CONFIDENTIAL

F.R. Note No. 126/1954
Research Programme
Objective B5/3C

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THE SPONTANEOUS HEATING AND IGNITION OF WET COTTON BALES

BY

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Summary

A review has been made of the fire hazards associated with the carriage and storage of baled cotton, with special reference to the possibility of spontaneous heating and ignition in wet bales.

It has been concluded that spontaneous ignition is unlikely to occur in wet cotton bales.

A clear distinction should be made between wet bales that have been salvaged from a fire and those that have not. The former must be regarded as highly dangerous in view of the possibility that internal smouldering may escape detection and cause a fresh outbreak of fire after a period of weeks. Salvaged bales that have been carefully "picked" are likely to be free from risk of rekindling.

August, 1954.

File No. F.1040/17/4

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"known causes" of a series of 346 cotton warehouse fires.

No actual examples have been quoted to show the length of time for which a fire-packed bale may smoulder. O'Sullivan [8] indicates that a suspected bale should be quarantined for at least 48 hours but may be considered safe only if no fire breaks out within a week; Lucas [5] quotes estimates of from three to eight days as the time taken for fire to break out. For reasons that will appear later seven or eight days is probably an underestimate of the maximum time.

THE BEHAVIOUR OF COTTON BALES INVOLVED IN FIRES

As in many fires that involve bales of fibres, the complete extinction of well established fires in stocks of baled cotton cannot be effected in the initial attack; smouldering persists and can be extinguished only by removing the bales, and applying water to each one affected (Appendix). Such smouldering has been known to persist for seven weeks [9].

An effect that appears to be especially marked in cotton bales is the tendency for fire to burrow deeply into a bale and to smoulder for long periods after the fire on the outside of the bale has been extinguished. As in fire-packed bales, the smouldering may continue with no outward sign until it eventually breaks out at the surface again - although not, presumably, until the outside of the bale has dried.

This effect appears to have been first studied and described by Höpke [9] who published drawings of a bale that was relatively lightly damaged on the outside, in a warehouse fire at Bremen in 1892, but contained two cavities in the interior that originated from points on the outside and were still smouldering actively fourteen days after the fire. He stated that many similar bales were found. On another occasion Höpke observed the re-kindling of a lightly damaged bale that remained in the debris for seven weeks after a fire; this, and other bales, had been under observation for most of the period and all fire was thought to have been extinguished. Again, a bale that had been involved in a fire in Bremen floated in the river Weser for three or four weeks before being retrieved; it then appeared to be undamaged but, when the bands were loosened, flames shot out of the interior.

More recent examples observed by members of the Liverpool Salvage Corps are described in the Appendix. In particular, a salvaged bale was seen to re-kindle suddenly after standing in an open yard with others for three weeks, and bales that had floated in a canal for two weeks after a fire were found to have fire still in them; one of these last had smouldered to ashes in the interior.

The points at which smouldering has penetrated into a bale are often difficult to detect, although smouldering in the interior may be extensive. Where, however, a salvaged bale has had the damaged outer layers picked off by hand until dry undamaged cotton is reached (Appendix), it should be possible to make quite sure that the bale is free from internal smouldering.

Cotton bales vary widely in density and, according to Lucas [5], all the serious fires involving cotton bales in Egypt occur in the low density bales from the ginneries, either during transport to Alexandria or in storage there. These bales have densities of between 12.5 and 19 lb/ft^3. At Alexandria the cotton is rebaled for export in bales of density about 38 lb/ft^3, and Lucas states that very few fires originate in these bales.

No information has been found to show how the tendency for cotton bales to smoulder internally depends on their density. However, some, at least, of the bales in which smouldering was observed by Höpke were of American origin and had a density of about 28 lb/ft^3.

THE SPONTANEOUS HEATING AND IGNITION OF WET COTTON BALES

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INTRODUCTION

In response to an enquiry by the Ministry of Transport and Civil Aviation a review has been made of the fire hazards associated with the carriage and storage of bales of raw cotton, with special reference to the possible occurrence of spontaneous heating and ignition in wet bales. The enquiry covered bales that have been wetted by fresh water or sea water, but are otherwise undamaged, and bales that have been salvaged after a fire and have been wetted by water used to extinguish the fire. The review is based on the literature and on information obtained during a visit to the Liverpool Salvage Corps (Appendix).

The reputation of a material for undergoing spontaneous ignition may depend on purely negative evidence, i.e. on the frequent occurrence of fires for which no alternative cause of ignition can be found. Usually, however, there are certain features associated with the outbreak or development of fires in the material that appear to be positive evidence for spontaneous ignition. When evaluating the evidence for spontaneous ignition in a given material it is therefore necessary to consider first all the known ways in which the material may become ignited and also how the material behaves when involved in a fire. This is the course that has been adopted in the following study of fires in cotton bales.

CAUSES OF FIRE IN COTTON BALES, OTHER THAN SPONTANEOUS IGNITION

Causes of fires in cotton have been surveyed recently by Braidech et al [1, 2]. Cotton bales may be ignited by the usual accidental sources such as careless smoking and sparks from locomotives. In addition, friction and impact between the steel ties of adjacent bales, and the fracture of ties, have been cited as causes of the frequent fires which occur during the carriage of cotton bales by rail in the United States [1, 2]. It has recently been reported [3] that the ignition of cotton by the impact between steel ties has been demonstrated experimentally, and it is remarked that this affords an explanation of fires that have hitherto been attributed to spontaneous ignition. Causes of ignition such as the above are likely to be effective mainly with relatively dry bales.

The ignition of cotton by electrical sparks is possible [1-5] although not all attempts to effect it experimentally have been successful [6]; it appears that a train of sparks is necessary [3, 4]. Ignition by electrostatic discharges has been reported to occur only in cotton gins and, in these, only under conditions of very low atmospheric humidity such as occur, for example, in Egypt [5] and in the south-western half of the Cotton Belt in the United States [1, 2]. It would not occur at all in wet cotton bales.

There is one known cause of fires in baled cotton that, so far, appears to be peculiar to cotton and is of interest to the present enquiry. It is the inclusion, in bales, of small locks of cotton that have been ignited in the gin by friction or sparks and have escaped detection. These so called "fire-packed" or "hot" bales may continue to smoulder in the interior for "days or weeks" [1, 2] without any outward sign of fire until, eventually, the smouldering reaches the surface and breaks into flame. Fire-packed bales are regarded as a common cause of outbreaks of fire in storage yards, warehouses, railway wagons and ship's holds. O'Sullivan, [8] Chief Officer of the Memphis Fire Department, states that in a series of 470 cotton fires 55 per cent were caused by fire-packed bales; and statistics [7] published by the National Fire Protection Association show this cause as comprising 25 per cent of the

The difficulty experienced in extinguishing fires in cotton bales depends on the fact that raw cotton is not easily wetted and water penetrates a bale very slowly; the floating bales described above demonstrate this in a striking way.

THE SPONTANEOUS HEATING AND IGNITION OF COTTON

Evidence. Cotton, especially wet cotton, appears to have long had a reputation for being liable to spontaneous ignition. In statistics published by the National Fire Protection Association [7] spontaneous ignition accounts for 10 per cent of the "known causes" of a series of fires in cotton warehouses. It is not stated what proportion, if any, of the fires attributed to spontaneous ignition occurred in wet cotton.

Firth [10] states that clean dry cotton does not undergo spontaneous heating and ignition, and that fires in clean cotton that are apparently due to spontaneous ignition can usually, on further investigation, be shown to have been caused by an external source of ignition. The present survey has produced no reason for doubting this.

On the other hand it is well known that cotton can heat, and sometimes ignite, spontaneously when impregnated with many vegetable and animal oils, or with materials, such as paints, that contain these oils. Experimental studies of the heating and ignition from ordinary temperatures have been confined mainly to tests with the more highly unsaturated oils distributed on cotton waste at relatively low packing densities [11-13]. Marini [14] is reported to have shown that bales of cotton treated with easily oxidisable fat may ignite spontaneously when heated, e.g. by prolonged exposure to the sun's rays.

Spontaneous heating has been observed in piles of wet and slightly heat-damaged cotton that has been removed from salvaged cotton bales (Appendix). No ignition has been observed after as long as three weeks, but prolonged self-heating such as this is accompanied by considerable discoloration of the cotton.

Smith et al [15] found that the piling, in the field, of cotton that had not fully matured, and that contained a high average moisture content owing to the presence of green leaves and green unopened bolls, resulted in damage to the cotton by heating. The highest temperatures recorded in the piles were 133 and 149°F (56 and 65°C). Well matured cotton, relatively free from green matter, sweated slightly but did not heat. In this example heating of the cotton itself is not clearly distinguished from the heating of the foreign green matter.

Sen [16] observed no rise in temperature in either cotton or jute, with a moisture content of 50 per cent, stored in sealed jars under "adiabatic conditions" for seven months.

There appear to be no recorded examples of wet cotton bales undergoing spontaneous heating or ignition. In the Report [17] of the enquiry into the explosion of S.S. "Fort Stikine" at Bombay in 1944 it is stated that heating was observed in salvaged cotton damped with sea water, but it is not clear whether the cotton was loose or in bale. Häpke [9] quotes the experience of Bremen Warehouse Companies and others who, at times during the course of many years, had handled and stored many consignments of cotton wetted both by sea water and by fresh water. Wet patches on bales deteriorated and became pulpy, but although wet bales were sometimes held in storage for periods of months they had never been observed to undergo spontaneous ignition or even heating.

Häpke's study. The only general study of the question of spontaneous ignition in wet cotton that has been found is one published by Häpke [9] in 1893. It has already been referred to above but will here be considered in more detail.

It appears that in the late 19th Century considerable quantities of baled cotton wetted by both sea water and fresh water were transported and stored, and that the standards of practice in the handling of cotton were low. Thus, it was apparently common practice for cotton bales to be carried in open railway waggons with no protection from rain or from sparks from locomotives. Fires were frequent and were commonly attributed to spontaneous ignition, both in wet and dry cotton.

Following a fire that destroyed 50 tons of cotton in five waggons the Reich State Railway banned the carriage of wet cotton by rail on the supposition that it was prone to spontaneous ignition. Chambers of Commerce and the Bremen Cotton Exchange objected to the decree on the grounds that it would hamper trade and that the Rhine cotton mills would be driven to importing cotton through Belgian and Dutch ports. Further, warehouse companies claimed to have stored wet cotton for long periods without incident. In view of these objections, and expert advice to the effect that wet cotton did not ignite spontaneously, the decree was withdrawn.

It is evident that some opinions on the occurrence of spontaneous ignition in cotton, both wet and dry, are likely to have been influenced to some extent by commercial interest. It is therefore worth noting further that, according to Häpke, Insurance Companies and Underwriters at the time did not regard wet cotton as liable to spontaneous ignition.

Häpke asserted that the spontaneous ignition of cotton was absolutely out of the question and that all fires were due to flying sparks or other external causes. He showed that features of cotton fires that were apparently evidence for spontaneous ignition were, in fact, part of the normal behaviour of cotton ignited by an external source. In particular, the tendency for fire to break out in a cotton bale that had been salvaged from a fire was not due to spontaneous ignition; it was due, instead, to the emergence of a smouldering fire that had been in progress in the interior of the bale undetected since the bale was salvaged. As described above, the existence of this effect has been well established by Häpke's observations and by modern experience.

According to Häpke's account the importance of the above effect, and the impossibility of spontaneous ignition in cotton, was pointed out by Professor Kraut, of the Hanover Technical School, in 1868 when acting as expert witness in litigation before the Supreme Court of Hanover following a fire in a consignment of cotton carried by rail. Professor Kraut succeeded in convincing the Court that the fire was due not to spontaneous ignition but to sparks from locomotives; judgement was given against the Hanover Railway Management, the carriers of the cotton.

Häpke refers also to an enquiry, on behalf of the British Board of Trade and following a fire in S.S. "City of Montreal" in 1887, on the possibility of spontaneous ignition in cotton. Apparently expert opinion was unanimous that fires in cotton were due always to external ignition. In preparation for his evidence at this enquiry Dr. Dupre, Official Chemist to the Home Office, showed that four pounds of cotton enclosed in a metal box with a loosely fitting lid, and ignited by a spark, smouldered for four days and burst into flames as soon as the lid was raised.

The fires in cotton carried by rail, quoted by Häpke, that were initially supposed to have been due to spontaneous ignition, occurred in circumstances in which the opportunity for ignition by sparks from locomotives was very great. On the other hand, some of the other incidents of fire that he quotes could have been attributed more reasonably to spontaneous ignition. Häpke's contention, expressed or implied, that they were due to external ignition followed by undetected smouldering for a long period must be regarded as an alternative explanation that is plausible in view of the known behaviour of cotton; but in no case was the source of ignition traced. This is so, for example, for the Bremen Warehouse fire of 1892 in which the outbreak occurred four weeks after the cotton had been put into store; during this period the warehouse was sealed and it is stated that no one had entered.

Two incidents of fire described to Häpke by a Captain Willigerod involved cotton taken on board two different ships in New York; one occurred before stowage was complete and the other after one of the ships had been five days at sea. In each case the fire was quickly controlled and was traced to one bale that was actually burning. Captain Willigerod was apparently convinced that the bales had been ignited on the outsides, but it is not clear to what extent he examined the interior of each; one was "promptly hurled overboard". It is possible that these bales may have been fire-packed bales, the existence of which does not appear to have been recognized at the time.

<u>The possibility of spontaneous ignition in wet cotton.</u> Firth [10] states that, in general, warmth and moisture facilitate the bacterial breakdown of dirty or contaminated cotton. He suggests that this may give rise to a condition favourable to auto-oxidation which may ultimately give rise to fire.

Dubosc [18] has noted that spontaneous heating and, very often, ignition occurs during the steeping of oily cotton waste (obtained from cotton spinners) in the manufacture of hand-made paper. He states that the heating is due to fermentation and suggests that such heating might act as a "primer" to further spontaneous heating and ignition in wet bales of raw cotton containing cotton seeds.

Marini [14] is reported to have suggested that spontaneous combustion of cotton may be caused by "fermentation by thermophilic organisms with a development of combustible gases catalysed by the presence of traces of iron". Sen [16] has shown that inflammable gas, consisting of methane and a small proportion of hydrogen, is produced during the anaerobic fermentation of cotton; but he points out that, although the gas might be produced in damp dirty cotton in loose "borahs", it would be dissipated by diffusion into the surrounding air. The highest temperature attainable by biological activity is about 75°C (see below) and it is not clear how methane and hydrogen could ignite spontaneously at this temperature.

With the possible exception of Marini's suggestion, whose paper has not been seen in the original by the author, none of the above suggestions is based on evidence that spontaneous ignition actually occurs in wet cotton bales.

Finally it is appropriate to consider the possibility of spontaneous ignition in wet cotton in the light of what is known of spontaneous heating and ignition in vegetable material in general.

The evolution of heat during the biological decomposition of moist vegetable matter is generally well known and, in certain materials, has been studied extensively. A supply of air is necessary and the rate of heat production depends on the composition of the material. Thus Norman [19] found that the stage of rapid heat production in the decomposition of oat straw corresponded with the rapid disappearance of hemicelluloses. When the hemicelluloses were used up, and attack on the more resistant cellulose began, the rate of heat production fell.

There is no reason for supposing that the spontaneous heating of wet cotton is due to a cause other than biological activity. Since cotton consists of about 94 per cent cellulose [20] it may be expected that the rate of heat generation in cotton will be less than in most other vegetable material. The absence of marked heating in wet cotton bales may be partly due to this, but probably depends also on the restricted air supply.

The maximum temperature attainable through biological activity is about 75°C; although temperatures of from 40 to 60°C are perhaps more common.

Apart from certain oilseeds, in which the presence of oxidisable oils may be a contributory factor, the only vegetable material for which it is known with certainty that a stage of biological heating is followed by further heating to ignition is hay, either of grass or of alfalfa. Although the details of the process have not yet been worked out, it is clear that the hay becomes capable of undergoing rapid oxidation as a result of the biological decomposition [21, 22].

The stem and leaf fibres such as jute, hemp, and sisal, from which most of the accompanying soft tissue has been removed by retting or by mechanical means, are known to heat when moist. But it is doubtful whether heating proceeds to ignition [23]. Experimental studies of the heating of moist jute have not revealed any tendency for the temperature to exceed the maximum possible for the biological stage, i.e. about 75°C [24, 25].

It appears that the spontaneous heating of vegetable material does not necessarily always lead to ignition and, further, ignition is known with certainty to occur only when whole stems and leaves are present initially. These facts do not suggest that spontaneous ignition in wet cotton is very likely to occur.

CONCLUSIONS

This survey has produced no evidence that bales of clean cotton, either wet or dry, are liable to undergo spontaneous ignition. On the other hand effects such as the ignition of bales by means that might for long be unsuspected, e.g. the friction and impact of bands, and the ability of bales to smoulder internally without detection, are likely to have been responsible for both dry and wet bales acquiring a reputation for spontaneous ignition.

It is concluded that spontaneous ignition is unlikely to occur in wet cotton bales.

Spontaneous ignition may occur only in bales of cotton contaminated with oxidisable materials such as drying oils.

As pointed out by Kraut and emphasized by Häpke, the danger associated with cotton bales salvaged from a fire lies not in the possibility of spontaneous heating and ignition, through wetness, but in the possibility that internal smouldering may escape detection and cause a fresh outbreak of fire after a period of weeks.

It is concluded that, in assessing the fire hazard of wet cotton bales, a clear distinction should be made between bales that have been salvaged from a fire and those that have not. The latter are likely to undergo deterioration only; but, of the former, those that have been damaged by fire must be regarded as highly dangerous. Salvaged bales that have been carefully "picked" are likely to be free from risk of re-kindling.

Bales that have been salvaged from general warehouses and stores, but are not actually damaged by fire, should be examined for contamination by oxidisable materials.

ACKNOWLEDGMENTS

The author is greatly indebted to Mr. E. J. H. Catt, Chief Officer of the Liverpool Salvage Corps, and to his staff for generous help and advice.

The translation of the relevant section of Häpke's book [9] was carried out by Mr. L. E. D. de Hora of the Joint Fire Research Organization.

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APPENDIX

THE RECOVERY OF WET AND FIRE-DAMAGED COTTON BALES

The following is an account of the recovery of wet and fire-damaged cotton bales as practised by the Liverpool Salvage Corps. The account is based on a visit made by the author and the Director of the Joint Fire Research Organization to the Liverpool Salvage Corps on 6th April, 1954, and on subsequent correspondence with Mr. Catt, the Chief Officer.

The situation facing the Salvage Corps after a fire in cotton may consist of anything from a single warehouse floor stacked with smouldering bales to a warehouse in which floors carrying burning cotton bales have collapsed into the basement. Wet, burnt, and still smouldering bales are removed - a hose being used to extinguish the fire in these last. This process may take several weeks after a large fire, and smouldering bales are found throughout this period.

Salvaged bales are stood in an open yard to await "picking". During this period the bales are watched carefully for signs of re-kindling. There is a strong tendency for fire to burn into the interior of a bale (often via sampling holes where there is a reduction in density), and smouldering may continue for long periods with no outward sign. This smouldering fire may destroy most of the interior of a bale and may break out on the surface again at any time. On one occasion a bale re-ignited after standing in the salvage yard for three weeks without showing any sign of internal fire.

An incident of special interest is the following. During fire-fighting operations on a cotton storage site in Manchester in 1943 about one hundred bales of cotton were thrown into the canal alongside the site. These were salvaged a fortnight later and some were found to have fire still in them. One, in particular, that had floated for half a mile was towed back and, while it was being lifted from the water it collapsed; it had burnt to a shell with the centre reduced to ashes. On another occasion a bale was found to have burnt to a shell after five or six weeks.

It is sometimes possible to locate the hole where fire has burrowed into a bale; the fire may then be extinguished by introducing a jet of water.

All wet and charred bales are hand picked, i.e. the outer layers are picked off until undamaged cotton is reached. The pickings are sorted into grades that vary from the outer charred "crusts", through wet discoloured cotton, to wet but otherwise undamaged cotton.

The graded pickings are next dried. Pickings of each grade are spread out separately, to a depth of about 6 inches, on a single layer of wire trays on either side of a drying-room ("kiln") with a central gangway. An array of steam pipes is situated about one foot below the wire trays. The steam pressure was stated to be about 80 p.s.i.(gauge); this corresponds to a steam temperature of 162°C or 324°F. The temperature in the drying room, indicated by a thermometer on a central pillar, was said to rise to 150-160°F during the drying of the cotton. The kiln is ventilated by a forced draught.

During drying the cotton is turned over by hand to prevent it sticking to the trays and becoming overheated in the lower layers. Fires break out occasionally during drying both in pickings that have been charred and those that have not. The fires start in the cotton dust that accumulates on the steam pipes and spreads to the cotton in the trays by means of hanging strands of cotton. Fires are betrayed by wisps of smoke and, if seen in time, can be put out before the whole batch of cotton becomes involved; the tray immediately over the steam pipes involved is lifted and the dust extinguished and removed. There is no indication that charred crusts tend to ignite spontaneously during drying.

After they have been dried the graded pickings are re-baled with the aid of hydraulic presses. On specific enquiry it was learnt that the bales of charred crusts are not regarded as hazardous.

Occasionally it happens that graded pickings are accumulated at a rate that is higher than that at which they can be dried; they are then put into piles. Piles of damp pickings heat spontaneously within a few days and may become too hot to handle. It is customary to break down and turn over the piles frequently, not to avoid ignition but to prevent deterioration. Although piles are generally turned over every two or three days they have occasionally been left undisturbed for as long as three weeks. After such a period the cotton becomes discoloured brown in the centre of the pile but there have been no signs of ignition. It was learnt from Mr. Hubbard (who was in charge of cotton reclamation) that in his thirty years' experience a pile of damp cotton had never heated to ignition.

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