Limiting Safe Surface Temperature of Combustible Materials

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TECHNICAL NOTE

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PREPARED FOR Association of Canadian Fire Marshals and Fire Commissioners

SUBJECT LIMITING SAFE SURFACE TEMPERATURE OF COMBUSTIBLE MATERIALS

In discussing the installation of electrical appliances, the Canadian Electrical Code (1966) specifies 90°C (194°F) as the maximum temperature which adjacent combustible materials shall be permitted to attain. As other documents have mentioned a maximum of 160°F, NRC has been asked to resolve the apparent incompatibility and specify an appropriate value.

TEMPERATURE DEPENDENCE OF REACTIONS

The temperature dependence of exothermic reactions (chemical reactions in which heat is generated and liberated, as opposed to endothermic reactions during which the involved material absorbs heat) in relation to the fire hazard of combustible surfaces is well summarized by Lawson. (1) In discussing the hazard to combustible panels created by the proximity of hot flue pipes he commented "Significant panel temperatures are 100°C and 250°C. Below 100°C a combustible panel may be considered to offer a low fire hazard; as the temperature is increased beyond this limit the rate of decomposition of cellulose materials will progressively increase until a temperature of 250°C is reached, when the reaction becomes exothermic and combustible gases are rapidly evolved."

In a more detailed discussion of the thermal degradation of cellulose MacKay (2) commented that in an atmosphere of nitrogen a strong exotherm beginning at 230°C has been observed (3). Ten years ago, referring to the heating of wood in air, Browne (4) suggested that right up to a temperature of 280°C reactions are largely endothermic (i.e. the material absorbs heat) and the principal gaseous products are non-combustible.

For wood that is free-standing in air the temperature at which extreme hazard develops is about 340°C (5) (ranging between 300°C and 410°C). This is the theoretical value, derived from heat transfer considerations, at which the pilot ignition of wood occurs when it is subjected to radiant heating. "Pilot ignition" involves a small igniting source of localized high temperature, such as a spark or a small "pilot" flame, that does not contribute appreciably to the heating of the surface of the solid material. Ignition thus occurs when the combustible gases and vapours, issuing from the solid, form a fuel-air mixture that is within the limits of flammability in the region of the high temperature source.

Although years ago wood or related cellulosics constituted virtually the only combustible building materials in existence, this is no longer the case. The ignition characteristics of most other combustible building materials do not, however, warrant separate detailed discussion in the present context.

The temperatures so far mentioned are considerably higher than either of the safety criteria quoted earlier. Justification for such lower values largely results from consideration of the hazards associated with the self-heating of materials as a result of microbiological or chemical reactions generating heat within the material itself.

THE HAZARD OF SELF-HEATING

When most common materials are stored at temperatures below about 100°C, a fairly uniform equilibrium temperature develops. Some materials, however, such as wood fibreboard, palm kernels and rags soaked in linseed oil, can self-heat to ignition even in enclosures maintained at temperatures much below 100°C. Whether or not a bulk of material will develop a thermal instability constitutes a thermal conductivity problem which involves a term representing the generation of heat by exothermic reactions. Solutions to this problem have been derived (6). Table I lists the computed critical radius for two materials in spherical form.

Table I

COMPUTED CRITICAL RADIUS (SPHERE)

Material	20°C	48.9°C	82.2°C	100°C
Wood fibreboard	148 ft	22 ft 4 in.	45 in.	19.7 in.
Cotton gauze soaked with raw linseed oil*	26 in.	5.6 in.	1.4 in.	0.67 in.

* 1 part of oil to 6 parts of cotton by weight

The three-dimensional spherical heat flow problem involving a fixed temperature boundary condition differs from the cylindrical and plane cases where the material extends to infinity. If in each case it is assumed that $\theta_r = 0$ for $t \leqslant 0$ and $\theta_R = \theta_o$ for $t > 0$, then for the one- and two-dimensional (i.e. the plane and cylindrical) cases, $\theta_r \rightarrow \theta_R$ as $t \rightarrow \infty$ for all values of r. For the three-dimensional (i.e. the spherical) case, on the other hand, θ_r falls off with increasing r, that is $\theta_r = \theta_o R/r$ where $\theta_R = \theta_o$ at $r = R$. It is therefore not surprising that the critical dimensions for the one- and two-dimensional versions of the self-heating problem are lower than those given in Table I. It has been found that, to a close approximation, the constant factors 0.514 (one dimension) and 0.775 (two dimensions) [6] give the appropriate critical dimensions.

Were hazard to be completely eliminated the above considerations would suggest adoption of a temperature criterion little higher than room temperature, if not below it! The alternative approach is first to disregard, in this context, the hazard created by oil-soaked rags, which is outstandingly greater than that of any other common material. The hazard is well known and it is possible to ensure that oil-soaked rags are segregated from other combustible material.

Of the remaining common materials, wood fibreboard is the most likely to be subject to spontaneous ignition. It is generally found only in thicknesses of 0.5 inch; so, according to Table I and the reference to the one-dimensional problem, it should be impossible to cause ignition from a surface at a temperature of 100°C.

To ensure that the hazard does not pass unrecognized it might be mentioned that coal is a common material which exhibits self-heating to an extent likely to be hazardous under bulk storage conditions. It will, however, be assumed that coal will not be stored in areas where temperatures can rise appreciably above room temperature.

EXPERIENCE WITH STEAM PIPES

Fires caused by steam pipes are interesting because, if the service pressure is known, the steam pipe temperature is also known. Many of the plants used for heating buildings operate on so-called low pressure, which is certainly below 100 psi (165°C) and probably below 50 psi (138°C). High pressure systems, on the other hand, can operate at a pressure as high as 3,000 psi (370°C), although until recently pressures in excess of 350 psi (222°C) were unusual.

As very high pressure steam lines can be expected to constitute a hazard, it is fires started by low pressure steam pipes that are particularly interesting. These are rare, but as long ago as 1911 an inspection bureau [7] had gathered together reports of more than a dozen such fires that had occurred at one time or another, principally in the eastern United States. Because most of the fires involved the ignition of wood, the author of the article favoured the theory that the steam pipes, over a long period of time, converted nearby wood to charcoal which then ignited spontaneously.

Various attempts to duplicate this phenomenon in the laboratory have failed to produce ignition. At NRC [8] one particular experiment, involving samples of wood and fibreboard at temperatures in the region of 250°F, was continued for 4 years. Considerable charring resulted but no ignition occurred; nor did excessive temperatures develop.

In a comprehensive discussion of the likelihood of ignition of wood at moderately elevated temperatures, Matson, et al. [9] reported fires initiated by steam pipes where steam temperatures of only 100°C were involved. Reference to a fire initiated by a ventilation pipe carrying air at a temperature of no more than 65°C can probably be disregarded because wood shavings and large quantities of wood were apparently involved and the incident can probably be classed as associated with self-heating. Several references are quoted which state that the hazard at low temperatures is related to the formation of charcoal. To balance the picture the following quotation from Voight [10], concerning domestic heating installations, is given: "No authentic cases of ignition of wood either in the laboratory or as exposed for long periods around heating installations at temperatures below 150°C (302°F) have been obtained. As a tentative measure of hazard, temperatures frequently exceeding 125°C (257°F) should probably be considered hazardous, but temperatures might occasionally reach 150°C (302°F) without creating a hazard necessarily to be recognized in a building code or fire prevention ordinance."

If it is postulated that, despite lack of laboratory confirmation, generation of charcoal constitutes a hazard, then information regarding the dependence of charcoal generation on temperature becomes interesting. G. C. McNaughton [11], of the U. S. Forest Products Laboratory, reports exploratory tests on small, kiln-dried hard maple wedges. Samples which had been exposed to 107°C for 1,050 days assumed a light chocolate shade and lost about 8% of their dry weight. Those exposed to 120°C for 1,235 days became appreciably embrittled and of a dark chocolate colour, losing 27% of their dry weight. Those exposed to 140°C for 320 days assumed the appearance of charcoal and lost 58% of their dry weight.

The conditions given by almost three years of heating at 107°C appear to be near to the limit of acceptability and 100°C would appear to be an appropriate choice of upper limiting temperature.

STRENGTH CRITERIA

It is possible that, although currently assumed to have been aimed at reducing fire hazard, the temperature restrictions contained in some building codes were originally chosen to preclude excessive loss of strength of wood.

Matson et al. [9] quoted MacLean [12] as concluding that if a good service life is desired, wood should not be exposed under service conditions where temperatures appreciably higher than 66°C (150°F) will be encountered.

Ingberg showed that, in compression, several species of wood lost 50% of their strength at a temperature of about 106°C, the temperature-strength relation in the range ambient to 100°C being roughly linear.

CONCLUSIONS

Investigations into the decomposition of wood and cellulose indicate that up to temperatures in the region of 250°C the principal reactions are endothermic and, over-all, the gaseous products of pyrolysis are non-flammable.

Safe temperature criteria nearer to those currently specified can be derived by considering the hazard resulting from self-heating. Excluding consideration of certain vegetable oil-soaked rags, which would require choice of very low temperatures, 100°C would appear to be a satisfactory choice.

Although it has never been conclusively demonstrated in a laboratory, experience with the use of steam pipes suggests that, occasionally, generation of charcoal constitutes a hazard associated with subsequent self-heating. The rate of generation of charcoal at a temperature of 100°C should be sufficiently low as virtually to eliminate hazard.

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