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Sumi, K.; Tsuchiya, Y.

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SPONTANEOUS IGNITION

RELATION BETWEEN AMBIENT TEMPERATURE
AND SIZE OF SPECIMEN

by

K. Sumi and Y. Tsuchiya

Division of Building Research, National Research Council of Canada

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A combustible material or a combination of reactive materials may undergo slow chemical reaction with the evolution of heat. If the rate of heat generation is greater than the rate of heat dissipation, the temperature of the specimen rises. The rise in temperature accelerates the rate of reaction and causes further temperature rise. This self-heating process is one of the primary causes of spontaneous ignition. Materials that have a tendency to heat spontaneously include alfalfa meal, fish meal, coal, charcoal and rags contaminated with drying oils.

Some of the most important factors that contribute to self-heating reactions are: ambient temperature, size (or volume), heat of combustion and insulation properties of the material. Finely divided materials, e.g., sawdust, are more susceptible to self-heating than solid materials. The reasons are two-fold: the larger surface area of divided materials results in greater rate of heat generation and the lower thermal conductivity (or greater insulation property) retards heat transfer and dissipation. The self-heating tendency increases with the amount of material because heat generation depends on the volume (which is proportional to the third power of the diameter) while heat dissipation depends on the surface area (which is proportional to the second power of the diameter). For a given temperature, there is a minimum size necessary for spontaneous ignition. The term "critical radius (or diameter)" is used to describe this minimum size.

The effect of ambient temperature is also two-fold. A higher ambient temperature increases the rate of reaction and retards heat dissipation. For a given specimen size, there is a minimum temperature or "critical temperature" at which spontaneous ignition could occur. Knowledge of the relation between critical size and critical temperature of materials is important to the fire investigator. It is not practical to obtain this information directly from simple experiments by varying ambient temperature and size of specimen.

There is, however, a theoretical relation between critical diameter (or radius) and critical temperature. This relation could be calculated if the physical properties of the material (specific heat, thermal conductivity, density and heat of combustion) and the kinetic constants of the self-heating reaction are known. The latter may be determined by means of an adiabatic furnace such as the one in the Fire Research Section of the National Research Council of Canada.

In this paper the determination of kinetic constants of a self-heating reaction is shown, and the results of calculations giving the relation between critical radius and surface temperature for four different materials are presented.

APPARATUS

A diagram of an adiabatic furnace is shown in Figure 1. The furnace design is similar to that described by Gross and Robertson.*

METHOD

A wire mesh holder containing about 100 cu cm of sample is positioned in the adiabatic furnace. The specimen is heated to a pre-set temperature. The furnace is then switched to the adiabatic mode and the specimen is allowed to self-heat by its heat of reaction. During the adiabatic heating period, the temperature surrounding the specimen is maintained at the same temperature as the centre of the specimen. The specimen temperature is recorded from the start of the adiabatic heating period until ignition occurs. If the temperature increase under the adiabatic mode is too slow or too fast the experiment is repeated after adjusting the pre-set temperature.

The temperature-time curve for white pine sawdust obtained from an adiabatic furnace experiment is shown in Figure 2. The kinetic constants are obtained by plotting the natural logarithm of the rate of heating as a function of the reciprocal of absolute temperature. Activation energy, E, is calculated from the slope of the regression line and $\ell n(fQ/c)$ is obtained from the intercept of the Y-axis, where f is the frequency factor, Q is the heat of reaction and c is the specific heat of the sample.

RESULTS

The relation between critical radius and surface temperature for the self-ignition of a sphere of white pine sawdust and three other samples has been calculated. These data are presented in Figure 3. The sample that showed the greatest tendency towards spontaneous ignition was cellulose impregnated with linseed oil, followed by white pine sawdust, rigid urethane foam, and cellulose.

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* D. Gross and A.F. Robertson. J. Res. National Bureau of Standards, 61, 413 (1958).

CONCLUSIONS

The determination of kinetic constants of a self-heating reaction using an adiabatic furnace has been described. These data combined with the more common physical properties of the material permits the solution of general self-heating equations including those where size and temperature become critical and ignition results. The relation between critical temperature and critical size of a self-heating material are thus obtained. Such information is extremely difficult to obtain directly from simple experiments in which ambient temperature and sample size are varied.

The fire service in Canada is being made aware of the capability available at the National Research Council of Canada to determine the relation between ambient temperature and size of specimen for spontaneous ignition to occur. When such information is needed to establish the cause of a fire, the fire investigator is encouraged to ask the cooperation of the fire scientist. Exchange of information on self-heating problems should be of mutual benefit to both.

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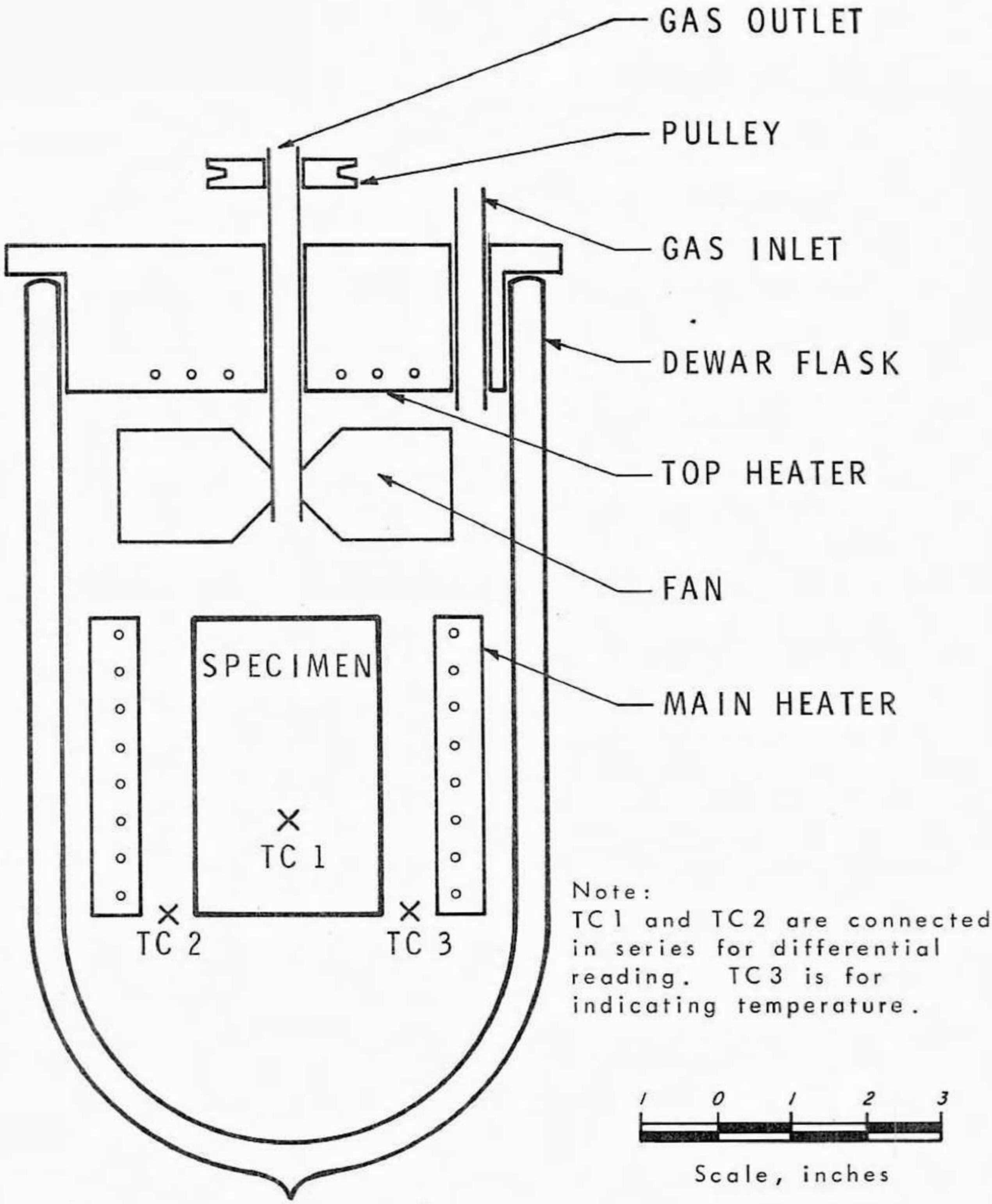

FIGURE 1

ADIABATIC FURNACE

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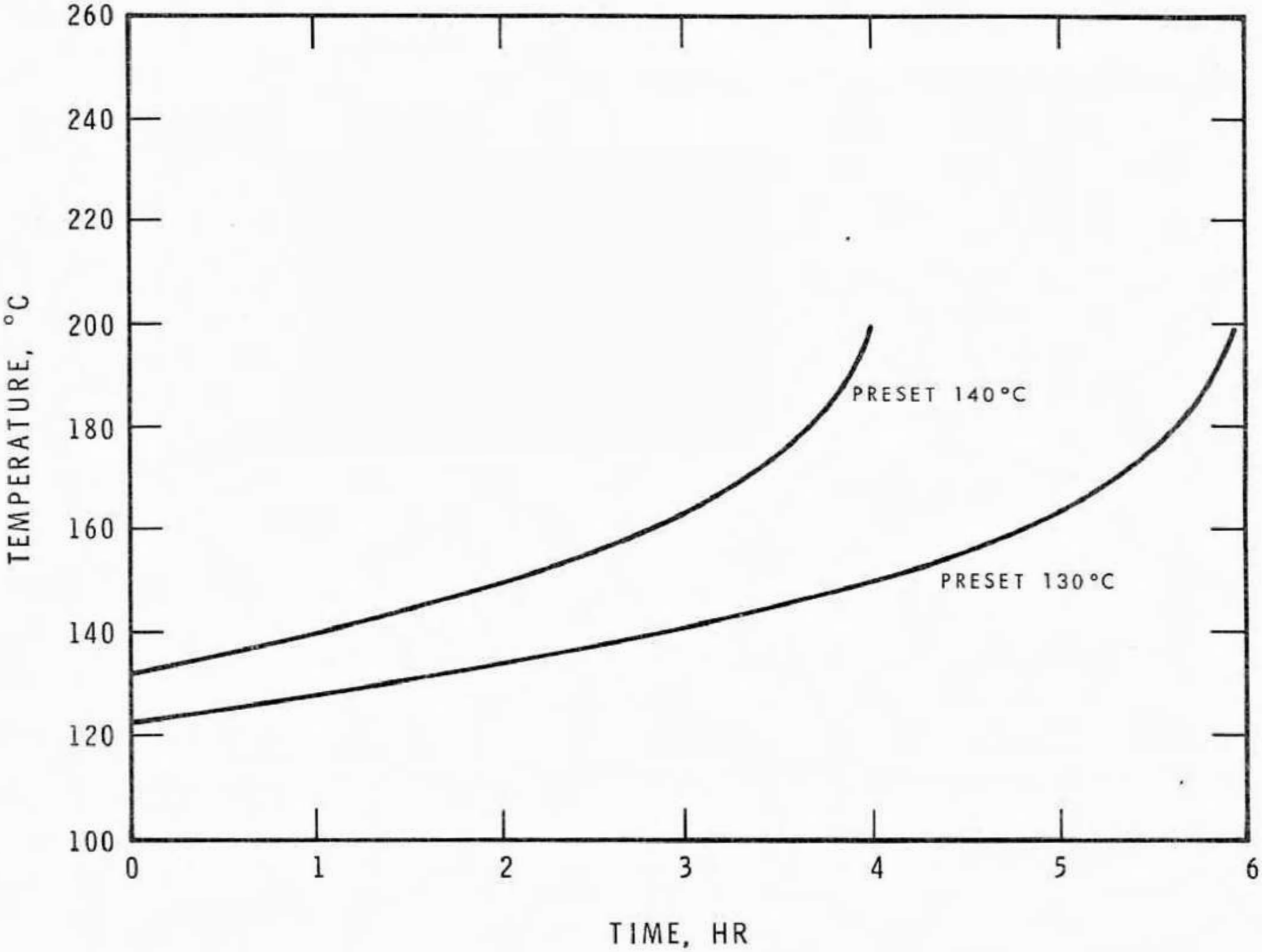

FIGURE 2

SELF-HEATING OF WHITE PINE SAWDUST IN ADIABATIC FURNACE

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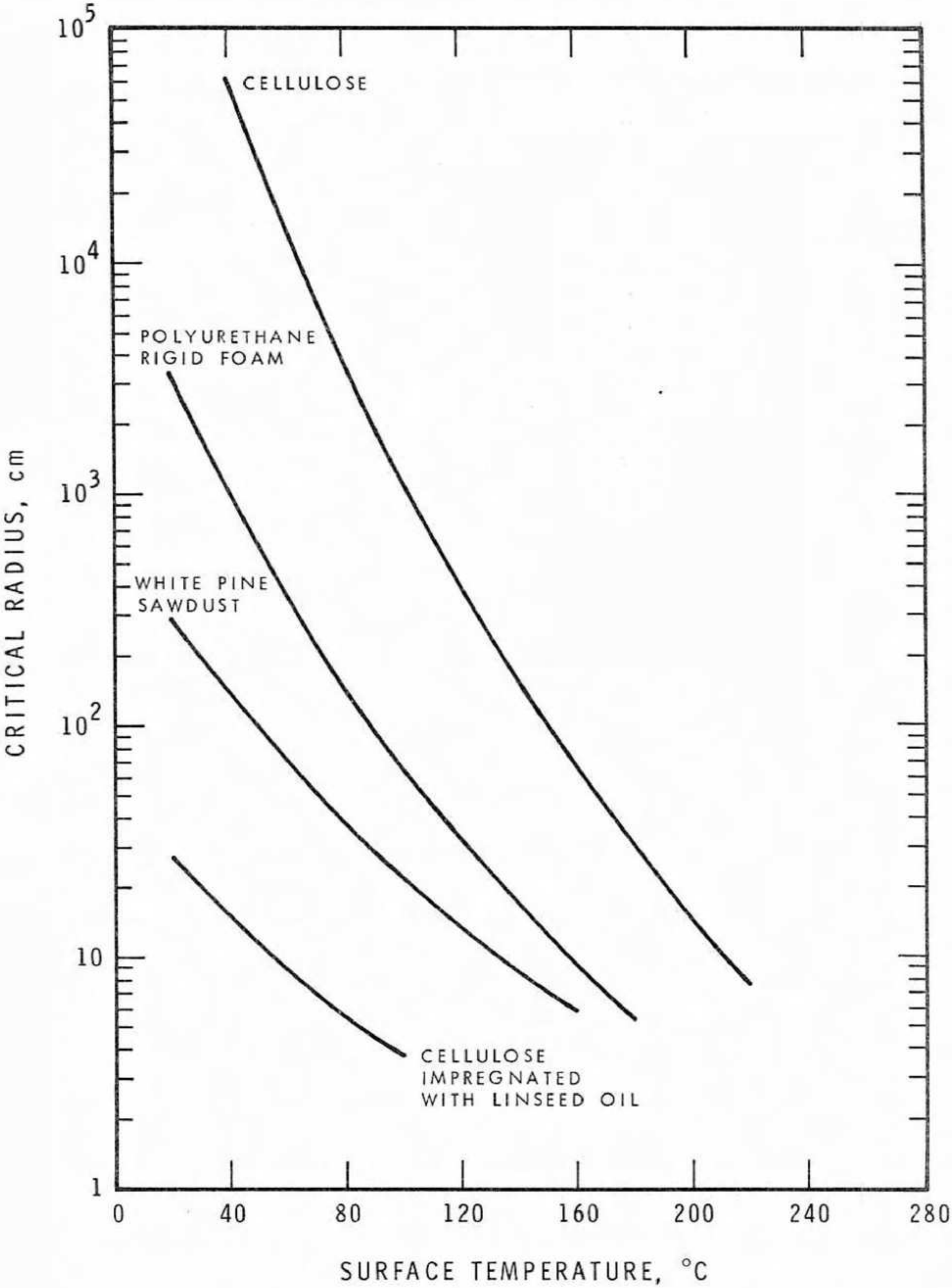

FIGURE 3

SURFACE TEMPERATURE AND CRITICAL RADIUS FOR SPHERICAL PILES OF MATERIALS