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JOINT FIRE RESEARCH ORGANIZATION

THE USE OF WETTING AGENTS FOR FIREFIGHTING
II. THE EXTINCTION OF FIRES IN FIBROUS MATERIALS

by

P.C. Bowes and G. Skeet

Summary

Water containing a wetting agent, "Wet Water", has been compared with plain water for the extinction of a test fire in straw.

The main conclusion is that wet water will be more effective than plain water for the extinction of fire in fibrous materials that are not easily wetted by plain water and are packed so densely that plain water cannot easily penetrate.

This conclusion does not necessarily imply that wet water should be used in practical firefighting. The question of practical application is discussed in Part 1, where it is pointed out that the decision to use wet water depends on a number of factors, some of which may prove to be adverse to an extent that outweighs any advantage arising from increased effectiveness for fire extinction.

Note

This note supersedes the brief account of the fire extinction ~~lists~~ tests on straw given in Part I (F.R. Note 135, pp. 7-8), this account requires revision in detail now that the investigation is complete. The conclusions in Part I are not affected.

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1. INTRODUCTION

When fire occurs in stocks of fibrous material it spreads rapidly over the surface and penetrates into the interior of individual stacks to produce deep-seated smouldering fires. These deep-seated fires usually continue to burn after the surface fire has been extinguished, and can be extinguished only by dismantling the stacks and applying water to each pocket of fire as it is discovered. This operation may take anything from a few days to several weeks to complete.

Published experiences of the use of solutions of wetting agents ("Wet water") for dealing with fires of the above type, and some accounts of tests under controlled conditions, were reviewed in Part I (1)*. Both the experience and the tests suggested that the use of wet water enables faster control of such fires and reduces the residue of deep-seated smouldering. It was considered that the use of wet water for such fires was worth further investigation.

This note gives an account of an investigation in which wet water was compared with plain water for the extinction of fires in straw. Straw was chosen for the test fires because it was a readily available material of the required type.

2. EXPERIMENTAL AND RESULTS

2.1. General

2.1.1. Method. The method of Bryan and Smith (3) was used in which the test fire was rotated slowly about a vertical axis, and the water was applied by means of a mechanically operated jet that oscillated on a pivot in a vertical plane through the centre of the fire. The jet was placed so as to cover the top and side of the fire.

2.1.2. Apparatus. The general arrangement of the apparatus is shown in Figure 1. The test fire was supported on a turntable on a hydraulic jack and rotated at 6.98 r.p.m. Changes in the weight of the fire were observed by means of a pressure gauge in the hydraulic system, and could be measured to within about 3 per cent. The jet was driven at a rate of 57·6 oscillations per minute and it retraced its path over the fire at every fourth revolution of the turntable.

A fixed gutter below the rim of the turntable collected the water that ran off the fire, and a hood behind the fire collected that part of the applied water that overshot the fire as the burning straw diminished in volume. The water that ran-off ("run-off") and the water that overshot the fire were measured in all tests.

Both the wet water and plain water were initially supplied from graduated tanks under air pressure, but in the later series of tests the plain water was taken direct from the main. A 5/32 in. jet was used and the delivery was 3·03 gal/min.

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*Since Part I was written a paper by Bertschy et al (2) has been received in which it is shown that wet water is more effective than plain water for the extinction of a test fire consisting of a loose layer of cotton waste ignited after sprinkling with petrol. The water was applied as a coarse spray.

The plain and wet water were supplied alternately to the jet through the same pipe system. Before tests with plain water the pipe system was washed free of wetting agent by allowing plain water to flow through for fifteen to thirty minutes. Surface tension measurements on the plain water showed that this washing was usually adequate. However, after several months' use it was found that plain water would become slightly contaminated with wetting agent if allowed to stand in the pipe system for long. This effect appeared to be due to absorption of wetting agent by the short lengths of rubber hose in the pipe system, and it was remedied by replacement of the hose.

The tests were carried out in a shed that was free from draughts producing any obvious effect on the test fires.

2.1.3. Test fire. Wheat straw was used in all tests. Three main series of tests were carried out, for each of which a single consignment of straw was used. As far as could be judged each consignment consisted of straw from a single type of wheat, with a proportion of grass and weeds, but the quality or, possibly, the variety differed from one consignment to another.

In the first two series of tests the straw was packed at chosen densities, and as uniformly as possible, in cylindrical baskets of 6 in. steel mesh 36 in. high and 23 in. in diameter. In the third and fourth series mechanically packed bales were used.

The fire was ignited either externally, by the application of a blowlamp to the bottom edge for one or two revolutions of the turntable, or internally by means of an electrically-fired incendiary device placed in the centre. The incendiary device was based on a fixed weight of a mixture of sawdust and potassium nitrate in the proportions of about 5 : 1 by weight.

2.1.4. Wetting agent. The wetting agent, a non-ionic type, was an aqueous solution of an alkyl-phenyl substituted polyethylene glycol and was used at a dilution containing 2 per cent by volume of the stock solution. This dilution corresponded to a concentration of approximately thirty-five times the minimum concentration of stock solution required to give the maximum lowering of surface tension.

2.1.5. Test procedure. Each series of tests differed slightly in detail, as will be described below, but the general procedure was to ignite the straw, allow a certain preburn, and then to apply a fixed quantity of water. The basket or bale was then removed from the turntable, set aside for a certain time, and finally examined for signs of rekindling. The standing period provided an opportunity for a partly extinguished fire to die out; it was assumed that if the residual fire did not die out in the period allowed, it was of sufficient magnitude to constitute a hazard in practice.

Five tests were carried out for each of a series of increasing applications of both wet and plain water, with the object of determining the range of applications within which the proportion of the fires that were extinguished changed from a low to a high value.

The appropriate series of applications of water to use could not be decided beforehand but had to be found by actual trial. On the basis of a few tests it was possible to estimate roughly the range within which it was worth while carrying out the full number of tests; although some adjustment, such as extension of the upper or lower end of the range, was sometimes necessary at an advance stage. Within this scheme the order in which the tests in a series were carried out was randomised as far as possible.

2.2. Series 1. Tests with straw at low packing density. External ignition

In these tests the straw was packed at a mean density of $2{\cdot}2 \pm 0{\cdot}03$ lb/ft^3 and had a total weight of 19 lb. This density was chosen by trial as resulting in a fire that, following external ignition, burnt fairly freely, and also penetrated underneath and into the straw to become partly inaccessible to direct application of the water jet.

The mean moisture content of the straw was 12 per cent.

A preburn period of 3 minutes was used in these tests; during this period the loss in weight was $5{\cdot}5 \pm 0{\cdot}5$ lb. The jet was in position A shown in Figure 1.

Following application of the water the basket was set aside for 15 minutes. If the fire had not been extinguished the evolution of steam and smoke increased during this period and, on tipping out the contents of the basket, some part of the straw near the bottom would glow or rekindle into flame. If this glowing or rekindling did not occur the fire was judged to be out - even if, as happened on a few occasions, a small amount of smoke was still being given off at the end of the fifteen minutes.

Stages in a typical test are shown in Plate I; plain water was used in the test shown and the fire was not extinguished.

Results. The results of the thirty-five tests in this series are given in Table 1 which gives the number of fires extinguished in five tests at each of the specified applications of wet and plain water. The amounts of water applied, as given in the table, are mean values for each group of five tests and represent water that actually reached the fire, i.e. the water delivered by the jet less that which overshot the fire. The corresponding times of application given in the table are calculated from the rate of delivery of 3·03 gal/min and represent the time for which the jet was actually hitting the bale.

Table 1 includes the mean value of the run-off, for each group of five tests, expressed as a percentage of the application; and also the mean value of the weight of water present in unit weight of straw in the bale, at the end of the application, for each group of five tests. The latter quantity will be called the Specific Water Load; it is the ratio of the difference between the application and the run-off* to the weight of the bale at the end of the preburn. The range of variation of the above quantities is indicated in this, and in later tables, by a single standard deviation calculated for each complete set of results for plain water and wet water.

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* The change in weight of the straw during the application of water would have been preferable for the purpose of calculating the specific water load, but for reasons found after the tests the ram pressure readings in this series of tests could not be regarded as trustworthy for obtaining the change in weight.

Table 1

Results of fire extinction tests (Series 1)

Straw density 2·2 lb/ft^3. External ignition. Five tests at each application

Water applied. gal (± 4 percent)	4·7	5·5	6·1	6·7	S
Time of application. min	1·55	1·82	2·02	2·21	
Fires extinguished. Plain water	1	1	4	5	-
Fires extinguished. Wet Water	2	1	3	-	-
Mean run-off. Per cent. Plain water	33	39	43	48	3
Mean run-off. Per cent. Wet water	29	37	38	-	3
Mean specific water load. Plain water	2·33	2·40	2·54	2·50	0·19
Mean specific water load. Wet water	2·43	2·54	2·82	-	0·18

S = standard deviation.

It is concluded from the results in Table 1 that there was no difference between the ability of wet water and plain water to extinguish the test fires. The number of extinctions in five tests increased from one to three or more when the amount of either wet or plain water applied was increased from 5·5 to 6·6 gal; i.e. when the time of application was increased from 1·82 to 2·02 min. or more.

Analysis of the complete set of results showed that, as the mean values given in Table 1 indicate, there was no significant relation between the specific water load and the amount of plain water applied within the range of applications covered; but, for wet water, the specific water load underwent a significant increase as the application was increased. (The correlation coefficients were 0·41 for the twenty tests with plain water and 0·74 for fourteen tests with wet water).

Table 2 compares the mean specific water load for bales in which the fire was extinguished with that for bales in which fire was not extinguished. For wet water, data at applications of 4·7 and 6·1 gal. are used and analysed separately; but, for plain water, the data for all tests have been used together since the specific water load was independent of the application (above).

Table 2

Relation between extinction and specific water load

	Wet water				Plain water	
	O	N	O	N	O	N
Mean application. gal.	4•7	4•7	6•1	6•1	-	-
Number of tests	2	3	3	2	11	9
Mean specific water load	2.47	2•40	2•67	3•04	2•50	2•37
Standard deviation	0•15	0•07	0•10	0•14	0•21	0•14

O = fire out; N = fires not out.

For plain water, and for the 4•7 gal. application of wet water, there is no significant difference between the mean specific water loads for bales in which the fire was extinguished and bales in which fire was not extinguished. For the 6•1 gal. application of wet water the mean specific water load is just significantly greater* for the bales in which fire was not extinguished than for those in which it was. Interpretation of these results is reserved for the discussion later.

At the end of all the tests in this series the straw packing was found to be wetted almost throughout; any fire that survived was found in small dry patches of straw at the bottom of the basket.

In these, as in all later tests, the flames from the surface fire were extinguished so rapidly by both wet and plain water (usually during one revolution of the test fire) that it was not possible to detect a difference between wet water and plain water in this respect.

A considerable amount of steam and smoke was produced during the application of the water in these tests and the amount appeared to be greater with wet water than with plain water.

2.3. Series 2. Tests with straw at intermediate packing density. Internal ignition

In this series of tests the straw was packed to a depth of 30 in. in the fire basket, and at the highest density that could be achieved by hand packing; the mean density was $3•5 \pm 0•2$ lb/ft^3.

The position of the jet in relation to the fire was changed to the position B shown in Figure 1 so that a high proportion of the water was applied to the top of the straw. The position of the collecting hood was altered correspondingly.

The straw was ignited in the centre. When the igniter had been fired the straw smouldered slowly, for a period that varied between about ten and thirty minutes, until the fire reached the outside of the bale; flame then appeared and spread over the outside. The water was applied at the nearest whole minute after the first appearance of flame.

The standing period following the application was fifteen minutes. The criterion of extinction was the absence of smouldering straw when the straw was unpacked at the end of the standing period.

The results are given in Table 3. It was possible to carry out only three tests at each application, and the table gives the number of extinctions in each group of three.

*"t" = 3•38 and has a probability of about 4 per cent for 3 degrees of freedom.

Results of fire extinction tests (Series 2)

Straw density 3.5 lb/ft ^{3}. Internal ignition.

Three tests at each application

Water applied. gal. (± 3 per cent)	9.4	14	19	24
Fires extinguished.				
Plain water	-	1	3	1
Wet water	1	0	2	-

The results in Table 3 show no difference in the effectiveness of plain and wet water in this series of tests. Also there is no clear relationship between the proportion of fires extinguished and the amount of either wet water or plain water applied.

During the preburn period discoloration of the straw sometimes extended to the top of the packing, and heavy charring extended to within a few inches of the top; but the fire always broke out either at the bottom of the packing or at a point not more than half way up the side.

In this series of tests, and in subsequent series in which the bales were ignited internally, it was found that the charred region inside the bale varied considerably in size, shape, and position.

It was noticed that, as would be expected, the wet water formed a continuous film on the straw while plain water tended to form drops; but, also, plain water formed a continuous film on straw that was discolored by what appeared to be tarry products from the smouldering fire. This latter effect would tend to diminish any difference in the ability of plain water and wet water to penetrate to the seat of the fire.

2.4. Series 3. Tests with straw bales of high density. Internal ignition

Mechanically baled straw was used in this series. The mean weight of the bales as used was 37.5 lb and the dimensions were 20 x 24 x 18 in. The mean density was 7.5 ± 0.5 lb/ft^3, and the moisture content of the straw was 14 per cent.

The bales had a layer structure with the straw strands flattened in the plane of the layers. The bales were placed on the turntable with these layer planes horizontal, since it was thought that, in this position, they would present the greatest resistance to penetration by water applied mainly from above.

The jet was in position B relative to the bale (Figure 1) and its amplitude of oscillation was adjusted to cover the longest diagonal of the bale. Because the bales were rectangular it was inevitable that, at times during the rotation of a bale, the applied water failed to strike the bale when the jet was at either end of its traverse; the water that missed at the lower end of the traverse became included in run-off.

Following ignition at the centre, bales smouldered for periods that varied between 16 and 124 minutes before flame appeared on the outside. As in the previous series of tests the fire broke out either on the under-side of the bale or at a point not more than half way up a side. The application of water was begun at the nearest minute after the first appearance of flame. The loss in weight during the total preburn period, including smouldering and flaming was 1.7 ± 1.3 lb.

After the application of water, bales were removed from the turntable and allowed to stand for thirty minutes before being taken apart. If a bale had not been extinguished signs of rekindling were sometimes evident during the thirty minute standing period, but the ultimate decision on extinction was always based on examination of the interior.

Plate 2 shows stages in a typical test of this series. The bale shown rekindled within thirty minutes of the end of an application of 25•3 gal. of plain water.

The results of the tests in this series are given in Table 4. The table includes the mean run-off expressed as a percentage of the application, and the mean specific water load in the bales at the end of the applications. The specific water load is, here, the ratio of the increase in weight of the bale during the application of water, as measured on the turntable, to the weight of the bale at the end of the preburn.

Table 4

Results of fire extinction tests (Series 3)

Straw density 7•5 lb/ft^3. Internal ignition
Five tests at each application

Water applied. gal. (± 3 per cent)	9•2	14	19	24	27	37	S
Time of application. min.	3•4	4•6	6•3	7•9	8•9	12•2	
Fires extinguished.							
Plain water	-	-	-	2	3	4	
Wet Water	1	5	5	-	-	-	
Mean run-off. Per cent.							
Plain water	-	-	-	81	87	95	5
Wet water	49	60	63	-	-	-	8
Mean specific water load.							
Plain water	-	-	-	1•01	0•97	1•06	0•30
Wet water	1•58	1•94	2•34	-	-	-	0•23

S = standard deviation

It will be seen from Table 4 that with wet water the number of fires extinguished in five tests at each application increased from one to five when the amount of water applied was increased from 9•2 to 14 gal.; with plain water the number of fires extinguished increased from two to four out of five when the application was increased from 24 to 37 gal. Wet water was clearly more effective than plain water, and it may be estimated that an application of from two to three times as much plain water as wet water was required to achieve a high proportion of extinctions in this series of tests.

The specific water load increased with the amount of wet water applied but was independent of the amount of plain water applied, within the ranges of application covered. (The correlation coefficients, calculated from the complete set of results, were 0•83 for the wet water tests and $<$ 0•1 for the plain water tests).

In Table 5 the mean specific water load for bales in which fire was extinguished is compared with that for bales in which fire was not extinguished. Of the wet water results those obtained at the application of 9.2 gal. only have been used for this purpose, but for plain water the results of all tests have been used.

Table 5

Relation between extinction and specific water load

	Wet water		Plain water	
	O	N	O	N
Number of tests	1	4	9	6
Mean specific water load	1·48	1·61	0·94	1·09
Standard deviation	-	0·13	0·33	0·19
O = fires out; N = fires not out.				

There is no significant difference between the mean specific water loads for bales extinguished and bales not extinguished, either for wet water or plain water*.

Some of the bales were weighed at the end of the standing period before they were dismantled. At the end of this period drainage had practically ceased and the weight of water retained in the bales was about 1·2 lb per pound of straw for wet water and about 0·5 lb per pound of straw for plain water.

Most of the bales treated with wet water were found to be saturated when opened, but a few had small patches of dry straw near the bottom - apart from the patch were fire survived.

A few of the bales treated with plain water were also found to have patches of completely dry straw inside. Most of them, however, appeared to have water distributed throughout (except of course where the fire survived); but, in so far as a proportion of the water was present as droplets, the straw was only partially wetted.

2.5. Series 4. Further tests on straw bales of high density. Internal ignition

A further series of tests of the same kind as Series 3 was carried out on a new batch of wheat straw. The straw had been combine harvested and the bales were smaller than before; their dimensions as prepared for test were about 13 x 18 x 18 in., and their mean density was $7{\cdot}3 \pm 0{\cdot}6$ lb/ft^3. The mean moisture content of the straw was 20 per cent, which was considerably higher than in previous tests.

The test procedure was altered in this series in that the bale was left to stand on the turntable for 30 minutes after the application of water, and it was weighed on the turntable both at the end of the application and at the end of the standing period. The time taken for the fire to burn to the outside of the bale varied between 10 and 138 min. and the mean loss of weight in the preburn period was $1{\cdot}5 \pm 0{\cdot}8$ lb.

*"t" has a probability greater than 10 per cent in both cases. It may be noted that, for the plain water data, a difference between the mean specific water loads of 0·31 would be required for significance at the usual 5 per cent level.

The results of the tests of this series are given in Table 6. The number of fires extinguished is expressed in the table as a fraction of the number of tests at each application, since this number was not constant as hitherto. The run-off includes drainage during the standing period and, as before, it is expressed as a percentage of the application. In addition to the mean specific water load the table includes the mean weight of water per unit weight of straw present in the bales, after draining for 30 min., for each set of tests at a given application. This latter quantity will be called the Mean Specific Retention. Both quantities are calculated from weighings on the turntable.

Table 6

Results of fire extinction tests. (Series 4)

Straw density 7·3 lb/ft ^{3}. Internal ignition

Water applied. gal. (± 2 per cent)	5·3	7·2	9·1	S
Time of application. min.	1·75	2·4	3·0	
Fires extinguished.				
Plain water	-	4/7	4/5	-
Wet water	2/5	5/5	-	-
Mean run-off. Per cent.				
Plain water	-	80	76	9
Wet water	57bn	67	-	10
Mean specific water load				
Plain water	-	1·55	1·42	0·20
Wet water	1·78	2·12	-	0·65
Mean specific retention.				
Plain water	-	0·70	0·70	0·16
Wet water	1·09	1·18	-	0·35

S = standard deviation

The results in Table 5 show that wet water was more effective than plain water in this series of tests, but the difference in the effectiveness of the wet and plain water was less than in series 3. It may be estimated that the amount of plain water that had to be applied to achieve a high proportion of extinctions was between 1 and 1½ times the amount of wet water required.

The specific water load and the specific retention were independent of the amount of water applied for both wet water and plain water. Data for all tests have therefore been used for the comparison, in Table 7, of the mean specific water loads, and also the mean specific retentions, for bales in which fire was extinguished and for bales in which it was not. There is no significant difference between the means for either quantity, either for wet water or plain water.

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Table 7

Relation of extinction to specific water load and specific retention

	Wet water		Plain water	
	O	N	O	N
Number of tests	7	3	8	3
Mean specific water load	1·98	1·87	1·52	1·36
Standard deviation	0·36	0·63	0·21	0·11
Mean specific retention	1·16	1·08	0·72	0·65
Standard deviation	0·21	0·61	0·13	0·20

O = fires out; N = fires not out.

In this series of tests the mean specific water load for wet and plain water (Table 6) do not differ by as much as in series 3; thus they are about 2·0 and 1·5 for wet and plain water respectively, compared with about 2·0 and 1·0 respectively in series 3.

Examination of the bales after the tests in this series showed that all bales on which plain water had been used, and all but two of the bales on which wet water had been used, contained patches of dry straw additional to those in which fire survived; occasionally these dry patches were fairly extensive.

3. DISCUSSION

3.1. Results of investigation

In all the tests carried out in this investigation, even including those in which the straw was ignited externally, extinction of the fire depended on penetration of the applied water into the bale. It is appropriate, therefore, to discuss the results in terms of the time for which water was applied, rather than of the amount applied.

The relative effectiveness of wet water and plain water for extinguishing the test fires varied from one series of tests to another. In series 3 and 4 the use of wet water effected a high proportion of extinctions, in replicated tests, after a shorter time of application than was required with plain water; and the specific water load was higher at the end of the applications of wet water than it was for plain water. It may be concluded that, in these two series, wet water penetrated the straw both more rapidly and more extensively than did plain water. This conclusion implies that the penetration of plain water was hindered by opposing capillary forces due to the straw having been not easily wetted by plain water. But, in the absence of an independent wetting test, it cannot be decided whether the similarity in the fire extinction results for wet and plain water in series 1 was the result of easier penetration by plain water due to the lower packing density of the straw or to the straw having been as easily wetted by plain water as it was by the wet water.

Over the range of application times used in each series of tests, i.e. over ranges within which there was an increase in the proportion of fires extinguished at a given time of application, the mean specific water load at the end of an application tended to be constant independent of the application time for each series of tests with plain water and for the tests with wet water in series 4. In series 1 and 3 the mean specific water load increased slightly with increasing applications of wet water.

In all series of tests but one, with both wet water and plain water, there was no significant difference between the mean specific water loads for bales in which fire was extinguished and for bales in which fire was not extinguished; the exception was a group of five tests with wet water (Table 2) in which the specific water load tended to be higher for bales in which fire was not extinguished. Similarly, there was no significant difference between the mean specific retention, after drainage, for bales in which fire was extinguished and for bales in which it was not.

The results summarised in the two preceeding paragraphs imply that any additional quantity of water that may have been required in the bales to bring about the change from a low to a high proportion of extinctions was small compared with the variations in specific water load between bales in a series. After most of the tests in series 1 and 3, both the wet water and plain water were found to be distributed almost throughout the bales; there was no large difference, that could be detected at sight, in the distribution of water in bales in which fire was extinguished and in those in which fire was not extinguished. It is probable, therefore, that in all series of tests the water load at the lower times of application was not far from the minimum required for a high proportion of extinctions.

It appears that water loads of the order of 1·0 lb and 1·5 lb of plain water per pound of straw, in series 3 and 4 respectively, were sufficient for extinction of the fire. Extinction with wet water in these series entailed water loads of the order of 2·0 lb per pound of straw. By comparison with plain water the extent of the penetration by wet water, in the time required to reach the fire and extinguish it, was greater than necessary; the wet water may have penetrated appreciably into the straw itself.

3.2. Extinction mechanism

The following simple picture of the way in which the fires in the straw bales were extinguished in these tests accords with the above results.

The momentum of the water jet applied to the straw bales will be largely destroyed within a short distance of the surface. Further penetration of the water into the bale will then be under the influence of gravity, assisted or hindered by capillary forces according to whether the water does or does not wet the straw. Owing to local variations of packing density, the arrangement of the straw, and the extent to which the straw is wetted, some paths will be more favourable than others to the penetration of water through a bale; so the rate of penetration will vary in different parts of the bale.

It is therefore reasonable to suppose that the extinction of a fire in a bale of straw, or indeed any other similar material, depends on the building-up of a head of water in the bale and on maintaining the head for a time sufficient to ensure penetration throughout the bale. Given the necessary head, penetration can proceed in any direction dictated by the local structure of the bale. If the application of water is discontinued too soon the head of water will be destroyed by drainage through the more favourable paths, the penetration along less favourable paths will slow down and eventually stop, and the fire will be likely to survive in the dry patches of straw that remain.

The water load in the bale at any instant may be regarded as consisting of water that will be lost by drainage when the application is stopped, and water that will remain when drainage ceases; it is largely the former that provides the head of water for penetration. When the water load reaches a maximum the rate of drainage, or run-off, will equal the rate of application.

The above would explain how fires in the tests described in this report were able to survive the standing periods, which were long compared with the application times, in spite of the fact that the water load at the end of an application was nearly sufficient for extinction of the fire.

The above remarks apply to the penetration of both plain and wet water. With wet water, however, the capillary forces will always favour penetration. Capillary forces become relatively more important in controlling the penetration of a liquid into a porous solid as the pore size is reduced. Hence, the difference in the rates of penetration of plain water and wet water into a mass of fibrous material that is not easily wetted by plain water will increase as the packing density of the mass is increased.

With water applied to a bale of straw at a steady rate, the maximum specific water load will depend on the packing density, which will determine the total voids; on the stem diameter and wall thickness, which will determine the proportion of the total voids available to the passage of water; and on the extent to which the straw is damaged and water is able to enter the stem cavities. These factors, and hence the maximum specific water load, may be expected to vary between bales in a given batch of straw and also, perhaps even more widely, between batches of straw from different varieties or species of plant.

4. CONCLUSIONS

The following conclusions are concerned solely with the relative effectiveness of wet water and plain water for the extinction of fires in fibrous materials. The application of these conclusions, and other factors, to the use of wet water in practical firefighting are discussed in Part 1 (1)

1. Wet water was more effective than plain water for the extinction of a submerged fire in a closely packed bale of straw, but no difference was found between wet and plain water used to extinguish a fire in straw that was packed relatively loosely.

2. The relative effectiveness of wet water and plain water differed for different batches of straw.

3. In those series of tests in which wet water was more effective than plain water for fire extinction the weight of water held by unit weight of straw, at the end of an application of water sufficient to effect a high proportion of extinctions in replicated tests, was higher when wet water was used than when plain water was used.

4. Also, in those series of tests in which wet water was more effective for fire extinction, the run-off was less, both in proportionate and absolute amount, when wet was used than when plain water was used.

5. It is believed that the factors controlling the relative fire extinction ability of wet and plain water are sufficiently well understood for the results of this investigation to be extended to all fibrous materials.

6. Thus, wet water will be more effective than plain water for the extinction of fire in fibrous materials that are not easily wetted by plain water and are packed so densely that plain water cannot easily penetrate.

7. With materials less easily wetted than straw the difference in the effectiveness of wet water and plain water may be expected to be greater than observed above for straw at comparable packing densities; with materials that are more easily wetted the difference in effectiveness will be less.

8. A water penetration test should enable a preliminary selection to be made of materials on which wet water might be worth using as a fire extinguisher. Since the rate of penetration, the water load, and the run-off are all factors pertinent to the evaluation of wet

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water for firefighting, it is suggested that the penetration test could, in fact, be a determination of the time taken to achieve a maximum water load, or an arbitrary fraction of the maximum, using the method and conditions of the present investigation.

9. The above conclusions are considered to apply only to the extinction of fires by the simple application of water. If the fibrous material is pulled apart or turned over during the attack on the fire, plain water may be found to be almost as effective as wet water for extinction.

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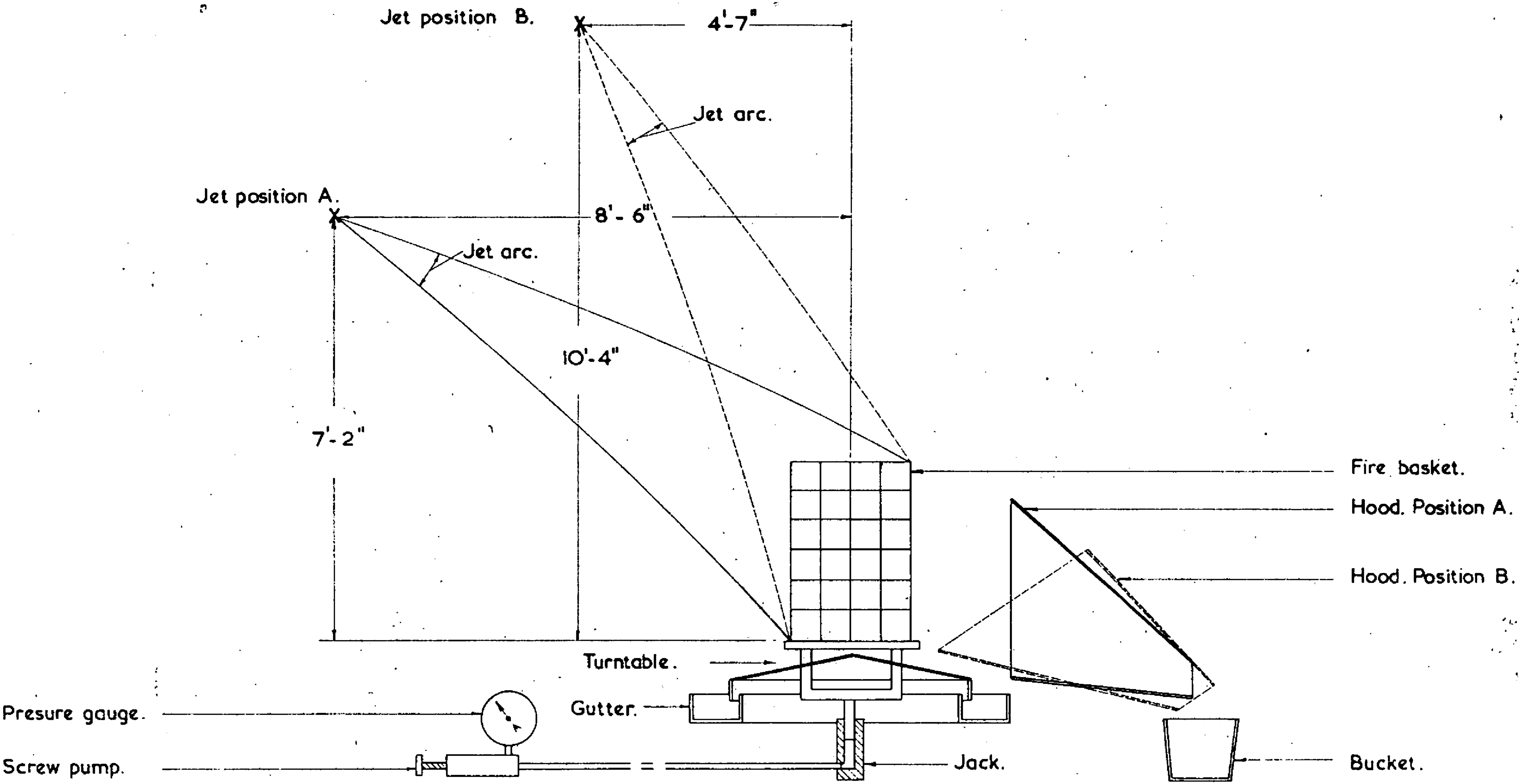
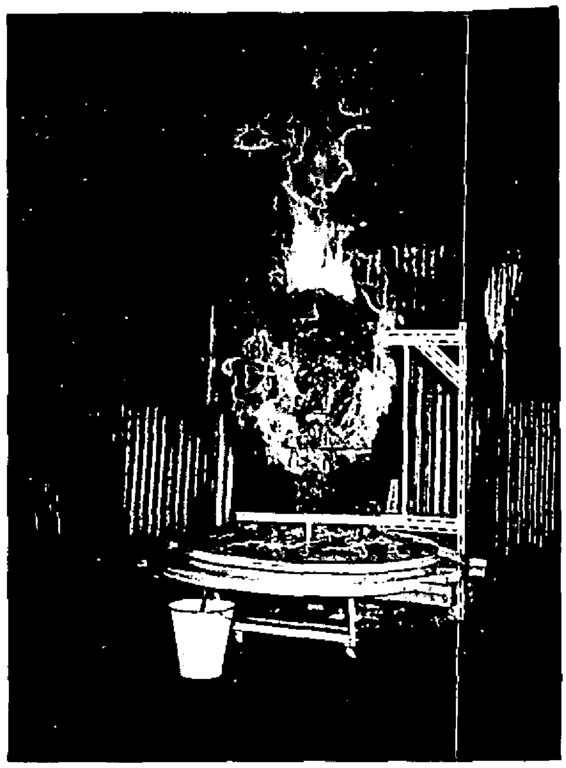
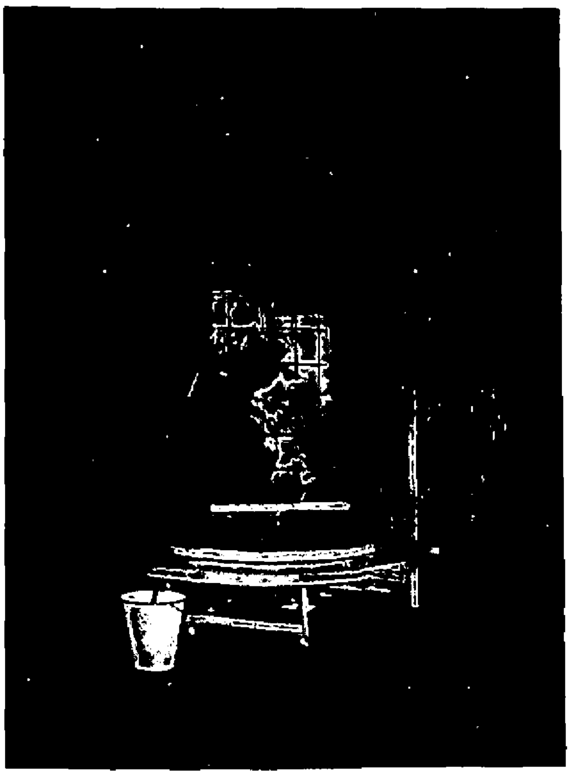


FIG. 1. ARRANGEMENT OF APPARATUS FOR FIRE EXTINCTION TESTS.

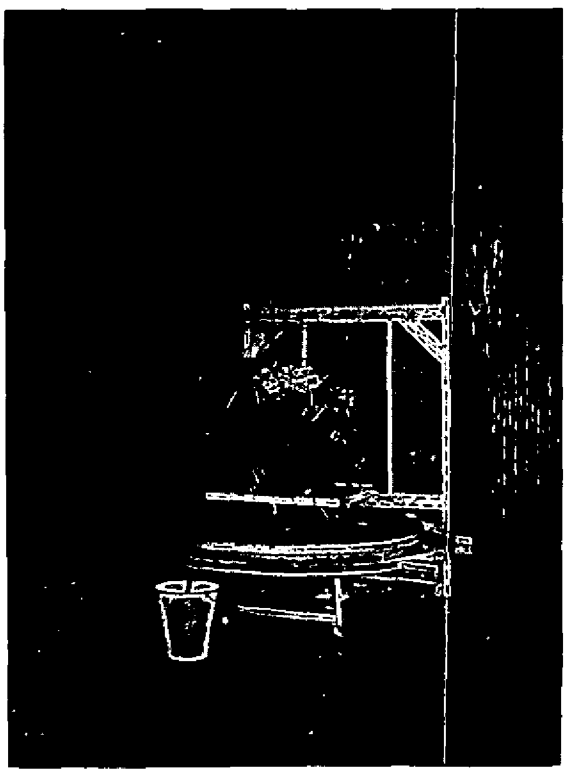
IGNITION OF STRAW



FIRE JUST PRIOR TO ATTACK
(3 min PREBURN)



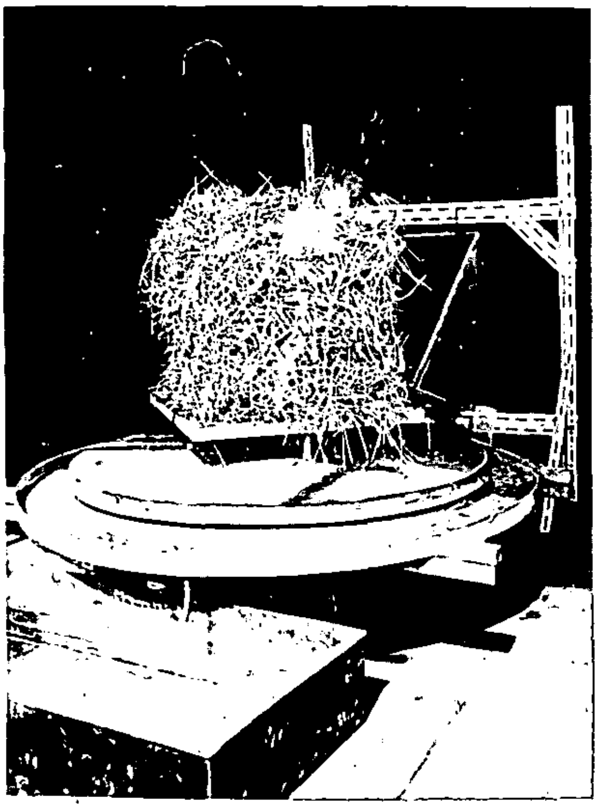
APPLICATION OF WATER



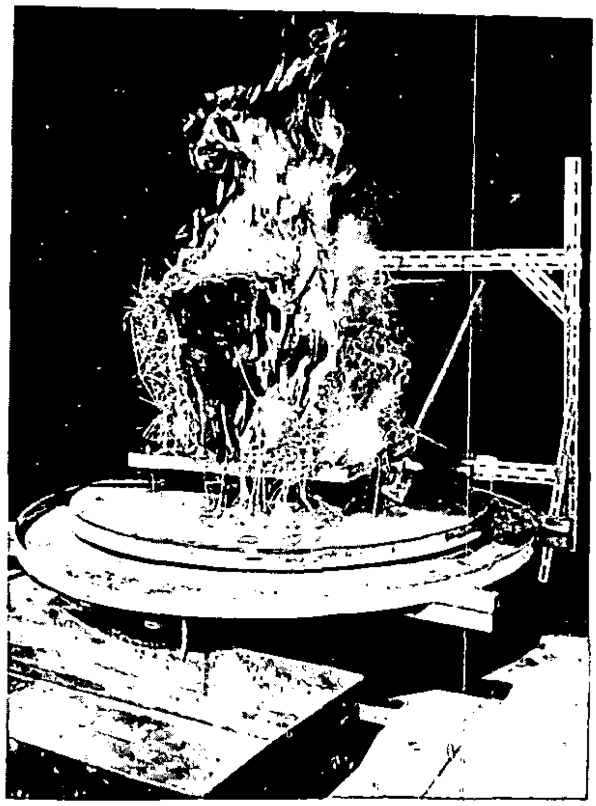
END OF APPLICATION. OF
5·5 gal. FIRE WAS NOT
EXTINGUISHED

PLATE. I. FIRE EXTINCTION TESTS WITH STRAW
PACKED AT 2·2 lb/ft^3

DS96505/1 147 60 10/55CL

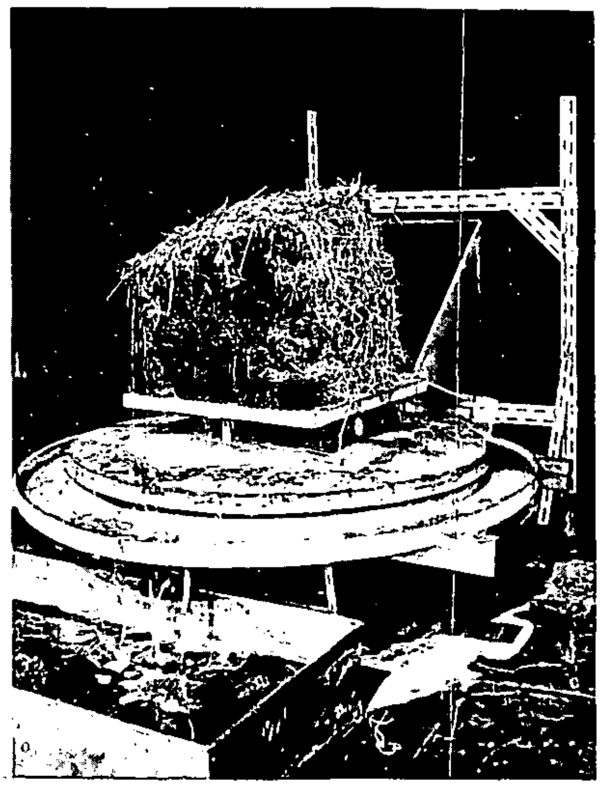


BALE SMOULDERING AFTER IGNITION IN CENTRE



FIRE BREAKS OUT AND SPREADS OVER OUTSIDE OF BALE
(104 min AFTER IGNITION)

APPLICATION OF WATER



BALE AFTER APPLICATION OF 25·3 gal. FIRE WAS NOT EXTINGUISHED

PLATE. 2. FIRE EXTINCTION TEST WITH STRAW BALE AT $7 \cdot 5$ lb/ft^3

DS96505/2 147 60 10/55CL