83	98			4.3				3.53		
1.6		16.8	76.37	127			7.4				4.51		
1.7		15.3	69.55	106			6.4				3.76		
1.8		11.5	52.28	88			31.4				2.13		
1.9		11.0	50.00	91.0			40.4				1.91		
1.10		10.0	45.46	93.0			50.9				1.59		
1.11		9.0	40.91	96.0			60.9				1.32		
1.12		6.8	30.91	100.0			81.4				0.70		
1.13		8.0	36.36	98.0			70.9				1.02		
1.14		7.0	31.815	76.0			53.4				0.852		

TABLE 3

Hose length between gauges 1 and 4 180 ft, 54.9 m
Total hose length 180 ft, 54.9 m

Experiment No 2
Hose Dia $\frac{3}{4}$ in, 19 mm
Injection Downstream from pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
2.1	1	19.2	87.28	57.0			8.9				1.82		
2.2		20.5	93.19	63.5			10.4				2.00		
2.3		23.0	104.55	74.0			13.4				2.28		
2.4		17.0	77.28	46.0			7.3				1.46		
2.5		13.3	60.46	63.5			39.9				0.89		
2.6		11.5	52.27	71.5			53.9				0.66		
2.7		9.8	44.55	77			60.4				0.63		
2.8		10.8	49.10	73			57.4				0.59		
2.9		12.7	57.73	67.5			51.9				0.59		
2.10		13.5	61.37	65			46.4				0.70		
2.11		14.8	67.28	77			42.4				1.30		
2.12		15.2	69.10	84.5			50.4				1.28		
2.13		12.3	55.92	89.0			70.9				0.68		
2.14		15.3	69.55	77.5			50.4				1.02		

TABLE 4

Hose length between gauges 1 and 2 150 ft, 45.7 m
2 and 3 300 ft, 91.5 m
3 and 4 150 ft, 45.7 m
Total hose length 600 ft, 183 m

Experiment No 3
Duraline Hose Dia $1\frac{3}{4}$ in, 44.5 mm
Injection -

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
3/1	0	75	340.94	83.5			11				0.820		
3/2	1	67	304.58	83.5			20.25				0.715		
3/3		79	359.13	102.5			25.5				0.871		
3/4		82	372.76	102.5			20.25				0.930		
3/5		91	413.68	102.5			10.0				1.046		
3/6		92	418.23	102.5			5.0				1.103		
3/7		111	504.6	154.5			7.5				1.66		
3/8		112	509.14	153.5			5.0				1.68		
3/9		107	486.42	153.5			19.8				1.512		
3/10		49	222.75	52.5			21.5				0.351		

TABLE 5

Hose length between gauges 1 and 2 150 ft, 45.7 m
2 and 3 300 ft, 91.5 m
3 and 4 150 ft, 45.7 m
Total hose length 600 ft, 183 m

Experiment No 4
Hose Dia $1\frac{3}{4}$ in, 44.5 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
4/1	0	73	331.9	97	80	44.5	27	0.769	0.803	0.792	0.790		
4/2	1	92	418.2	97	83	56	41.2	0.634	0.611	0.669	0.632		
4/3	0	81	368.2	118	97	55.5	33.7	0.95	0.938	0.986	0.953		
4/4	1	99.5	452.3	117	100	67.5	48.5	0.769	0.735	0.856	0.775		
4/7	1	136	618.25	145	110.5	43.5	6.3	1.56	1.515	1.68	1.568		
4/8	1	131	595.5	134	102	40	6.6	1.447	1.402	1.511	1.44		
4/10	1	118	536.4	112	88	41	15.4	1.085	1.063	1.158	1.093		
4/11	1	127	577.3	135.5	106.5	50	18.5	1.311	1.278	1.425	1.323		
4/12	1	131	595.5	135	104	43	10	1.402	1.379	1.492	1.413		
4/13	1	112	509.2	96	73.5	30.5	7.2	1.017	0.973	1.054	1.00		
4/14	1	108	491	96	75.5	35.5	13.6	0.927	0.904	0.99	0.932		
4/15	1	104	472.8	96	78	40	20.6	0.814	0.859	0.877	0.853		
4/16	1	97	441	96	80	48.5	30.6	0.724	0.712	0.809	0.739		
4/17	1	86	391	75	62.5	38.5	24.2	0.565	0.543	0.647	0.575		

TABLE 5 (continued)

Hose length between gauges

Experiment No
Hose Dia
Injection

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
4/18	1	76	345.5	61.5	52.5	33	23.3	0.407	0.441	0.438	0.432		
4/19	1	56	254.6	62.5	57.8	46.5	40.7	0.212	0.255	0.262	0.246		
4/20	1	63	286.4	77.5	71	58.5	50.6	0.294	0.282	0.356	0.304		
4/21	1	76	345.5	78	68.5	49.5	39.2	0.429	0.429	0.465	0.438		
4/22	1	69	313.7	66.5	58	42	33.2	0.384	0.362	0.398	0.376		
4/23	1	106	482	95	75	36.5	14.7	0.904	0.871	0.986	0.908		

TABLE 6

Hose length between gauges 1 and 2 900 ft, 274.4 m
Total hose length 900 ft, 274.4 m

Experiment No 5
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection -

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
5.1	0	272	1237	144	9.5						1.03		
5.2		262	1191	146	20.5						0.96		
5.3		242	1100	148	40						0.83		
5.4		222	1009	122	32.5						0.69		
5.5		200	909	101	26.85						0.57		
5.6		153	696	63	16.75						0.36		
5.7		165	750	62	8.25						0.42		
5.8		111	505	65	40						0.20		
5.9		140	636	63	20.5						0.34		
5.10		121	550	63.5	34.05						0.24		

TABLE 7

Hose length between gauges 1 and 2 300 ft, 91.5 m
2 and 3 300 ft, 91.5 m
3 and 4 300 ft, 91.5 m

Total hose length 900 ft, 274.4 m

Experiment No 6
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
6.1	1	344	1564	133	92	50.5	7.9	0.93	0.94	0.96	0.94		
6.2	1	334	1518	133	98	60.0	21.2	0.79	0.86	0.88	0.84		
6.3	1	326	1482	135	102	67.5	31.5	0.75	0.78	0.81	0.78		
6.4	1	310	1409	138	108	78.0	46	0.54	0.67	0.72	0.69		
6.5	1	294	1337	140	114	86.5	58.5	0.59	0.62	0.63	0.61		

TABLE 8

Hose length between gauges 1 and 2 300 ft, 91.4 m
2 and 3 300 ft, 91.4 m
3 and 4 300 ft, 91.4 m
Total hose length 900 ft, 274.4 m

Experiment No 7
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
7.1	2	376	1709	131	93	50.5	8.6	0.86	0.96	0.95	0.92		
7.2	2	366	1664	132	97	59.5	21.6	0.79	0.85	0.86	0.83		
7.3	2	356	1618	133.5	101	67.5	31.5	0.74	0.76	0.81	0.77		
7.4	2	346	1573	136	105	74.5	42.0	0.70	0.69	0.74	0.71		
7.5	2	320	1455	135	109	82.5	54.0	0.59	0.60	0.64	0.61		

TABLE 9

Hose length between gauges 1 and 2 600 ft, 183 m
2 and 3 600 ft, 183 m
3 and 4 600 ft, 183 m
Total hose length 1800 ft, 549.7 m

Experiment No 8
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection -

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
8.1	0	171	777	153	120	85.0	50.1	0.37	0.40	0.39	0.39		
8.2	0	181	823	152	114	75.0	35.1	0.43	0.44	0.45	0.44		
8.3	0	194	882	150.5	108	65.0	20.6	0.43	0.49	0.50	0.49		
8.4	0	203	923	149.5	104	57.0	7.6	0.51	0.53	0.56	0.54		

TABLE 10

Hose length between gauges 1 and 2 600 ft, 183 m
2 and 3 600 ft, 183 m
3 and 4 600 ft, 183 m

Total hose length 1800 ft, 549 m

Experiment No 9
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
9.1	1	226	1027	94	68	38.5	6.8	0.29	0.33	0.36	0.33		
9.2	1	214	973	96	73	47	19.3	0.26	0.29	0.31	0.29		
9.3	1	197	896	98	78.5	57	33.3	0.22	0.24	0.27	0.24		
9.4	1	184	836	99	82.5	65	45.5	0.19	0.20	0.22	0.20		
9.5	1	162	736	101	88	74	59	0.15	0.16	0.17	0.16		
9.6	1	273	1241	147	104	57	6.25	0.49	0.53	0.57	0.53		
9.7	1	266	1209	149	108	65	17.0	0.46	0.49	0.54	0.50		
9.8	1	252	1146	149	114	75	32.4	0.40	0.44	0.48	0.44		
9.9	1	238	1082	150	120	85	48	0.34	0.40	0.42	0.39		
9.10	1	222	1009	147.5	122	92.5	59.1	0.29	0.33	0.38	0.33		

TABLE 11

Hose length between gauges 1 and 2 600 ft, 183 m
2 and 3 600 ft, 183 m
3 and 4 600 ft, 183 m
Total hose length 1800 ft, 549 m

Experiment No 10
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
10.1	2	278	1264	147.5	106	58	5.5	0.47	0.54	0.59	0.54		
10.2		266	1209	149.5	112	69	30.6	0.42	0.49	0.55	0.49		
10.3		246	1118	152.5	119	84	42.6	0.38	0.40	0.47	0.41		
10.4		228	1036	154.5	127	945	60.1	0.31	0.37	0.39	0.36		
10.5		150	662	104.5	91	77	60.1	0.15	0.16	0.19	0.17		
10.6		186	846	99.5	78	58	35.4	0.24	0.23	0.26	0.24		
10.7		106	482	78.0	72	67	59.1	0.067	0.056	0.089	0.071		
10.8		160	727	76.5	64	51	37.1	0.14	0.15	0.16	0.15		
10.9		200	909	72.5	54	34.5	14.5	0.21	0.22	0.23	0.22		

TABLE 12

Hose length between gauges 1 and 2 1800 ft, 548.8 m
2 and 3 1200 ft, 365.9 m
3 and 4 600 ft, 182.9 m
Total hose length 3.600 ft, 1097 m

Experiment No 11
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
11.1	1	155	705	105	57.5	26	11.6	0.18	0.18	0.16	0.18		
11.2	1	173	786	125.5	68	28	8.4	0.22	0.23	0.22	0.22		
11.3	1	185	841	143	75	28.5	5.5	0.26	0.26	0.26	0.26		
11.4	1	200	909	163	85	32	5.5	0.29	0.29	0.3	0.3		
11.5	1	125	568	85.5	49	20	6.0	0.16	0.14	0.16	0.15		
11.6	1	100	455	66.5	45.5	30.5	23	0.079	0.084	0.084	0.082		

TABLE 13

Hose length between gauges 1 and 2 75 ft, 22.9 m
2 and 3 450 ft, 137.2 m
3 and 4 450 ft, 137.2 m
Total hose length 975 ft, 297.2 m

Experiment No 12
Hose Dia $2\frac{3}{4}$ in, 70 m
Injection Into pump

Run No	RWA dose rate	Flow rate gal/min	Flow rate l/min	Corrected pressure gauge readings (lbf/in^2) P_1	P_2	P_3	P_4	Pressure loss per 30 m (bar) ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall	Reynolds Number Re	Overall Friction factor f
12.1	1	268	1218	89	79	44	8.2	0.90	0.53	0.54	0.55		
12.2	1	257	1168	93	83.5	52.5	19.5	0.860	0.47	0.49	0.51		
12.3	1	243	1105	97	88.0	60.5	30.7	0.82	0.42	0.45	0.46		
12.4	1	232	1055	99	92.0	67	40.5	0.63	0.38	0.40	0.41		
12.5	1	218	991	102	94.5	73.5	50.5	0.68	0.32	0.35	0.36		
12.6	1	298	1355	148	135.5	88.5	40.0	1.13	0.71	0.73	0.75		
12.7	1	300	1364	147	133	83.0	31.0	1.27	0.75	0.78	0.81		
12.8	1	313	1423	144	131	75.5	20.0	1.18	0.84	0.84	0.86		
12.9	1	321	1459	142	126	69.5	10.0	1.45	0.85	0.89	0.92		
12.10	1	324	1473	140	124	66.5	5.6	1.45	0.87	0.92	0.94		
12.11	1	257	1168	79.5	69.5	37.5	3.3	0.91	0.48	0.52	0.53		
12.12	1	242	1100	83.0	75.0	46.0	15.7	0.72	0.44	0.46	0.47		
12.13	1	224	1018	88.0	80.0	56.1	30.2	0.73	0.36	0.39	0.41		
12.14	1	203	922	92.0	85.0	66.5	45.5	0.63	0.28	0.32	0.32		

TABLE 13 (continued)

Hose length between gauges 1 and 2 75 ft, 22.9 m
2 and 3 450 ft, 137.2 m
3 and 4 450 ft, 137.2 m
Total hose length 975 ft, 297.3 m

Experiment No 12
Hose Dia $2\frac{3}{4}$ in, 70 mm
Injection Into pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
12.15	1	182	827	96.0	91.0	76.0	59.5	0.45	0.23	0.25	0.26		
12.16	1	145	659	61.5	58.5	50.0	39.8	0.27	0.13	0.15	0.15		
12.17	1	185	841	55.0	49.0	35.0	19.8	0.54	0.21	0.23	0.25		
12.18	1	207	941	50.0	44.0	25.0	4.8	0.54	0.29	0.31	0.31		

TABLE 14

Hose length between gauges P and R 900 ft, 274.4 m
1 and 2 450 ft, 137.2 m
2 and 3 450 ft, 137.2 m

Total hose lengths 900 ft, 274.4 m between primary and relay pumps
900 ft, 274.4 m after relay pump

Experiment No 13
Hose dia $2\frac{3}{4}$ in, 70 mm
Injection Into primary pump

Run	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)					Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_P	P_R	ΔP_{2-1}	ΔP_{3-2}	ΔP_{3-1} overall	ΔP_{P-R}		
13.1	1	212	963	64	35	6.3	53	6.0	0.41	0.43	0.44	0.35		
13.2	1	227	1032	72	39	6.8	61	9.0	0.50	0.49	0.49	0.39		
13.3	1	257	1168	94	50.5	8.3	82	11.0	0.66	0.64	0.65	0.54		
13.4	1	278	1264	118	64	9.9	101	10	0.81	0.82	0.82	0.69		
13.5	1	303	1377	142	77	11.5	121	9	0.98	0.99	0.98	0.84		
13.6	1	322	1464	162	88	12.9	152	21	1.12	1.13	1.12	0.99		
13.7	1	275	1250	115.5	66	16.1	83	3	0.75	0.75	0.75	0.60		
13.8	1	298	1355	123.5	65.5	6.2	104	8.5	0.88	0.89	0.88	0.72		
13.9	1	307	1396	131	69	6.4	121	18.5	0.94	0.94	0.94	0.77		
13.10	1	315	1432	139	74.5	6.7	141	30.0	0.97	1.02	1.00	0.84		
13.11	1	320	1455	144	76.5	6.9	152	36.0	1.02	1.04	1.03	0.88		
13.12	1	217	986	71	40	10.7	52.5	2	0.47	0.44	0.46	0.38		

TABLE 15

Hose length between gauges 1 and 2 300 ft, 91.5 m
2 and 3 525 ft, 160 m
3 and 4 300 ft, 91.5 m
Total hose length 1125 ft, 343 m

Experiment No 14
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate gal/min	Flow rate l/min	Corrected pressure gauge readings (lbf/in^2) P_1	P_2	P_3	P_4	Pressure loss per 30 m (bar) ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall	Reynolds Number Re	Overall Friction factor f
14.1	0	340	1546	142.5	107	47	8.7	0.80	0.78	0.87	0.81		
14.2	1	375	1705	137.5	105	48	10.74	0.74	0.85	0.85	0.77		
14.3	1	400	1818	157.5	120	55	11.5	0.85	0.84	0.98	0.88		
14.4	1	355	1614	147.0	118	66.5	32.3	0.66	0.67	0.77	0.69		
14.5	1	327	1487	149.5	124.5	81.0	51.8	0.57	0.56	0.66	0.59		
14.6	1	398	1809	156	119.5	54	11.5	0.85	0.85	0.96	0.87		
14.7	2	408	1855	154	119	55	12.0	0.79	0.83	0.97	0.86		

TABLE 16

Hose length between gauges 1 and 2 300 ft, 91.5 m
2 and 3 900 ft, 274.4 m
3 and 4 300 ft, 91.5 m

Experiment No 15
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection -

Run No	RWA dose rate	Flow rate gal/min	Flow rate l/min	Corrected pressure gauge readings (lbf/in^2) P_1	P_2	P_3	P_4	Pressure loss per 30 m (bar) ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall	Reynolds Number Re	Overall Friction factor f
15.1	0	315	1432	154.25	123.5	35	6.4	0.70	0.67	0.65	0.67		
15.2		295	1341	146.25	119.5	41	15.5	0.61	0.60	0.58	0.59		
15.3		279	1268	148.25	123.5	54	30.8	0.56	0.52	0.53	0.53		
15.4		266	1209	149.25	126.5	62.2	41.1	0.51	0.48	0.48	0.49		
15.5		242	1100	150.75	132.0	78.5	60.3	0.42	0.40	0.41	0.41		
15.6		194	882	100.75	88.0	51.1	39.6	0.29	0.27	0.28	0.28		
15.7		176	800	101.25	90.5	60.8	50.6	0.24	0.22	0.23	0.23		

TABLE 17

Hose length between gauges 1 and 2 300 ft, 91.5 m
2 and 3 900 ft, 274.4 m
3 and 4 300 ft, 91.5 m

Total hose length 1500 ft, 457.3 m

Experiment No 16
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
16.1	1	207	941	99.25	89	59.5	47	0.23	0.22	0.28	0.24		
16.2	1	238	1082	96.75	83.5	45.0	30	0.30	0.29	0.34	0.30		
16.3	1	266	1209	94.25	77.5	28.5	10.9	0.38	0.37	0.40	0.38		
16.4	1	330	1500	147.25	111.5	34.0	7.2	0.81	0.58	0.61	0.63		
16.5	1	317	1441	149.25	111.5	45.5	20.5	0.76	0.53	0.57	0.58		
16.6	1	290	1318	142.25	122.5	64.0	42.4	0.45	0.44	0.49	0.45		
16.7	1	278	1264	143.75	125	71.5	51.9	0.42	0.40	0.44	0.42		

TABLE 18

Hose length between gauges 1 and 2 300 ft, 91.5 m
2 and 3 900 ft, 274.4 m
3 and 4 300 ft, 91.5 m
Total hose length 1500 ft, 457.3 m

Experiment No 17
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
17.1	2	338	1537	146.25	112	35	7.6	0.77	0.58	0.62	0.63		
17.2	2	273	1241	144.25	128	78.5	60.4	0.37	0.37	0.41	0.38		
17.3	2	316	1437	139.75	118.5	54	31	0.48	0.49	0.52	0.49		

TABLE 19

Hose length between gauges 1 and 2 600 ft, 183 m
2 and 3 1800 ft, 548.8 m
3 and 4 600 ft, 183 m
Total hose length 3000 ft, 914.6 m

Experiment No 18
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection -

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
18.1	0	218	991	143.5	115	30.5	4.1	0.32	0.32	0.30	0.32		
18.2	0	204	927	145	120	45.5	22.25	0.28	0.28	0.26	0.28		
18.3	0	187	850	146	124.5	62.5	41.3	0.24	0.23	0.24	0.24		
18.4	0	174	791	147.5	127.5	71.5	53.25	0.23	0.21	0.21	0.21		
18.5	0	165	750	147.5	129	78.5	61.5	0.21	0.19	0.19	0.20		

TABLE 20

Hose length gauges 1 and 2 600 ft, 183 m
2 and 3 1800 ft, 548.8 m
3 and 4 600 ft, 183 m
Total hose length 3000 ft, 914.6 m

Experiment No 19
Hose Dia $3\frac{1}{2}$ in, 89 mm
Injection Downstream of pump

Run No	RWA dose rate	Flow rate		Corrected pressure gauge readings (lbf/in^2)				Pressure loss per 30 m (bar)				Reynolds Number Re	Overall Friction factor f
		gal/min	l/min	P_1	P_2	P_3	P_4	ΔP_{2-1}	ΔP_{3-2}	ΔP_{4-3}	ΔP_{4-1} overall		
19.1	1	242	1100	141.5	117	35.5	6.5	0.28	0.31	0.33	0.31		
19.2	1	238	1082	142	117.5	38.5	11.7	0.28	0.30	0.30	0.29		
19.3	1	230	1046	143	120	47.5	22.3	0.26	0.27	0.29	0.27		
19.4	1	210	955	144	125	63	41.3	0.21	0.23	0.25	0.23		
19.5	1	188	855	145.5	130	79.5	61.7	0.18	0.19	0.20	0.19		
19.6	1	153	696	98.0	87.5	53.5	51.25	0.12	0.13	–	0.11		
19.7	1	166	755	97.0	85	450	30.7	0.14	0.15	0.16	0.15		
19.8	1	118	536	99	92	69.5	61.5	0.079	0.085	0.090	0.085		

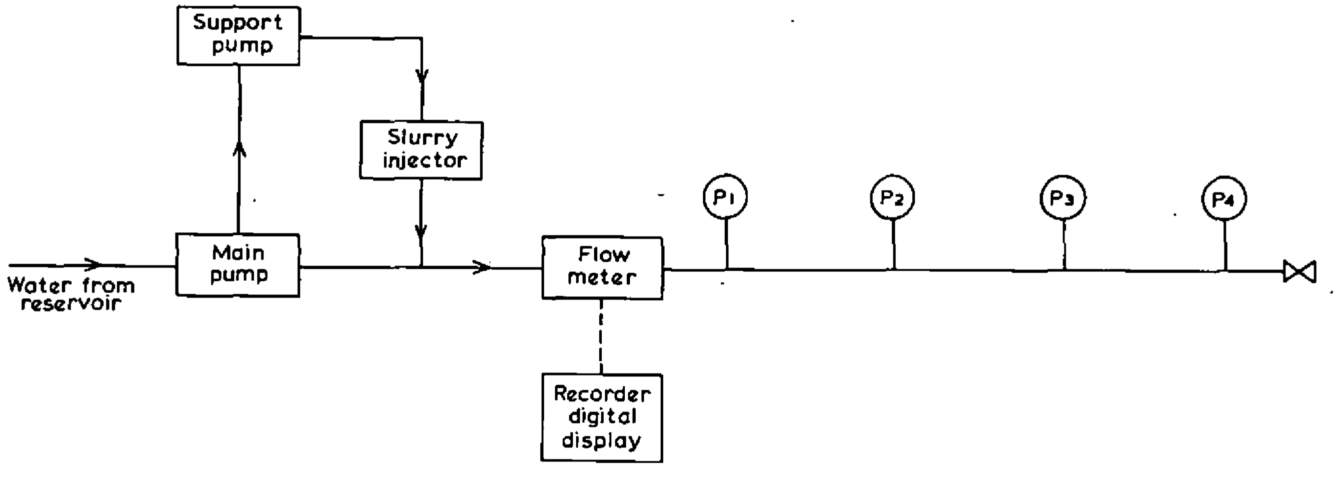

Figure 1 Schematic arrangement of equipment for tests involving injection of slurry downstream of pump

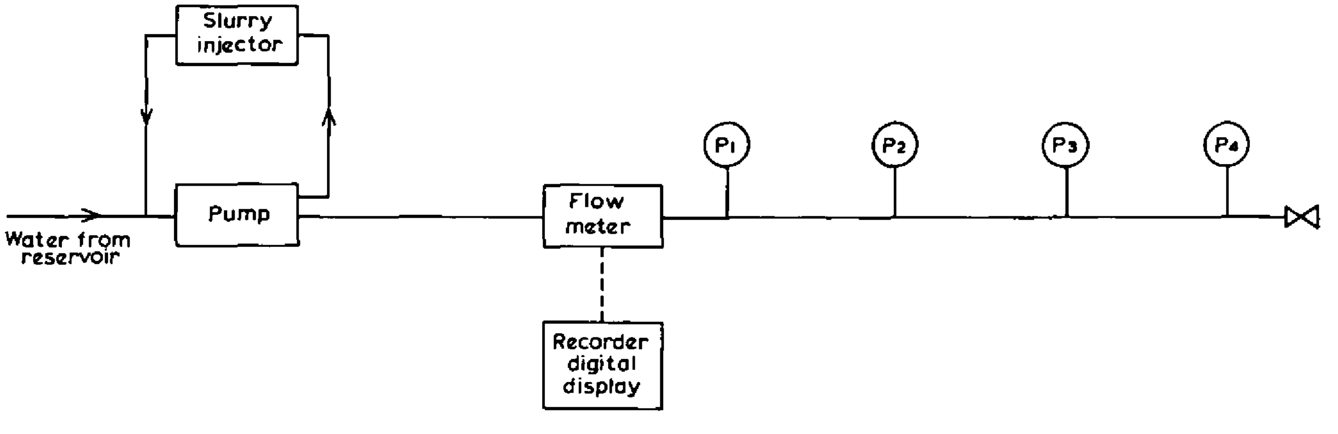

Figure 2 Schematic arrangement of equipment for tests involving injection of slurry into pump

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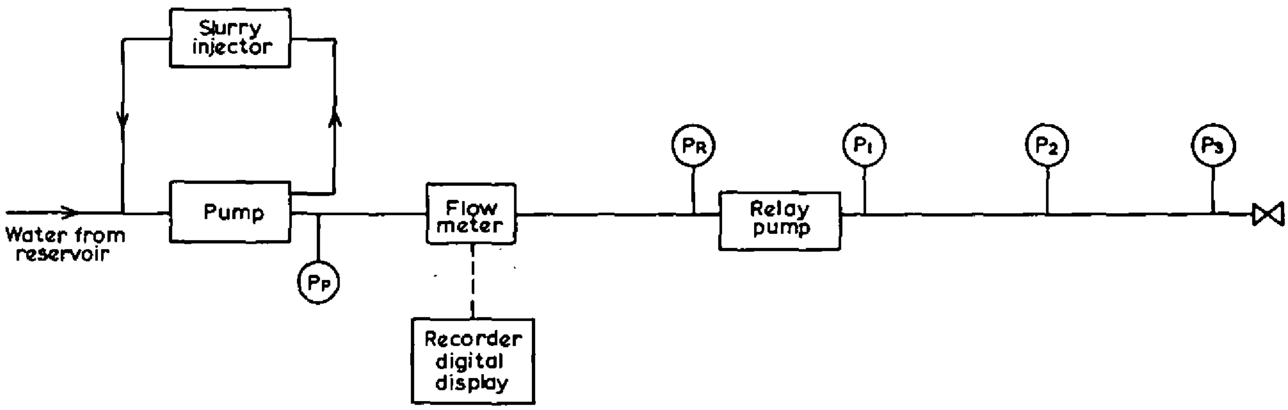


Figure 3 Schematic arrangement of equipment for tests involving relaying of treated water

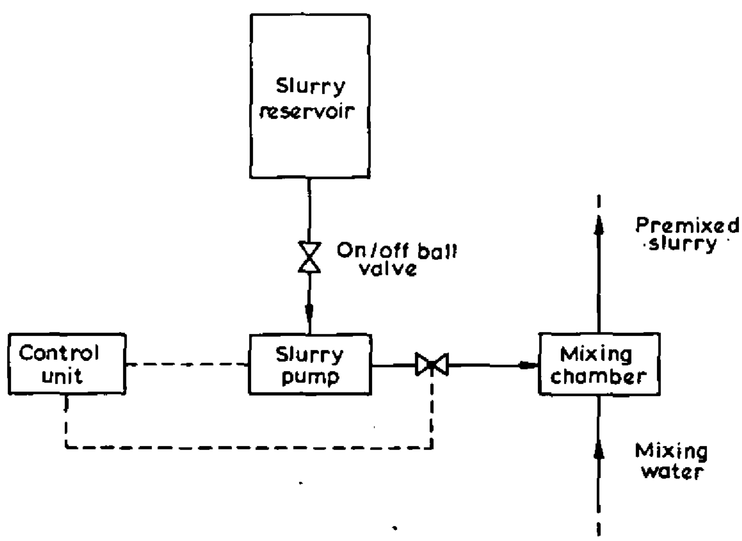


Figure 4 Schematic arrangement of slurry injector

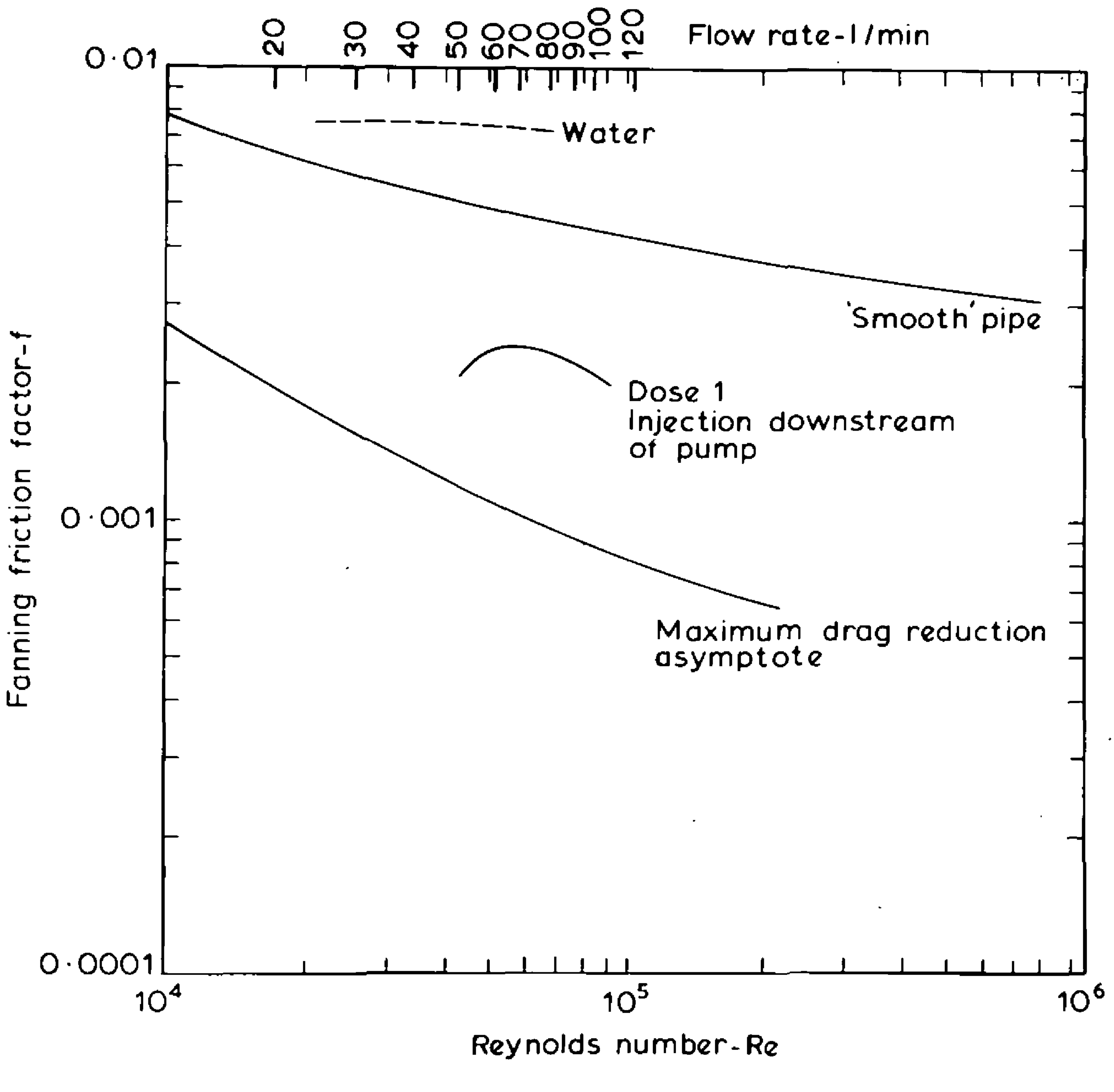


Figure 5 Summary of results for 3/4 in hose

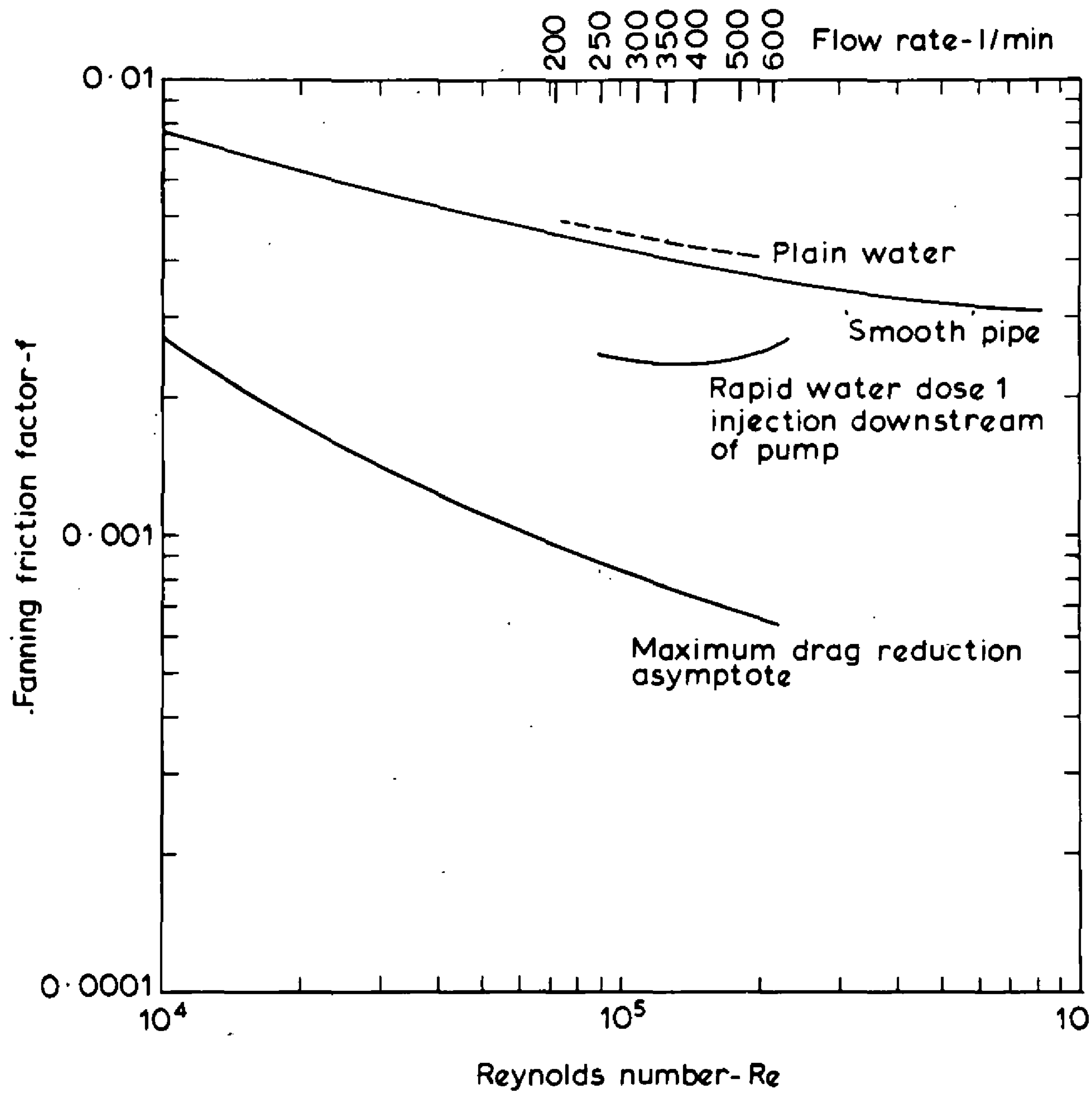
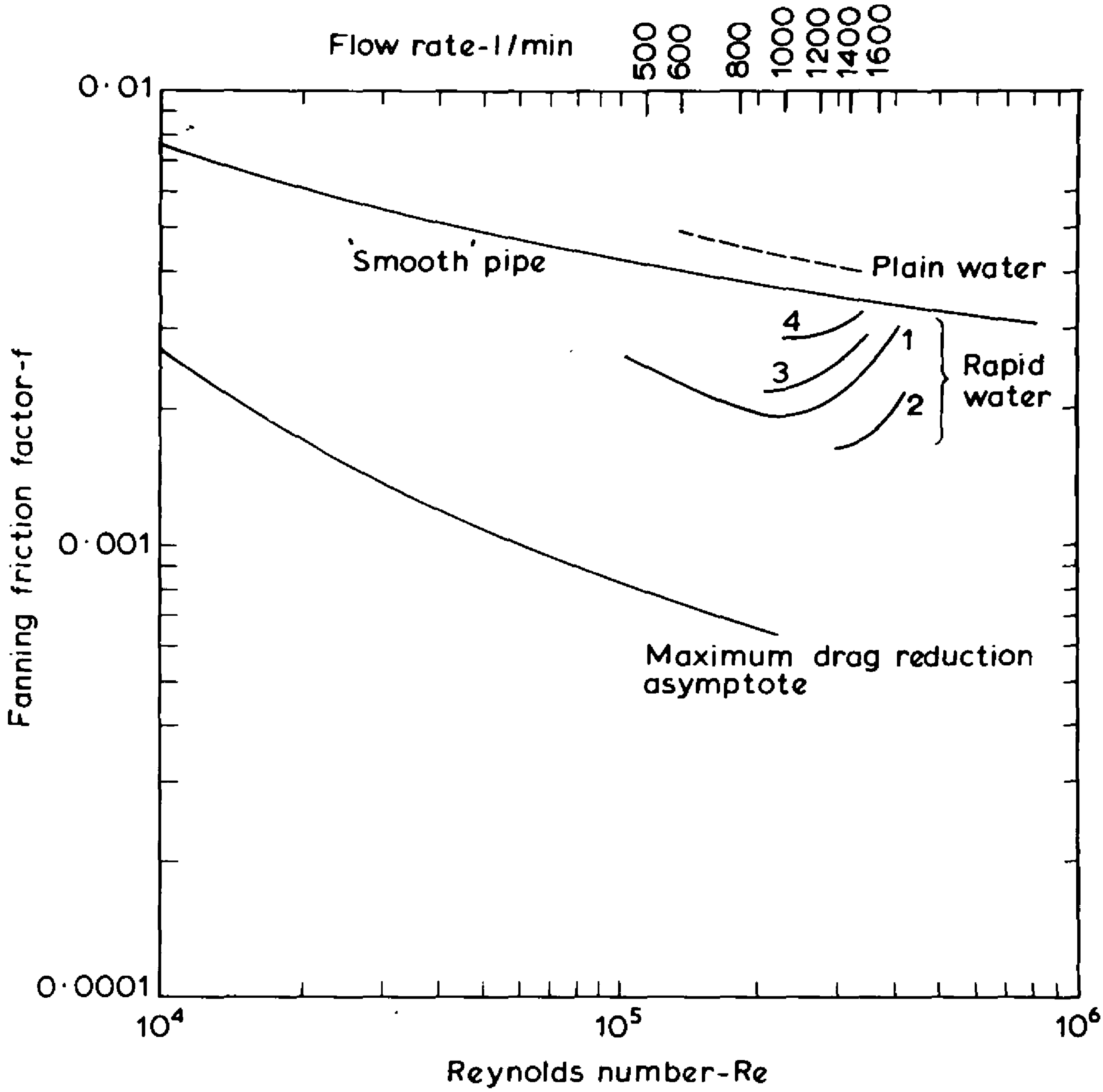


Figure 6 Summary of results for 1 3/4 in hose

13729 F.R.1033



1 Dose 1
injection downstream of pump-hose lengths up to 3600 ft

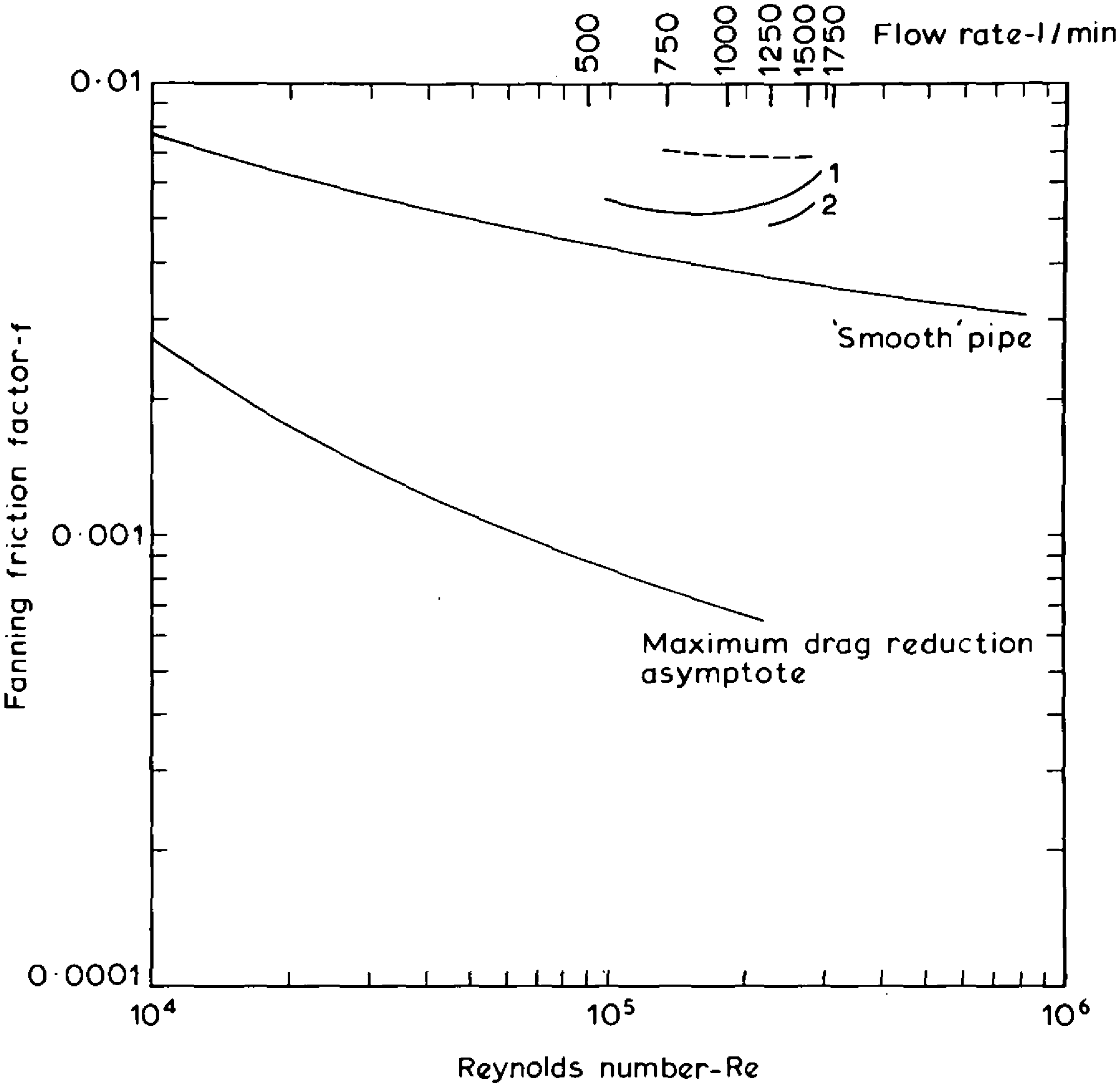
2 Dose 2
injection downstream of pump-hose lengths up to 900 ft

3 Dose 1
injection into suction inlet-hose lengths up to 900 ft

4 Dose 1
injection into pump, through 900 ft 2 3/4 in hose, through second (relay) pump, measurements taken on a second 900 ft length of 2 3/4 in hose

Figure 7 Summary of results for 2 3/4 in hose

13730 F.R. 1033



---- Plain water

—— Rapid water injected downstream of pump

1 Dose 1 hose length 1500 + 3000 ft

2 Dose 2 hose length 1500 ft

Figure 8 Summary of results for 3½ in hose

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