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PRESSURE LOSSES IN UK FIRE HOSE

by

P F Thorne, C R Theobald and P Mahendran

September 1975

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SUMMARY

Measurements of pressure losses in fire hose and calculated friction factors are reported, and show significant differences between makes of hose. The value for friction factor of 0.005 given in the Manual of Firemanship for all diameters of non-percolating hose is found to be inappropriate for 19 mm hose reel hose and 89 mm hose. Based on the reported measurements, values for these hoses of 0.0065 and 0.007 are more realistic. The high value for 89 mm hose can be attributed to the reduction in diameter of the instantaneous couplings. Coupling losses are also found to be significant in 70 mm hose.

Differences in hose wall construction give rise to large differences between different makes of 19 mm hose reel hose.

Measurements of hose stretching under pressure are also reported.

Department of the Environment and Fire Offices' Committee
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INTRODUCTION

The pressure losses which occur during the flow of water through fire hose are of practical interest to the operational fireman. Data on pressure losses in fire hose of different diameters as a function of flow rate is presented in graphical form in the Manual of Firemanship[1]. An overall average value of the Fanning friction factor for fire hose of all diameters is also given. For unlined hose the value given is 0.01 and for non-percolating hose 0.005. Knowing the friction factor (f) hose length (l) and diameter (d) and flow rate (Q_2), pressure loss (ΔP) can be calculated from the formula

$$\Delta P = \frac{k\ f\ l\ Q^2}{d^5} \qquad (1)$$

where k = 0.08 when l is in ft
Q is in gal/min
d is in ins
P is in lbf/in^2

and k = 9000 when l is in metres
Q is in litres/min
d is in mm
P is in bar

During a series of experiments concerned with Drag Reduction in fire hose[2], opportunity was taken to measure pressure loss and friction factors as a function of flow rate for a range of fire hoses of different diameters. Changes in the length and diameter which occur when fire hose is subject to internal pressure were also measured.

EXPERIMENTAL METHOD

The equipment and methods used to measure pressure losses and flow rates are described elsewhere[2].

Measurements of length and diameter were made on two lengths of hose chosen at random from among the hose used in the Drag Reduction experiments. Length was measured using a steel rule. Diameter was measured, using a vernier caliper gauge, at three points equally spaced along the hose, two separate measurements at right angles to each other being taken at each point.

Three makes of low pressure and one of high pressure 19 mm ($\frac{3}{4}$ in) hose reel hose were tested. Four makes of (44.5 mm) $1\frac{3}{4}$ in and one each of 70 mm ($2\frac{3}{4}$ in) and 89 mm ($3\frac{1}{2}$ in) hose were also tested. The 44.5 mm, 70 mm and 89 mm hose had not previously been used. All measurements were made prior to the commencement of the Drag Reduction experiments.

Fresh water at 10°C was used in the experiments.

RESULTS

The results of the pressure loss measurements are shown in Tables 1 to 12 in which pressure loss (bar per 30 m) is tabulated against flow rate (litres/min). The length of hose used in the measurement is also indicated.

These results were correlated using non-linear regression analysis, and from the regression lines friction factor (f) was calculated as a function of Reynolds number (Re). In all the calculations, the nominal lengths and diameters of the hoses were used. These friction factors are shown plotted, as a friction factor chart, against Reynolds number and flow rate in Fig.1. The 'smooth-pipe' curve is also shown.

Results of measurements of friction factor for 19 mm and 70 mm hose made on an earlier occasion[3] are also shown for comparison. Curves A_1 and A_2 are for the same brand of 19 mm hose reel hose. A_1 was determined in 1970 using a single 16.5 m length of hose and A_2 was determined in the present series of experiments using three 18.3 m lengths (total 54.9 m) connected together by hermaphrodite couplings.

Measurements of hose length and diameter are shown, for a range of pressures up to 10 bar (150 lb/in^2) in Tables 13 to 16, readings being shown separately for each of the two lengths of hose measured. Three diameter readings are shown, taken near each end and at the mid-point of each length. These diameters are the mean of two measurements made at right angles to each other.

DISCUSSION

1. Friction factor measurements

All calculations have been made on the basis of the nominal (ie unstretched) lengths and diameters of the hoses. The friction factors are therefore effective performance figures which reflect the effects of changes in diameter and length due to the level of internal pressure. These effects will, of course, decrease along the hose from the pump end to the discharge end of the hose.

<u>19 mm hose</u>

The curves marked A_1 and A_2 in Fig.1 are for the same make of hose. Whereas curve A_1 was obtained for a length of hose with no intermediate hermaphrodite couplings, curve A_2 was obtained with a length of hose with hermaphrodite couplings at the normal spacing of every 18.3 m (60 ft). Hermaphrodite couplings therefore apparently account for about eight per cent of the total friction factor for 19 mm hose in its normal Fire Service form, ie 18.3 m (60 ft) lengths connected together. Further measurements would be necessary in order to confirm this.

The friction factor curve for hose G, a type of hose which is 20-30 years old and is no longer in production, appears to be anomalous. The results for this particular hose fall below the 'smooth-pipe' correlation which represents the lowest friction factors normally encountered with hydraulically smooth, rigid wall, pipe. The results for this hose are also substantially lower than those for the other 19 mm hoses tested.

The anomaly with respect to the 'smooth pipe' correlation can be resolved by a consideration of the stretching under pressure of hose G. Subsequent to the trials a short (300 mm) length of hose G was obtained and its expansion under pressure measured. The results are shown in Table 13B. Although it was not possible to make accurate measurements of the increase in length for this sample, it is unlikely that its behaviour in this respect would be greatly different from the other hoses. An increase in diameter of about 8 per cent was measured at the highest pressure. This results in a connection factor of $1.08^5 = 1.47$, increasing the friction factor to about 0.0062, well above the smooth pipe correlation.

The differences between hose G and the other hoses can only be partially explained. Table 13A shows an average increase in diameter at the highest pressure of about 4 per cent for hose A. Measurements were not made on the other hoses. This results in a correction factor of $1.04^5 = 1.22$, leaving a difference of 42 per cent between hose G and A(2) as compared with 70 per cent based on 'effective' friction factors. Further explanations are based on the properties of the internal lining materials of the hoses but cannot be quantified at present.

Two properties are of particular relevance; surface roughness and compliance. Subjectively, hoses C and G were of similar internal roughness, being quite smooth to the touch. Hose A was noticeably rougher than hose B, both being more rough than hoses C and G. Surface roughness profile measurements would provide a more quantitative assessment of this factor but consideration of corrected friction factors for hose G and hose A in relation to a conventional friction factor chart results in an effective roughness height of 0.076 mm for hose A and 0.0076 mm for hose G. The wall of hose G was also found to be more supple than that of hose A. It is possible that an alternative type of Drag Reduction mechanism, not dependent on the presence in the fluid of an additive, might operate in the more compliant hose[6].

In view of the considerably lower pressure losses measured in hose G as compared with hose A, further research into the behaviour of hose G is required in order to fully identify and quantify the factors responsible for its different behaviour.

Data on some other hose of US and German manufacture also appear to be anomalous[7,8], and compliant wall drag reduction has been tentatively proposed as a factor[8].

44.5 mm hose

There was a considerable variation in friction factor for the different types of hose tested. The best result, D, in fig.1 was obtained with hose of the same construction as the 70 mm and 89 mm hose used in these experiments. All hose incorporated the same type of instantaneous coupling which, because the reduction in diameter was relatively small, was not expected to contribute substantially to the overall friction factor and certainly would not produce the large differences which were seen between different makes of hose. Subjectively, certain differences were seen between the hose particularly in respect of internal roughness and the presence or not of an internal longitudinal ridge due to seam construction. No detailed analysis was undertaken of the differences in construction and no correlation between hose properties and friction factor is presented.

On average, the overall figure for friction factor of 0.005 quoted in the Manual of Firemanship is a good guide although there will be notable exceptions which could differ by ± 20 per cent.

The hose possessing low values of 'effective' friction factor could possibly be exhibiting the kind of behaviour discussed above in connection with 19 mm hose.

70 mm hose

Two results are available. The correlation marked H in Fig 1, was obtained with three lengths of hose, of different manufacture, connected together. The individual brands of hose were not identified at the time the measurements were made. It is interesting to note that the friction factors for this hose and the new hose type D recently tested were not greatly different. Both were somewhat smaller than the overall figure of 0.005 quoted in the Manual of Firemanship, although this figure is seen to be a good guide.

89 mm hose

The value of friction factor for this hose was measured as 0.007. This is some 40 per cent higher than the overall value of 0.005 quoted in the Manual of Firemanship and is a unexpectedly high result. Reasons for this high value are discussed below.

2. Pressure losses in fire hose couplings

An unexpectedly high value of friction factor was found for 89 mm relaying hose. The internal profiles of standard instantaneous couplings for both 70 mm and 89 mm hose are shown in Figure 2[7]. Inspection of these profiles shows steps changes in diameter at the entrance to (and exit from) the coupling tail. There is a further reduction in diameter, which is substantial for the 89 mm coupling, at the mid point.

In the case of the 89 mm coupling, there is a two stage increase in diameter, as opposed to a single stage increase in the 70 mm coupling, downstream of the mid point. It is to be expected that a pressure loss will occur across such a constrictio: Calculation of the precise pressure loss is not straightforward, but estimates can be made on the basis of certain assumptions. In Appendix 1, three such estimates have been made, assuming that

a) the constriction behaves as a simple orifice (the worst case)
b) the constriction behaves as a venturi (the best case)
c) the constriction behaves as a sudden contraction in series with a sudden expansion (an intermediate case).

Some preliminary measurements of the pressure loss - flow rate characteristics of 70 mm hose couplings are shown together with the theoretical correlations outlined above in Fig 3. The sudden contraction/sudden expansion treatment provides the best correlation but the measurements show a tendency towards the case of the venturi at higher flow rates.

The friction factor of 70 mm hose (less the couplings losses) has been estimated using this preliminary data as follows. Coupling loss has been regarded as equal to $k\,Q^2$ where k is a function of Q. The normal 'hose' formula is

$$\Delta P = \frac{9000\ f\ l\ Q^2}{d^5}$$

Now $\Delta P_{hose} = \Delta P_{total} - \Delta P\ coupling$

$$\therefore \quad \frac{9000\ f_{hose}\ l\ Q^2}{d^5} = \frac{9000\ f_{total}\ l\ Q^2}{d^5} - n\ K\ Q^2$$

where n is the number of couplings associated with a length, l, of hose. For the hose tested $n = 1$ when $l = 23$ m

$$\therefore \quad \frac{9000 \times 23}{70^5}\ f_{hose} = \frac{9000 \times 23}{70^5}\ f_{total} - K$$

For a number of chosen values of f_{Total}, Q was calculated. This enabled $\Delta P_{coupling}$ to be read from fig 3 and hence K and f_{hose} could be calculated. The results are plotted as curve D1 for 70 mm hose on fig 1. This curve is a little below the curve D for 44.5 mm hose.

Although the internal diameter of a 44.5 mm hose couplings is, at its midpoint, larger than that of the hose, there is some reduction at the tails. The pressure losses due to 44.5 mm couplings cannot be regarded as negligible and the total friction factor (hose plus coupling) would be expected to be greater than that of the hose alone.

In addition, for a given hose wall material, hence given roughness height (e), the dimensionless ratio $^e/d$ would be higher by a factor of two for the smaller of the two hoses. At a Reynolds number of 10^5 inspection of a standard friction factor chart shows that this represents an increase in f of about five per cent.

No measurements of the losses of 89 mm hose couplings are available and it is therefore not possible to make a similar calculation for 89 mm hose. It is not known whether the analysis which predicted the order of magnitude of coupling losses for 70 mm hose would apply to 89 mm hose couplings.

More detailed measurements of hose coupling losses are clearly desirable. It would be profitable to explore more favourable internal profiles for hose couplings eg to approximate more closely to a venturi.

CONCLUSIONS

The value for friction factor of 0.005 quoted for all hose in the Manual of Firemanship is seen to be a good guide but there are some notable exceptions:

1) There is a wide variation in friction factor for 19 mm hose-reel hose. The worst hose tested has a friction factor some 76 per cent higher than the best. The explanation of this difference probably lies in the different wall construction of the hoses, particularly in respect of the compliance and roughness of the internal lining.

2) There is a wide variation in friction factor for 44.5 mm hoses currently available for fire service use. The worst of the hoses tested has a friction factor some 40 per cent higher than the best hose.

3) 89 mm relaying hose has a very high friction factor which can be largely attributed to the couplings. Effort spent on reducing the losses caused by couplings would be well spent; 70 mm hose would also benefit.

4) Further experimental measurements of coupling losses for all hose sizes are required.

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Table 1

Hose length between gauges: 180 ft 54.9m

Hose diameter: $\frac{3}{4}$ in, 19 mm

Brand A

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
11.4	51.8	87	30.9	2.12
12.5	56.8	104	37.3	2.52
14.2	64.6	132	47.9	3.17
13.5	61.4	83	3.4	3.00
14.7	66.8	98	4.3	3.53
16.8	76.4	127	7.4	4.51
15.3	69.6	106	6.4	3.76
11.5	52.3	88	31.4	2.13
11.0	50.0	91	40.4	1.91
10.0	45.5	93	50.9	1.59
9.0	40.9	96	60.9	1.32
6.8	30.9	100	81.4	0.70
8.0	36.4	98	70.9	1.02
7.0	31.8	76	53.4	0.85

Table 2

Hose length between gauges: 180 ft 54.9 m

Hose diameter: $\frac{3}{4}$ in, 19 mm

Brand B

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
12.2	55.46	87.5	33.9	2.02
10.6	48.18	66.0	27.4	1.46
9.2	41.82	51.0	20.9	1.13
14.5	65.91	79.0	7.4	2.70
16.0	72.73	94.0	6.9	3.28
18.4	83.64	119.0	7.3	4.21
17.2	78.19	104.0	8.3	3.61

Table 3

Hose length between gauges: 180 ft 54.9m

Hose diameter: $\frac{3}{4}$ in, 19 mm

Brand G

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
13.0	59.09	86	40.4	1.72
14.2	64.55	100	47.9	1.96
16.8	76.37	129	64.9	2.42
12.0	54.55	72	33.9	1.44
15.2	69.09	110	54.4	2.09
12.0	54.55	68	33.4	1.31
20.5	93.19	116	11.3	3.94
18.0	81.82	90.5	8.9	3.08
19.2	87.28	103	9.5	3.53
16.0	72.73	74	7.4	2.51

Table 4

Hose length between gauges: 159 ft 48.5 m

Hose diameter: $\frac{3}{4}$ in, 19 mm

Brand C

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
12	54.55	83.5	43.9	1.69
13.5	61.37	101	42.9	2.48
14.3	65.00	112	47.9	2.74
15.5	70.46	128	56.4	3.06
15.0	68.19	79	4.4	3.18
16.2	73.64	94	6.9	3.72
17.0	77.28	103	7.5	4.08
18.7	85.00	122	9.4	4.81
15.5	70.46	85	6.5	3.35

Table 5

Hose length between gauges: 600 ft 183 m

Hose diameter: $1\frac{3}{4}$ in, 44.5 mm

Brand D

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
75	341	83.5	11.0	0.82
67	305	83.5	20.25	0.72
79	359	102.5	25.5	0.87
82	373	102.5	20.25	0.93
91	414	102.5	10.0	1.05
92	418	102.5	5.0	1.10
111	505	154.5	7.5	1.66
112	509	153.5	5.0	1.68
107	486	153.5	19.8	1.51
49	223	52.5	21.5	0.35

Table 6

Hose length between gauges: 300 ft91.5 m

Hose diameter: $1\frac{3}{4}$ in, 44.5 mm

Brand A

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
71	322	96	54.2	0.93
67	304	88.5	49.3	0.87
59	268	89	58	0.71
85	386	119.5	58.4	1.38
97	440	116.5	36.2	1.79
108	490	115	14.3	2.25
107	486	113.5	13.9	2.22
67	304	88	48.7	0.88

Table 7

Hose length between gauges: 300 ft 91.5m

Hose diameter: $1\frac{3}{4}$ in, 44.5 mm

Brand F

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
124	563	112	4.75	2.40
122	554	109.5	4.6	2.33
115	522	98.5	3.9	2.11
103	468	79.5	3.0	1.71
96	436	82.5	14.8	1.51
88	400	84	25.7	1.30
61	277	87	59	0.62
73	331	97.5	57.5	0.89
83	377	108	58	1.12
61	277	88.5	58.7	0.66
73	331	99	58.5	0.90

Table 8

Hose length between gauges: 300 ft 91.5m

Hose diameter: 1¾ in, 44.5 mm

Brand E

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
69	313	96.5	58.5	0.85
82	372	93.5	42.5	1.18
90	409	115	57.5	1.42
88	400	116	56.3	1.33
93	422	114	44.8	1.54
95	431	112	40	1.61
107	486	109.5	19.7	2.00
115	522	110	9.9	2.23

Table 9

Hose length between gauges: 900 ft274.4m

Hose diameter: $2\frac{3}{4}$ in, 70 mm

Brand D

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
272	1237	144	9.5	1.03
262	1191	146	20.5	0.96
242	1100	148	40	0.83
222	1009	122	32.5	0.69
200	909	101	26.75	0.57
153	696	63	16.75	0.36
165	750	62	8.25	0.42
111	505	65	40	0.20
140	636	63	20.5	0.34
121	550	63.5	34.05	0.24

Table 10

Hose length between gauges: 1800 ft 549 m

Hose diameter: $2\frac{3}{4}$ in, 70 mm

Brand D

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
171	777	153	50.1	0.39
181	823	152	35.1	0.44
194	882	150.5	20.6	0.49
203	923	149.5	7.6	0.54

Table 11

Hose length between gauges: 1500 ft 457 m

Hose diameter: 3½ in, 89 mm

Brand D

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
315	1432	154.25	6.4	0.67
295	1341	146.25	15.5	0.59
279	1268	148.25	30.8	0.53
266	1209	149.25	41.1	0.49
242	1100	150.75	60.3	0.41
194	882	100.75	39.6	0.28
176	800	101.25	50.0	0.23

Table 12

Hose length between gauges: 3000 ft 914 m

Hose diameter: $3\frac{1}{2}$ in, 89 mm

Brand D

Flow Rate		Corrected pressure gauge readings (lbf/in^2)		Pressure loss per 30 m (bar)
gal/min	l/min	P_1	P_2	
218	991	143.5	4.1	0.32
204	927	145	22.25	0.28
187	850	146	41.3	0.24
174	791	147.5	53.25	0.21
165	750	147.5	61.5	0.20

Table 13A

Results of hose stretching measurements - 19 mm ($\frac{3}{4}$ in) hose-reel hose (Type A)

Pressure (bar)			0	1	5.3	8.8
Length (m)	Hose 1		17.55	17.55	17.63	17.63
	Hose 2		18.62	18.47	18.28	18.19
Outside diamater (mm)	Hose 1	d_1	30.99	31.24	32.00	32.11
		d_2	31.65	31.14	31.75	32.28
		d_3	31.78	32.00	32.56	32.51
	Hose 2	d_1	30.76	30.10	30.89	31.75
		d_2	30.94	32.00	32.64	33.02
		d_3	31.09	31.12	32.46	33.02
Mean percentage increase in diameter	Hose 1		0	0	2	2.7
	Hose 2		0	0.4	3.4	5.3

Wall thickness of unpressurised hose = 6.2 mm

Table 13B

Results of hose stretching measurements on short length of 19 mm ($\frac{3}{4}$ in) hose, (Type G)

Pressure (bar)	0	4	7	10
Mean outside diameter (mm)	31.02	32.5	33.11	33.52
Percentage increase in diameter	0	4.8	6.7	8.1

Wall thickness of unpressurised hose = 6 mm

Table 14

Results of hose stretching measurements - 44.5 mm ($1\frac{3}{4}$ in) non-percolating hose

Pressure (bar)			0	1	5.5	10
Length (m)	Hose 1		23.09	23.63	23.86	23.88
	Hose 2		23.07	23.27	23.63	23.77
Outside diameter (mm)	Hose 1	a		49.43	52.32	52.88
		b		49.35	52.71	53.34
		c		50.04	52.5	53.47
	Hose 2	a		49.53	51.84	52.71
		b		50.04	52.71	53.47
		c		50.67	52.71	53.59
Mean percentage increase in diameter	Hose 1			0	5.8	7.3
	Hose 2			0	4.6	6.3

Wall thickness of unpressurised hose = 2.08 mm

Table 15

Results of hose stretching measurements – 70 mm ($2\frac{3}{4}$ in) non-percolating hose

Pressure (bar)			0	0.7	2.7	6.9	10
Length (m)	Hose 1		23.20	23.25	23.15	23.70	24.00
	Hose 2		22.82	22.79	22.82	23.40	23.65
Outside diameter (mm)	Hose 1	a		95.97	77.22	79.78	80.80
		b		74.37	77.34	79.71	80.80
		c		74.55	77.14	79.63	80.65
	Hose 2	a		76.20	78.03	77.42	78.00
		b		75.82	76.21	77.17	78.18
		c		–	76.20	77.04	78.00
Mean percentage increase in diameter	Hose 1			0	3	6.4	7.8
	Hose 2			0	0.9	1.6	2.8

Wall thickness of unpressurised hose = 2.08 mm

Table 16

Results of hose stretching measurements –
89 mm (3½ in) non-percolating hose

Pressure (bar)			0	1	3.6	10
Length (m)	Hose 1		22.48	22.48	22.79	23.65
	Hose 2		23.02	23.02	23.35	24.24
Outside diameter (mm)	Hose 1	a		93.35	93.35	94.84
		b		93.17	94.03	95.25
		c		93.09	93.35	95.00
	Hose 2	a		92.25	92.96	94.87
		b		93.68	93.60	94.84
		c		92.71	93.60	94.72
Mean percentage	Hose 1			0	0.4	1.9
increase in diameter	Hose 2			0	0.5	2.0

Wall thickness of unpressurised hose = 2.08 mm

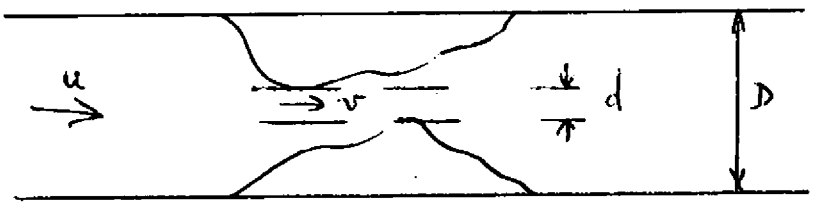
APPENDIX

Analysis of pressure loss in fire hose couplings

The internal profiles of instantaneous couplings for 70 mm and 89 mm hose are sketched in Fig 2. It can be seen that the profiles do not closely resemble any formal pattern for which a proven theoretical analysis is available.

Analyses can, however, be made on the basis of a number of assumptions. Three approaches will be outlined below.

1. A general analysis can be made by considering the coupling to be a constriction of arbitrary profile.



H = head loss over constriction.

An application of Bernoullis theorem yields the following well known formula

$$Q = C \; A_c \sqrt{2gH}$$

Where Q is volume rate of discharge

A_c is the cross sectional area of the constriction, at diameter d.

C is a factor comprising two separate elements

viz $C = C_D \; C_V$

where C_D is the coefficient of discharge

and C_V is the velocity of approach factor and is equal to

$$\frac{1}{1 - (A_c/A)^2}$$ where A is the cross sectional area of the pipe.

The pressure drop across the constriction $P = \rho gH$

$$Q = C_D \; C_V \; A_c \sqrt{2 \quad \Delta p/\rho}$$

and $$\Delta P = \frac{Q^2}{2 \; C_D^2 C_V^2 \quad A_c^2}$$

Depending upon the precise contour of the constriction a fraction, r, of the pressure loss is recovered downstream. If the contour produces excessive turbulence eg an orifice plate, then r might be 0.1 or below. If the contour is smoothly profiled, eg a venturi, then r might be 0.85 or higher.

Thus the permanent loss caused by the constriction is

$$\frac{(1 - r)\ \rho\ Q^2}{2\ C_D^{\ 2}\ C_V^{\ 2}\ A_c^{\ 2}}$$

The unknown quantities as far as a hose coupling is concerned are r and C_D.

For 70 mm hose $\Delta P = 1.7 \times 10^{-7} \frac{(1 - r)}{C_D^{\ 2}} Q^2$

Two extreme conditions, the orifice plate and the venturi, can be identified, however, and typical values assumed for C_D

viz orifice 0.65
venturi 0.97

Thus, for 70 mm hose, the following equations can be written

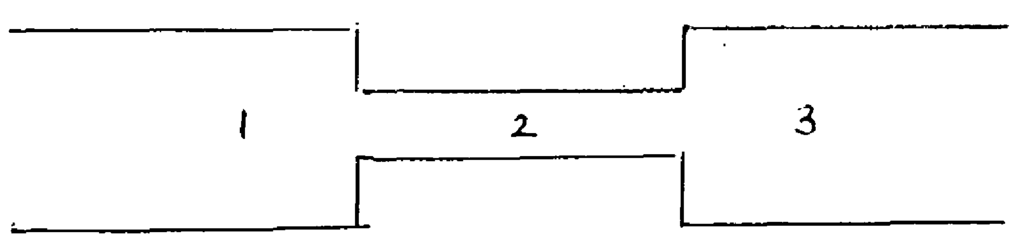
ΔP loss $= 3.6 \times 10^{-7}\ Q^2$ based on orifice
ΔP loss $= 2.7 \times 10^{-8}\ Q^2$ based on venturi

where ΔP is in bar
Q is in 1 m $^{-1}$

These two extreme cases are shown plotted in Fig 3.

The corresponding losses for the 89 mm hose will be 1.8 times the above.

An alternative approach can be made by considering the coupling to comprise a number of sudden or tapered contractions and expansions. The simplest case is to consider the coupling as a hidden contraction followed by a sudden expansion



Contraction $P_1 - P_2 = \frac{\rho}{2} \left[V_2^2 \left(\frac{1}{C_c} - 1\right)^2 + V_2^2 - V_1^2 \right]$

Expansion $P_3 - P_2 = \rho (V_2 - V_3) V_3$

Total $P_1 - P_3$

$$= \frac{\rho}{2} \left[V_2^2 \left(\frac{1}{C_c} - 1\right)^2 + V_2^2 - V_1^2 - V_3 (V_2 - V_3) \right]$$

$$= \rho/_2 \left[\frac{1 + kc}{d_2^4} - \frac{2}{d_1^2 \, d_2^2} + \frac{1}{d_1^4} \right] \left[5.4 \times 10^{-6} Q^2 \right]$$

C_c is the coefficient of contraction

Values of $k_c = \left(\frac{1}{C_c} - 1 \right)^2$ are available as a factor of A_2/A_1.(5)

a) In the 70 mm coupling $\frac{A_2}{A_1} = 0.597$

$K_c = 0.22$ $C_c = 0.681$

$\Delta P = 10^{-7} Q^2$

This is also shown plotted in Fig 3

b) For the 89 mm hose $\frac{A_2}{A_1} = 0.369$

$K_c = 0.375$

$\Delta P = 2 \times 10^{-7} Q^2$

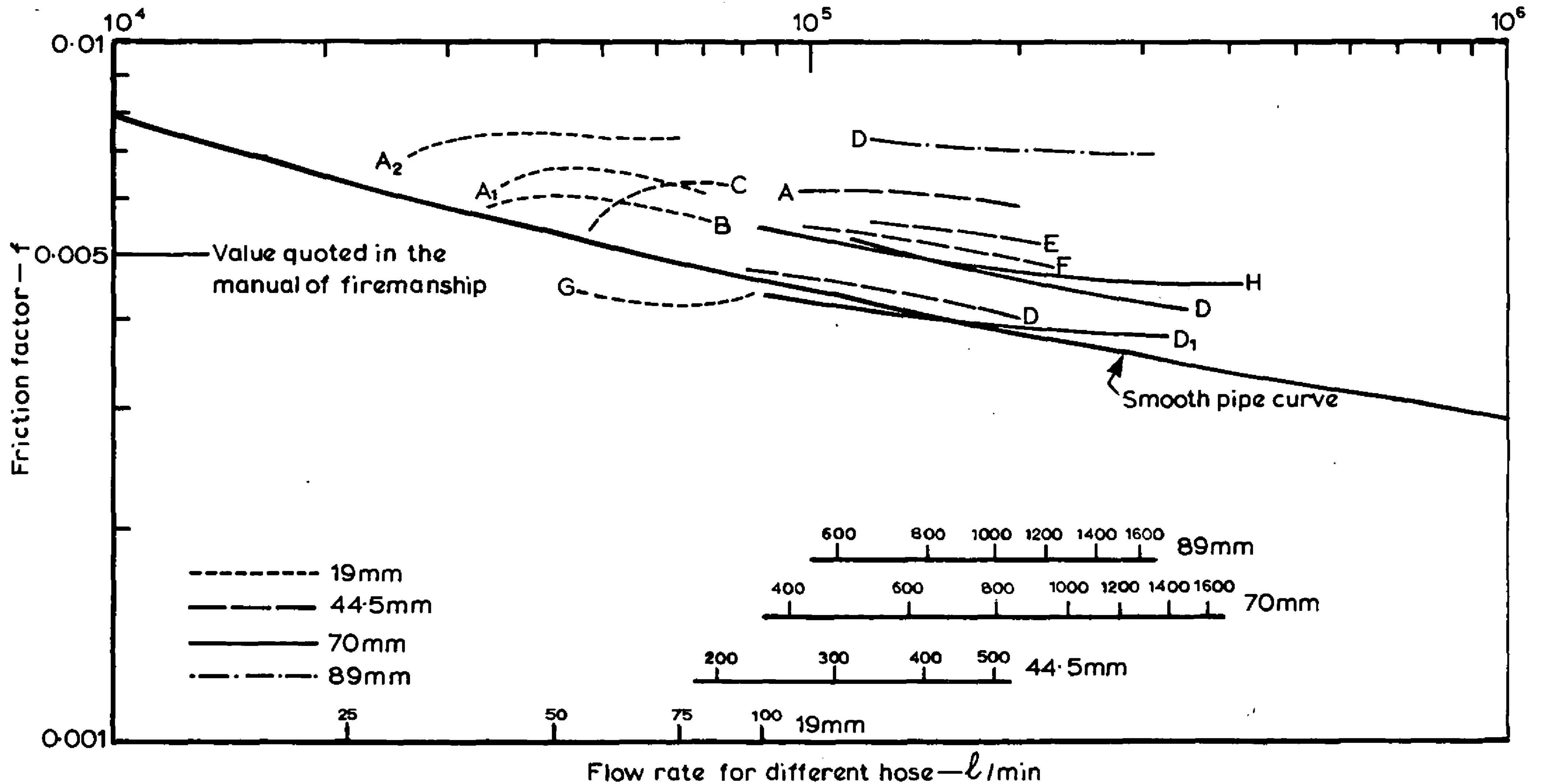


Figure 1 Friction factors for 19mm, 44·5mm, 70mm and 89mm hose with plain water as a function of flow-rate

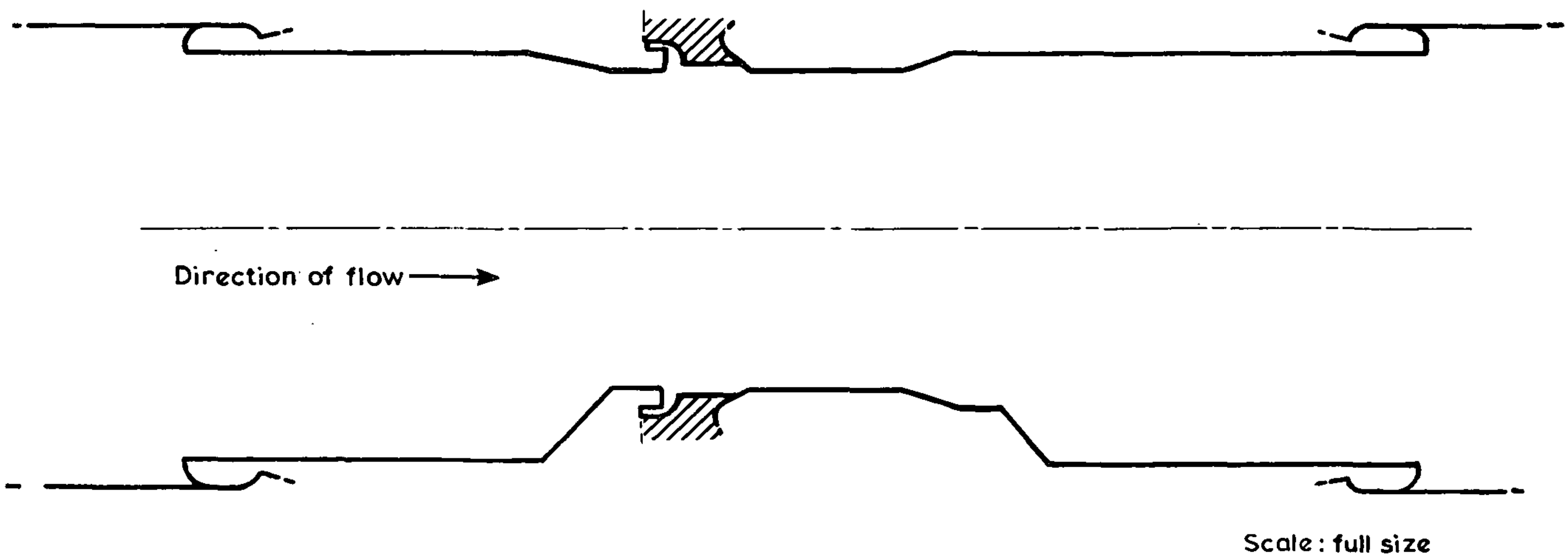
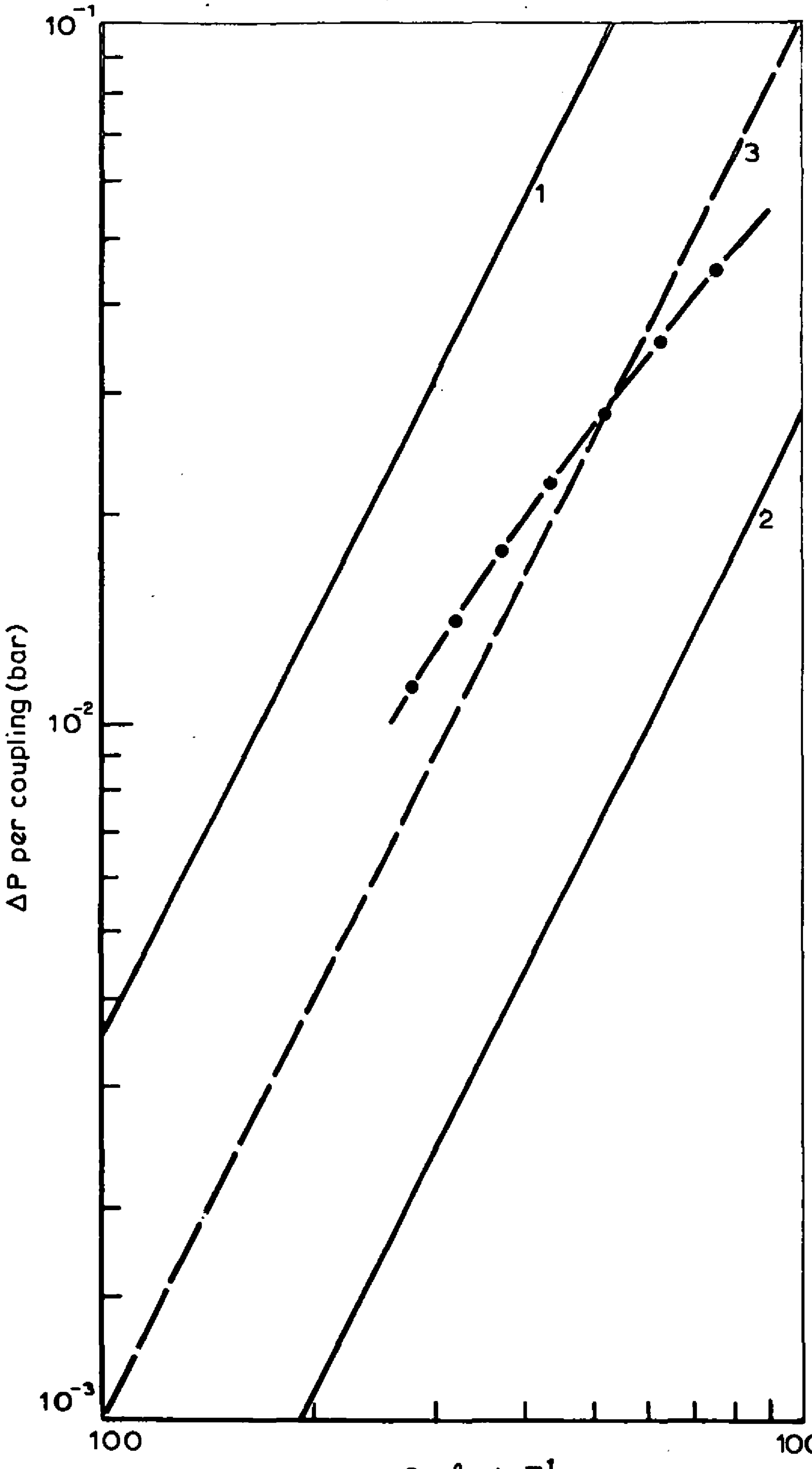


Figure 2 Sketch of internal profiles of standard instantaneous couplings for 70mm (upper profile) and 89mm (lower profile) hose — from B S 336



Theoretical correlations 1 Orifice plate

2 Venturi

3 Sudden contraction then expansion

●—●—●—● Experimental values

Figure 3 Pressure loss for instantaneous couplings in 70mm hose