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THE RELATIVE MERITS OF HIGH AND LOW PRESSURE WATER SPRAYS IN THE EXTINCTION OF LIQUID FIRES

by

D. J. Rasbash

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Fire Research Station
Boreham Wood,
Herts.

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Summary

From available information on the extinction of liquid fires with water sprays, an estimate has been obtained of the relative effect of increasing the pressure in a high pressure spray range (100-1,500 lb/in.^{2}) and a low pressure spray range (up to 100 lb/in.^{2}) in the extinction of these fires. It has been concluded that, after taking into account practical conditions which are likely to occur in the use of these sprays, it is not in general worth while increasing the pressure in the high pressure region.

Symbols

A	area of fire
E	efficiency exponent
P	pressure
Q	efficiency factor when extinction time is important
Q_1	efficiency factor when water consumption is important
R	rate of flow to the fire
a	exponent of pressure in efficiency equation
b	exponent of rate of flow in efficiency equation
t	time of extinction
x	exponent of pressure in equation connecting the variation of rate of flow with pressure under various practical conditions.

Introduction

In the application of water sprays to fighting fires it is important to know the best pressure at which to operate the nozzles. Recently there has been much difference in opinion on the relative merits of high pressure (up to 800 - 1,000 lb/in.^{2}) and low pressure (up to 100 lb/in.^{2}) sprays. A certain amount of information is available which allows a tentative empirical answer to be given in this problem, insofar as it concerns liquid fires.

Distinction between the effect of pressure and rate of flow

In considering the use of high pressure sprays in practice, a clear distinction must be drawn between the effect of pressure and the effect of rate of flow. For a given nozzle the rate of flow will increase as the square root of the pressure. However, under practical conditions the use of a higher pressure may result in a decrease in the rate of flow. Thus, for a given number of men the maximum rate of flow which can be handled will decrease as the square root of the pressure, since the reaction at the nozzles increases in direct proportion to the square root of the pressure. Again, for a given power output at the pump, the rate of flow will be inversely proportional to the pressure developed. If it is assumed that the size of a pump as specified by its volume or weight, is proportional to its power output then for a pumping unit of a given size, the rate of flow will be inversely proportional to the pressure. To justify an increase in pressure, then the increase in efficiency due to the actual pressure increase must at least counterbalance any decrease in efficiency resulting from a necessary decrease of rate of flow.

If the time of extinction of a fire is of greater importance than the amount of water used in the extinction, then the efficiency of a spray may be represented by a factor Q where

$$Q = \frac{A}{t} \ldots\ldots \qquad \ldots\ldots (1)$$

A = area of fire extinguished
t = time of extinction.

It may be assumed that Q will be some function of the rate of flow to the fire (R) and the pressure of the nozzle (P) and also of other spray properties such as the cone-angle, design of the nozzles, etc. If we wish to consider only the effects of rate of flow and pressure, then the effect of these factors may be expressed in the equation

$$Q \propto P^a R^b \ldots\ldots \qquad \ldots\ldots (2)$$

In equation 2, a and b are exponents depending on the fire and the type of spray used; they may also vary with the pressure and rate of flow as well.

If, on the other hand, the quantity of water used in the extinction is the more importnat factor, then the efficiency of the spray may be represented by Q_1 where

$$Q_1 = \frac{A}{Rt} = \frac{Q}{R} \ldots\ldots \quad Q_1 \qquad \ldots\ldots (3)$$

Combining equations 2 and 3 gives

$$Q_1 \propto P^a R^{b-1} \qquad \ldots\ldots (4)$$

If the pressure is increased, the rate of flow may also increase or for one of the practical reasons given above, it may have to be decreased. Thus, if an increase in pressure is necessarily accompanied by a certain variation in the rate of flow such that R P^x, then substitution in equations 2 and 4 shows that the overall effect of the increase in pressure on the spray efficiency will be expressed by equations 5 and 6.

$$Q \propto P^{a+bx} \qquad \ldots\ldots (5)$$

$$Q_1 \propto P^{a+(b-1)x} \qquad \ldots\ldots (6)$$

Henceforth, the exponent of P in equations 5 and 6 will be called the "efficiency exponent E". E is a function of a and b, and will depend on the limiting factor encountered in the practical use of the sprays. It may be noted that if E is significantly larger than zero then the efficiency of the spray will increase as the pressure is increased, but if E is significantly smaller than zero, the efficiency of the spray will decrease as the pressure is increased.

Table 1 gives the efficiency exponents for practical conditions in which the manpower, the pump power, and the nozzles impose the most important restraint as the pressure is increased.

Calculation of efficiency exponent

In order to apply the information in Table 1, it is necessary to know the values of a and b. These can be obtained from practical tests with sprays on fires. There are two ways in which tests may be conducted to give the values of a and b. Firstly, a direct correlation may be obtained between the efficiency of extinction and the pressure and the rate of flow at the fire area. Secondly, a correlation may be obtained between the efficiency of extinction and the spray properties at the fire area such as the entrained air current, the drop size of the spray as well as the rate of flow; using information on how pressure and rate of flow effects these properties, the exponents of pressure and rate of flow may be calculated. The first method has the limitation that other spray conditions, particularly the cone-angle and the method of spray production should be reasonably uniform throughout the test series, since the spray properties which determine extinction will depend in part on these other spray properties. The second method has the limitation that information on the effect of pressure on the spray properties at the fire is scanty, particularly for pressures above 100 lb/in.^{2}.

Information is available from three series of tests from which a direct correlation may be obtained between the efficiency of extinction and the effect of pressure and rate of flow. These correlations are summarised under series 1 to 3 in Table 2. Table 2 gives the source of information, a brief description of the fire used and the conditions under which the sprays were applied together with values of a and b and approximate 95 per cent confidence limits calculated as regression coefficients from the test results. Series 1 was carried out with low pressure sprays ($<$100 lb/in.^{2}) and series 2 and 3 with high pressure sprays (100-1,500 lb/in.^{2}). In series 2 and 3 the rate of flow at the fire area is not given but as the areas covered by the sprays used were either the same or less than the area of the fire, it may be assumed that all the water from the nozzle was usefully employed against the fire and that therefore, the rate of flow from the nozzle was proportional to the mean rate of flow to the fire area. Three series of tests are also available in which a correlation has been obtained between the efficiency of extinction and the properties of the spray at the fire area. Combining this information with information on the effect of pressure and rate of flow from impinging jet nozzles on the spray properties (6), the values of a and b were calculated for both low pressure sprays and high pressure sprays. These estimations of a and b are appropriate to nozzles consisting of multiple pairs of impinging jets of constant diameter delivering spray uniformly into a cone of constant angle. The results are given under series 4 to 6, in Table 3. It will be noted that a precise value for a high pressure spray is not given. This arises from the uncertainty of the effect of pressures above 100 lb/in.^{2} on the drop size of the spray. The available information (6), (7) indicates that the drop size of the spray is proportional to $p^{0\cdot0}$ to $^{-0\cdot2}$ and the ranges of values of a given are such as to cover this variation.

By combining the information in Table 1 with that in Tables 2 and 3, the efficiency exponents of the sprays were calculated. These are shown in Table 4 for the low pressure range and for the high pressure range. Table 4 shows that if neither manpower nor pump power were a limiting factor, and that the only limitations were the amount of water that could be obtained from a given nozzle, then the efficiency exponent would be significantly positive in most cases. It follows, that in general, it would be worth while increasing the pressure under these conditions. However, it will be noted that the efficiency exponents for low pressure conditions are substantially greater than those for high pressure conditions, and that it is more worth while to increase the pressure to 100 lb/in.^{2} than to increase the pressure considerably beyond 100 lb/in.^{2}. If the manpower or the pump power available were a limiting factor, then in general, for low pressure sprays, the efficiency exponent is either positive or not significantly different from zero, and for high pressure sprays, is either negative or not significantly different from zero. Thus in general, there may be an advantage in increasing the pressure in the low pressure range and a disadvantage in increasing the pressure in the high pressure range. However, the efficiency exponents for series 2 for conditions under which water consumption is critical are positive which indicates that there may be an occasional advantage in using high pressure sprays under these conditions.

Discussion

It is likely when sprays are used under practical conditions, that limitations of manpower and pump capacity will be important when high pressure sprays are used, and that limitations imposed by design of the nozzle will be important when low pressure sprays are used. Thus, for example, if a reaction at the nozzle of 50 lb weight is the maximum which will allow adequate control of the nozzle by one man, the rate of flow at 50 lb/in.^{2} would be limited to about 120 gal/min and at 500 lb/in.^{2} to 35 gal/min. Now if it is necessary to use $^1/16$ in. diameter impinging jets to obtain a satisfactory degree of break-up of the water, a nozzle containing 100 pairs of impinging jets would be required to give the maximum flow rate that could be handled at 50 lb/in.^{2}, whereas a nozzle containing only 8 pairs of jets would be required at 500 lb/in.^{2}. Therefore, if the pressure is 50 lb/in.^{2} considerable difficulty may be encountered in designing a nozzle to project a fine spray at the maximum flow rate a man can handle; if as a consequence, it is necessary to work at a lower rate of flow the nozzle design would impose the chief limitation on the rate of flow at this pressure. On the other hand, at a pressure of 500 lb/in.^{2} there would be no difficulty in designing a nozzle to give the maximum flow rate a man can handle and the nozzle reaction would impose the chief limitation on the rate of flow. Again, a pump of normal size can deliver approximately 700 gal/min at 100 lb/in.^{2} and it would be expected that a pump of similar size would deliver approximately 70 gal/min. at 1,000 lb/in.^{2}. At the higher pressure the water can be fed through one nozzle consisting of twelve pairs of $^1/16$ in. impinging jets. At the lower pressure, thirty-two times this number of pairs of jets would be required to cope with the maximum delivery the pump can give. Thus at the lower pressure nozzle design is likely to be a more important limitation on the rate of flow than the pump capacity, but the opposite would apply at the higher pressure.

The available information which has been summarised above indicates that when the limitation is imposed by the nozzle which can be designed, a substantial increase in efficiency may be obtained if the pressure is increased, particularly up to a pressure of 100 lb/in.^{2}. Since this limitation is likely to occur most for low pressure sprays, it may be concluded that it is worth while increasing the pressure at spray nozzles for fighting liquid fires up to 100 lb/in.^{2}. However, if manpower or pump-power were controlling factors, and this is likely to be the case at high pressures, then the increase in the efficiency on increase in pressure will be considerably less and in many cases there may even be a decrease in efficiency at higher pressures. Therefore, in general, there will be no advantage in increasing the pressure at spray nozzles to values considerably greater than 100 lb/in.^{2}.

References

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TABLE 1

Formulae for efficiency exponents

Practical restriction	Value of x	Formula for efficiency exponent	
		Q (time of extinction important)	Q_1 (water consumption important)
Given nozzle	$+\frac{1}{2}$	$a + \frac{b}{2}$	$a + \frac{b}{2} - \frac{1}{2}$
Given manpower	$-\frac{1}{2}$	$a + \frac{b}{2}$	$a - \frac{b}{2} + \frac{1}{2}$
Given pump-power or size	-1	$a - b$	$a - b + 1$

TABLE 2

Direct estimates of a and b for different fires

Series number	Reference number	Type of fire	Method of spray production	Method of spray application	No. of tests in series	Range of pressures covered lb/in.^{2}	a with 95% confidence limits	Range of rates of flow covered	b with 95% confidence limits
1	1	1 ft. diameter tank in laboratory; kerosine; 8 min. preburn.	Multiple impinging jet sprays mounted on a battery. Directional	Downwards, from a height of 5 ft. 9 in.	33	10-85	1.67 ± 0.35	0.12 - 0.24 gal ft.$^{-2}$min^{-1}	1·98 ± 0·74
2	2	10 gal. spill petrol fire in open air. 5 sec. preburn.	Multiple impinging jets mounted on a single nozzle. Directional.	Hand application	210	100-750*	0·41 ± 0·17	15-35 gal/min	0·64 ± 0·36
3	2	10 ft. square pool of petrol in open air. 5 sec. preburn.		Fixed application at an angle of about 45°	43	100-1500	0·21 ± 0·14	15-35 gal/min	1·35 ± 0·35

*A further 120 tests in this series were also carried out within the range of pressures 1000-1500 lb/in.^{2}; they were not included in the analysis as no extinction was obtained in 30 of the tests.

TABLE 3

Indirect estimates of a and b for different fires

Series number	Reference number	Type of fire	Methods of spray production	Method of spray application	No. of tests in series	Range of rates of flow covered gal ft.$^{-2}$ min.$^{-1}$	Estimated values of a and b with 95% confidence limits		
							a (<100 lb/in.^{2})	a (>100 lb/in.^{2})	b
4	3	1 ft. diameter petrol fire in laboratory. Preburn 15-300 sec.	Directional impinging jet sprays on a battery and non-directional impinging jet sprays on a nozzle. Directional swirl nozzle spray.	Downward from a height of 5 ft. 9 in. to 8 ft.	44	0.16-0.8	2.2 ±0.5	0.7 to 1.5 ±0.4	3.0 ±1.1
5	4	1 ft. diameter transformer oil fire in laboratory. Preburn 300 secs.	Directional impinging jet and swirl sprays. Non-directional impinging jet sprays. All from single nozzles.	Downward within an angle of 25° to the vertical from a height of 8 ft.	50	0.07-1.0	0.7 ±0.2	0.4 to 0.6 ±0.2	1.7 ±0.4
6	5	3 ft. and 4 ft. diameter transformer oil fires in a roofless structure. Preburn 300 secs.		Downward from height of 8 and 15 ft.	83	0.09-1.4	0.4 ±0.2	0.0 to 0.2 ±0.1	1.3 ±0.3

TABLE 4

Values of the efficiency exponent E for different practical conditions

Test series (see tables 2 and 3)	Increase in pressure up to 100 lb/in.^{2}						Increase in pressure above 100 lb/in.^{2}					
	Given nozzle		Given manpower		Given pump-power		Given nozzle		Given manpower		Given pump-power	
	Q	Q_1	Q	Q_1	Q	Q_1	Q	Q_1	Q	Q_1	Q	Q_1
1	2·66 ±0·51	2·16 ±0·51	0·68 ±0·51	1·18 ±0·51	-0·31 ±0·82	0·69 ±0·82	-	-	-	-	-	-
2	-	-	-	-	-	-	0·73 ±0·25	0·23 ±0·25	0·09 ±0·25	0·59 ±0·25	-0·23 ±0·40	0·77 ±0·40
3	-	-	-	-	-	-	0·89 ±0·23	0·39 ±0·23	-0·47 ±0·23	0·03 ±0·23	-1·14 ±0·23	-0·14 ±0·23
4	3·7 ±0·7	3·2 ±0·7	0·7 ±0·7	1·2 ±0·7	-0·7 ±1·1	0·3 ±1·1	2·2 to 3·0 ±0·7	1.7 to 2.5 ±0·7	-0·8 to 0·0 ±0.7	-0·3 to 0·5 ±0·7	-2·2 to -1·4 ±1·0	-1·2 to -0·4 ±1.0
5	1·6 ±0·3	1·1 ±0·3	-0·1 ±0·3	0·4 ±0·3	-1·0 ±0·4	0·0 ±0·4	1·2 to 1·4 ±0·3	0·7 to 0·9 ±0·3	-0·4 to-0·2 ±0·3	0·1 to 0·3 ±0·3	-1·3 to -1·1 ±0·4	-0·3 to -0·1 ±0·4
6	1·1 ±0·25	0·6 ±0·25	-0·3 ±0·25	0·2 ±0·25	-1·0 ±0·35	0·0 ±0·35	0·7 to 0·9 ±0·2	0·2 to 0·4 ±0·2	-0·7 to-0·5 ±0·2	-0·2 to 0·0 ±0·2	-1·4 to -1·2 ±0·2	-0·4 to -0·2 ±0·2