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ESTIMATION OF THE RATE OF VENTILATION REQUIRED FOR DRYING-OFF SOLVENTS IN ENCLOSURES.

by

P.C. BOWES.

SUMMARY

Estimates have been made of the rates of ventilation necessary for enclosures, of whose walls a relatively large area is treated with flammable solvent, in order that the drying time for the disappearance of fire hazard shall be similar to that determined experimentally for treated surfaces of small area.

For enclosures such as warehouses and, probably, roof spaces that can be ventilated by at least a trap door and are not sealed, the required rates of ventilation are likely to be attainable merely by opening all doors and windows, even if all interior surfaces are treated.

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Fire Research Station,
Boreham Wood,
Herts.

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INTRODUCTION

A previous note [1] describes a study of the fire hazards associated with the treatment of woodwork with flammable insecticidal preparations for the control of woodworm. In particular, a determination was made of the time that must be allowed for the flammable solvent in the preparations to dry-off sufficiently for the fire hazard to disappear. These drying times were determined for solvents applied to relatively small areas of treated wood and dried in the laboratory. In practice, however, the area treated may be large in relation to the volume of the enclosure, so that, unless the enclosure is ventilated, the atmosphere will tend to become saturated with solvent vapour, and drying will slow down or even stop before the residue of solvent in the wood has been reduced to a safe level.

The object of the present note is to estimate the rate of ventilation necessary for enclosures, of whose internal walls a relatively large area is treated with flammable solvent, in order that the drying time for the disappearance of hazard shall be similar to that found experimentally for test pieces of small area.

BASIS OF CALCULATION

The drying of a porous solid impregnated with a liquid involves two transport processes, either or both of which may control the rate of drying at a given stage in the drying. These processes are, first, evaporation from the outer surface of the solid into the ambient air and, second, transport of liquid or vapour within the solid to the outer surface of the solid. As long as the surface of the solid is saturated, the rate of drying will be controlled by the first process.

Stamm's review [2] of sorption data for cellulose and wood suggests that the sorption capacity of wood, in equilibrium with the saturated vapour of solvents of the types commonly used in insecticides, will be small - of the order of a few per cent, or even less than one per cent. In the tests of fire hazard [1] it was found that the residue of solvent (white spirit or kerosine) in the surface layers of treated wood, when it had dried sufficiently for the fire hazard to disappear, was of the order of 6 mg/cm^2. The depth of penetration was not known; but if the mean depth had been as great as 5 mm the above residue would have been 1.8% by weight, for a wood density of 0.63g/cm^3. This affords some justification for our first assumption, namely, that throughout the drying periods with which we are concerned, the surface of the wood was substantially saturated and the rate of drying was determined largely by the rate of evaporation from the surface of the wood.

At a given temperature the rate of evaporation of liquid from a surface into air depends on the difference between the partial vapour pressure of the liquid in the ambient air and the saturated partial vapour pressure at the given temperature, on the rate of air movement over the surface, and, probably, on the shape and disposition of the surface.

Now, let

A = surface area of treated woodwork, (cm^2),
w = weight of solvent dried-off per unit area in drying time t hours, (mg/cm^2),
V = volume of air into which evaporation takes place (litres),
c = average concentration of solvent in air at end of drying time.

(8/l)

Then, we have

$$V = \frac{wA}{c} 10^{-3} \text{ litres} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

It will now be assumed that for given values of w and c, the drying time t will, in practice, be constant for all values of V and A that satisfy equation (1), regardless of variation in the shape and disposition of the treated area.

This second assumption will be justified to the extent that the rates of convective air movement, in enclosures of interest here, are confined within fairly narrow limits, and also to the extent that the rate of mixing due to convection in an enclosure is sufficiently great, relative to the rate of evaporation, for the concentration of solvent in the air to be substantially uniform throughout the enclosure for the greater part of the drying time. It will be assumed for the present purpose that these conditions are fulfilled in practice.

The quantity w/c is a constant determined by the conditions of the experimental determination of drying time and can be evaluated by inserting in equation (1) the area of the test pieces and the volume of the laboratory in which the drying was carried out; provided of course that ventilation was negligible, as, in fact, it is likely to have been in the conditioning room used for the longer drying times [1]. Then for any other treated area, equation (1) can be used to calculate the volume of air into which $wA\ 10^{-3}$g of solvent must be evaporated to give a final concentration of c g/litre.

If in a given enclosure of volume v, an area is treated such that the required volume of air V is greater than the volume of the enclosure, the enclosure will have to be ventilated in order to achieve the required degree of drying in the experimental drying time t. If it is supposed that fresh air enters the enclosure and leaves with a solvent content of c g/litre, the necessary rate of ventilation will be, in accordance with the second assumption (above),

$$\frac{1}{t}\left(\frac{V}{v} - 1\right) \text{ changes per hour} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

or

$$\frac{V}{tv} \text{ changes per hour if } \frac{V}{v} \gg 1.$$

Since it is assumed that the concentration of solvent tends to be uniform in the volume of air V, this rate of ventilation will be the minimum required.

As soon as ventilation becomes appreciable, however, there is a possibility that the drying time for a given area of treated woodwork can be reduced below the value corresponding to the conditions of the experimental determination because of reduction in the solvent content of the air in the enclosure, by dilution, and because of a possible increase in the velocity of air movement over thetreated surface. In order to achieve this reduction in drying time the rate of ventilation will have to greater than the value calculated as above. The possibility of achieving an appreciable reduction will be greater the nearer the concentration of solvent vapour approached the saturation value in the experimental determination of drying time. The reduction in drying time cannot be calculated, but it is worthwhile calculating the final concentration of solvent vapour, as a fraction of the saturation value, reached in a laboratory determination of drying time in order to assess the likelihood of an appreciable reduction occurring in the presence of ventilation.

CALCULATION OF VENTILATION REQUIREMENTS

White Spirit

The drying time for disappearance of hazard, as indicated by spread of flame tests, for Corsican pine treated with white spirit was 48 hours. The weight of treatment was 38 ± 8 mg/cm^2 and the residue at the end of the drying period was 7 ± 4 mg/cm^2.

Five boards, each 30.5 cm x 9.5 cm (total area 1450 cm^2 or 1.56 ft^2) were tested at a time, and the volume of the room in which the drying was carried out was 2.95×10^4 litres (1042 ft^3).

By substitution in equation (1) we have

$$V = 20.4A \text{ litres}$$

or, expressing the volume in cubic feet and the area in square feet,

$$V = 670A \text{ cubic feet.}$$

The above formula has been used together with equation (2), in which t = 48 hours, to construct Fig 1 which shows the ventilation required for drying-off white spirit to a safe residue in 48 hours, as a function of the area treated, in enclosures of between 1000 and 10,000 ft^3. It is supposed that the enclosures are rooms and the range of areas has been chosen accordingly. As a guide to the ventilation required for drying the maximum area in a given room, ordinates have been drawn in Fig.1 (chain lines) corresponding to treatment of all six interior surfaces of a cubical room of each volume given.

The ventilation rates in Fig. 1 may be compared with the one to two changes per hour recommended for comfort in different rooms in dwellings[3]. Further, the rates, in the range covered, are below the rates said to be obtainable in dwellings with open doors and windows[3], i. e. one change in 2-5 min., or 12 - 30 changes per hour.

A useful conclusion that can be drawn from the above is that in enclosures such as warehouses and, probably, roof spaces that are ventilated by at least a trap door and are not sealed, a treatment with white spirit on all surfaces can be dried to a safe residue, within the experimentally determined time of 48 hours, with the ventilation obtainable by opening all doors and windows.

The weight of white spirit dried-off in the determination of drying time was about $30mg/cm^2$, whence the final concentration in the air of the room was 1.47×10^{-3}g./litre. It is thought that n-decane (boiling point 173°C) may be regarded as reasonably representative of those fractions of white spirit that are chiefly responsible for the survival of fire hazard on treated surfaces. The vapour pressure of n-decane at 20°C is given as 2.7 mm mercury [4], from which it may be calculated that the concentration of n-decane in an atmosphere saturated at 20°C, and at a total pressure of 760 mm of mercury, will be 2.1×10^{-2}g/litre. Hence, at the end of the drying period, the concentration of white spirit in the atmosphere was about 7% of the saturation value. This is a small fraction, and it is therefore concluded that ventilation would not result in a large decrease in the experimental value of the drying time obtained for white spirit.

Kerosine and ortho-dichlorobenzene.

The drying times for the disappearance of hazard following treatments with the above materials were 168 hours for kerosine and 72 hours for ortho-dichlorobenzene. Ventilation rates for enclosures treated with these materials may be obtained from Fig. 1 by multiplying the rates for corresponding treatment with white spirit by 0.29 in the case of kerosine and 0.67 in the case of ortho-dichlorobenzene.

However, the saturated vapour pressure of ortho-dichlorobenzene, and kerosine after the lightest fractions have evaporated in the first few hours, is likely to be less than 1 mm of mercury (compared with 2.7 mm for n-decane). The vapour pressure in the laboratory atmosphere during determinations of drying times for these materials may, with the weight of treatment tested, have become a fairly large fraction of the saturation value. It is probable, that with these materials ventilation, at rates well within those likely to occur in practice, would appreciably reduce the drying time; although it is, perhaps, doubtful whether the reduction would be sufficiently large to be of practical value, e.g. a reduction of 24 hours in the 72 at present recommended for ortho-dichlorobenzene.

APPLICATION OF RESULTS

The above estimates of rates of ventilation are intended to apply to enclosures having surface to volume ratios of the relatively low order of magnitude likely to occur in rooms etc., for the reason that the experimental determination of drying times were made in such an enclosure.

In situations where the ratio of treated surface to contained volume is much higher than in rooms, e.g. in spaces between joists under floors, inside stacks of treated timber etc., the required ventilation rates will be on a greatly increased scale. Thus, the minimum surface to volume ratio for such situations will be of the same order as that for a one foot cube, for which the required rate of ventilation, following treatment of all internal surfaces and calculated as above, will be 86 changes per hour; for spaces in timber stacks the rate could be very much higher than this. Spaces such as the above will tend to have the form of long, narrow, channels for which ventilation at the required rates can involve high velocities of air over the drying surfaces. Unless high rates of ventilation can be achieved, drying times will have to be increased for these situations. It is not possible to estimate what this increase should be.

CONCLUSIONS.

Although the estimates of ventilation requirements for drying-off solvents in enclosures have been made in a very simple way and can be only approximate, it is believed that they furnish a reasonable guide for practical purposes. Generally the effect of the assumptions, on which the estimates are based, has been to yield estimates of the minimum ventilation requirements.

When compared with published data on rates of ventilation occurring naturally, the estimates indicate that for enclosures such as warehouses and, robably, roof spaces that can be ventilated by at least a trap door and are not ealed, the required rates of ventilation to achieve drying sufficient for the ire hazard to disappear, in the time determined experimentally for small areas of reated timber, are likely to be within the range of rates attainable merely by eaving open all windows and doors, even if all interior surfaces are treated.

If, during an experimental determination of drying time, the concentration solvents in the laboratory atmosphere becomes a large fraction of the saturation value, the drying time determined will be an overestimate of the drying time for practical situations when ventilation is present.

The estimates are intended to apply to enclosures such as rooms. No estimates of ventilation rates have been made for situations in which the treated surface is relatively large compared with the enclosed volume (e.g. in stacks of treated timber). In general, they are likely to be too high to occur naturally and, in these situations, it will usually be necessary to increase the drying time.

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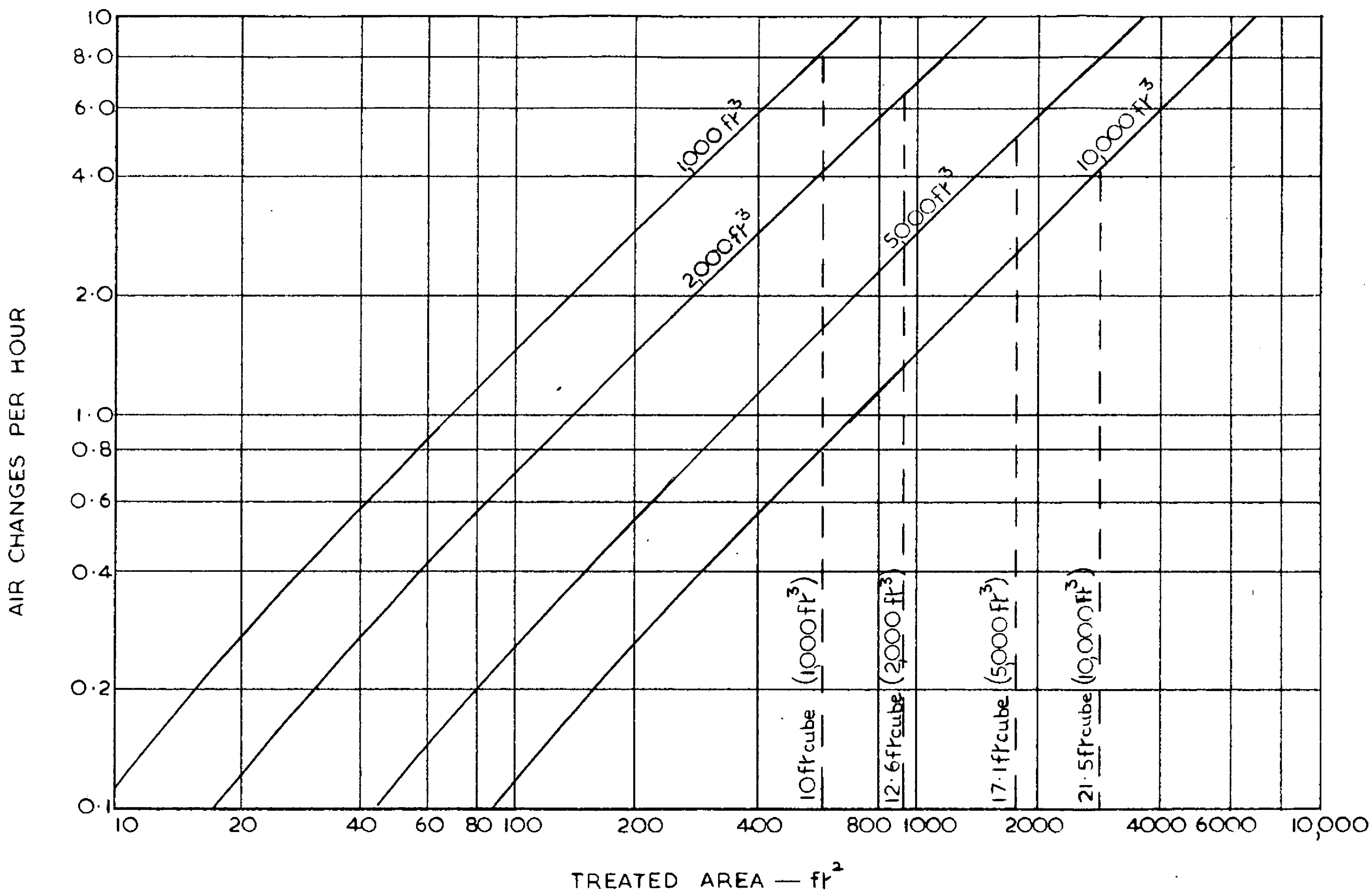

FIG.1. VENTILATION REQUIRED FOR DRYING WHITE SPIRIT TREATMENTS TO SAFE RESIDUE IN 48 HOURS