CONE CALORIMETER STUDIES OF WOOD SPECIES

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ABSTRACT

Cone calorimeter measurements can be used for the calculation of effective material properties, which can be used as input parameters in modeling of fire. Main parameter measured in Cone calorimeter is heat release rate. Some other parameters as time to ignition, effective heat of combustion, mass loss rate or total heat released is also measured in Cone calorimeter. Total heat released is important from the point of view of total energy available in material in fire situation. Cone calorimeter measurements were done on several wood species (oak, beech, spruce, poplar). Measurements were provided at external irradiances 30, 50 and 65 kW/m^2 in horizontal orientation. Heat release rate data were evaluated and compared as a function of external irradiance for various species of wood. Furthermore the influence of external irradiance on effective heat of combustion and total heat release was also evaluated for the period of flame combustion.

INTRODUCTION

One of the main questions which have to be answered when dealing with the problems of reaction to fire of materials is the contribution of material to the intensity of potential fire. Many test methods have been developed in order to test the reaction to fire of materials. In general these methods can be divided into small scale tests and full scale tests. Full scale test methods give more realistic picture of behaviour of materials in real fire than that of small scale tests. However full-scale tests are costly and it is not possible to test all the materials and their applications in real conditions (configuration of installations, room dimensions, various heat sources, etc.). Therefore the bench scale tests are commonly used, which are much less costly, specimens needed are small in dimensions and it is easy to perform these tests.

Currently accepted and used small scale reaction to fire tests were developed many years ago. Results of these tests are indices of "flammability". These indices of "flammability" often lack any physical meaning, they are strongly apparatus dependent and it is problematic to apply them to the real fire conditions. In new fire safety systems the engineering methods are used to evaluate the contribution of materials to fire. In such systems heat release rate data belong to the most important ones.

Probably most spread bench scale apparatus used for the measurement of the heat release rate is the Cone calorimeter. Some other parameters besides the heat release rate as time to ignition, effective heat of combustion, mass loss rate, total heat released, extinction area of smoke and CO/CO_2 yields are also measured in this instrument. Based on these data the effective material properties can be derived, which may serve as input parameters into mathematical models for the room fire scenario calculations. Currently there are several such models in use [1-6].

Wood belongs to the main building materials in many countries in the world, and it becomes more and more used in building industry. It has many advantageous properties from both processing and usage view. In this study we concentrated on the cone calorimeter study of the four species of wood with the aim to investigate the heat release rate during the different exposure levels. The influence of external irradiance on effective heat of combustion and total heat release was also evaluated for the period of flame combustion.

EXPERIMENTAL

Four wood species were tested in Cone calorimeter: oak, beech, spruce, poplar. Radial specimens were cut. The dimensions of specimens were 100x100 mm. Materials were conditioned to equilibrium at 55 % R.H. and 23 °C prior to testing. The thickness of the specimens was 16 mm. The edge frame was used during all experiments to minimize the edge effects. The specimen was placed on the low density ceramic fiber blanket, backed by a ceramic fiber board. Specimens were tested at the irradiance levels 30, 50 and 65 kW/m^2 in horizontal orientation. Two replicate measurements were provided for all materials and irradiance levels. Characterization of the tested materials is in table 1.

Table 1: Characteristics of the Tested Materials

Material Name	Botanical Name	Density [kg/m^3]	Moisture Content [%]
Spruce	Picea excelsa	506	10.2
Poplar	Populus	336	9.8
Oak	Quercus sessiliflora	620	10.4
Beech	Fagus silvatica	684	10.0

RESULTS AND DISCUSSION

Heat Release Data

The heat release rate (RHR) curves as the function of time measured at 3 external irradiances for spruce wood are presented in the Fig. 1. The shape of the curves is typical for wood and wood based materials. The first peak of the RHR curve corresponds to the conditions at the ignition and shortly after the ignition. After the ignition the flame burning takes place. The flame burning corresponds to the burning of the volatiles and char layer is formed in this process. The heat release rate passes through the maximum, when the char is not present on the burning surface. As the char layer is forming heat release rate is decreasing as the char forms the barrier of the heat transfer into the material. The second part of the curve represents quasi steady state burning. The char layer is already formed and burning of the material through the thickness is taking place. Heat release rate at this stage is approximately constant. The third part of the curve corresponds to the rear end effects. The last part of the curve (RHR values lower than 40 kW/m^2) represents mostly non-flame burning of the char residue on the solid - gas interface.

For the spruce wood the first maximum of the heat release rate is higher than the second peak for all irradiance levels. The influence of the external irradiance on heat release rate is evident. First and second peak as well as the middle part of the curves increase with the increasing external irradiance level as expected.

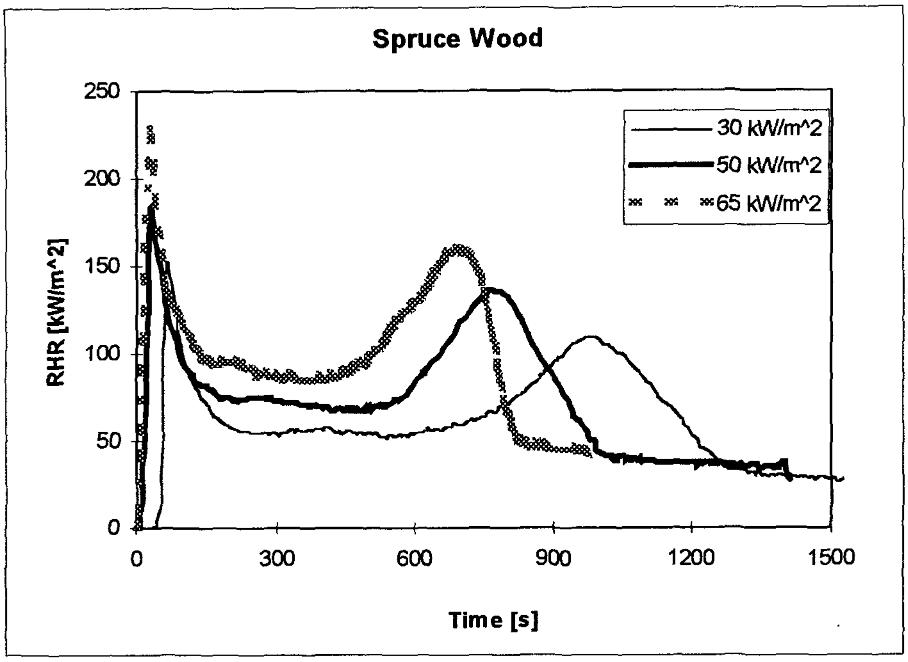

Fig. 1 Heat release rate as the function of time at three external irradiances for spruce wood.

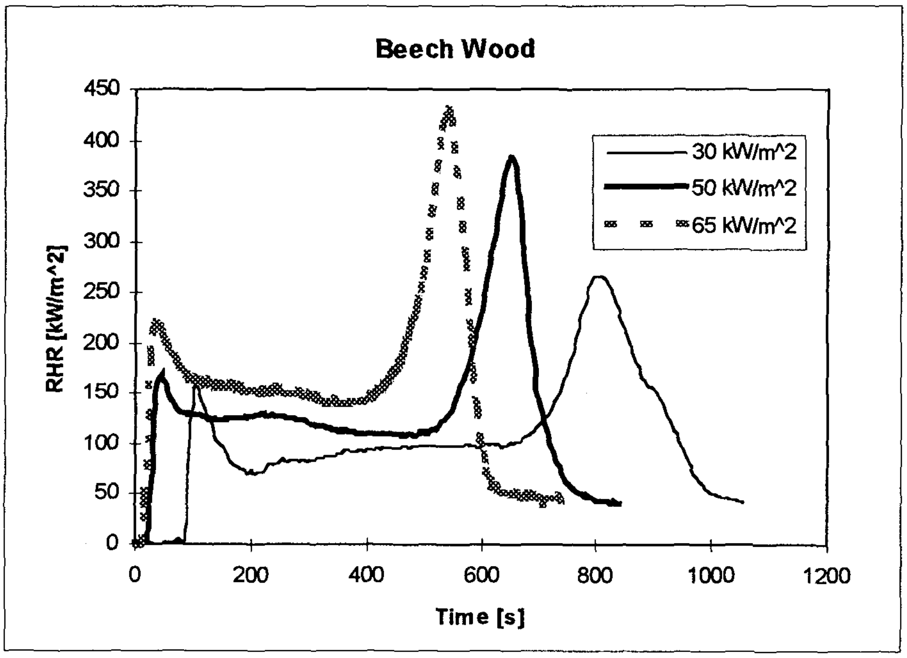

Fig. 2 Heat release rate as the function of time at three external irradiances for beech wood.

Similar curves were obtained for other tested wood species as well. However the RHR curves for beech wood had slightly different shape (Fig.2). After the first peak, the second part of the curves (quasi steady state burning) had relatively high values of RHR (more than 150 kW/m^2 at highest external irradiance) in comparison to other species (around 100 kW/m^2 at highest external irradiance). Furthermore the second peak was significantly higher than the first one at beech wood which was in contrast to other three tested wood species. This difference is probably due to the different anatomic structure and chemical composition of the beech and other wood species. The elemental analysis of all four tested wood species gives similar results for main chemical elements (C, H, O) [7]. There are differences in main chemical compounds in these wood species. Softwoods have generally higher lignin content than hardwoods. Spruce wood has around 45 % of cellulose and 27 % of lignin, while beech has around 40 % cellulose and 20 % lignin [7,8]. Poplar have similar lignin content than beech, around 21 % but higher cellulose content, around 48 % [9] . Oak has around 43 % of cellulose content and 25 % lignin content. Beech wood does not contain resins or tannin and the pores are diffuse, while oak contains tannin and the pores are unevenly distributed [10, 11].

The first peaks of RHR for all tested materials are presented on Fig. 3. It can be seen, that the difference in first peaks are not big regardless of wood species. Much stronger effect has the external irradiance. It means that after the ignition and before the char is formed (while the burning is taking place on the thin surface layer of "virgin" wood) the differences in chemical composition and physical properties of wood species do not have strong effect on RHR.

Total Heat Released

The total heat release (THR) is important parameter which characterizes the total available energy in the material in a possible fire situation. It can be found as the area under the heat release rate curve, measured in the Cone calorimeter. The burning time and consequently the burnout area of a material in the room test can be calculated based on the total heat release [5]. In the first stage of fire (prior to flashover) the flame burning is taking place at wooden materials. The correlation of total heat release as the function of external irradiance for four tested wood species is in Fig. 4. The total heat release presented in Fig. 4 corresponds to the flame burning during test. The summation of the heat released was taken from the beginning of test until the "flame out".

The total heat release strongly depended on density of wood. The higher density the higher the total heat released was measured. The increase of THR as the function of external irradiance was observed for oak and spruce. Slight change of THR was measured also for beech wood. For poplar the THR was not changed with external irradiance.

The effective heat of combustion (EHC) presented in Fig. 5 was calculated for the same time period as THR and represents mostly the heating value of volatiles. The char forming during the flame burning is not oxidized because the oxygen is consumed by flame. However this is true only approximately till the second peak. After this time the char starts to be combusted along with the weakening flame. During this period the instantaneous effective heat of combustion starts to increase. Therefore, the values of effective heat of combustion contain small contribution from char oxidation as well. The change of effective heat of combustion with the increasing external irradiance was very small for all four materials (the biggest change was measured for oak). The change in EHC with changing external irradiance is due to the fact, that more complete combustion is taking place and probably more char is combusted at higher external irradiances. The measured values for all four materials were between 9.3 MJ/kg and 12.2 MJ/kg.

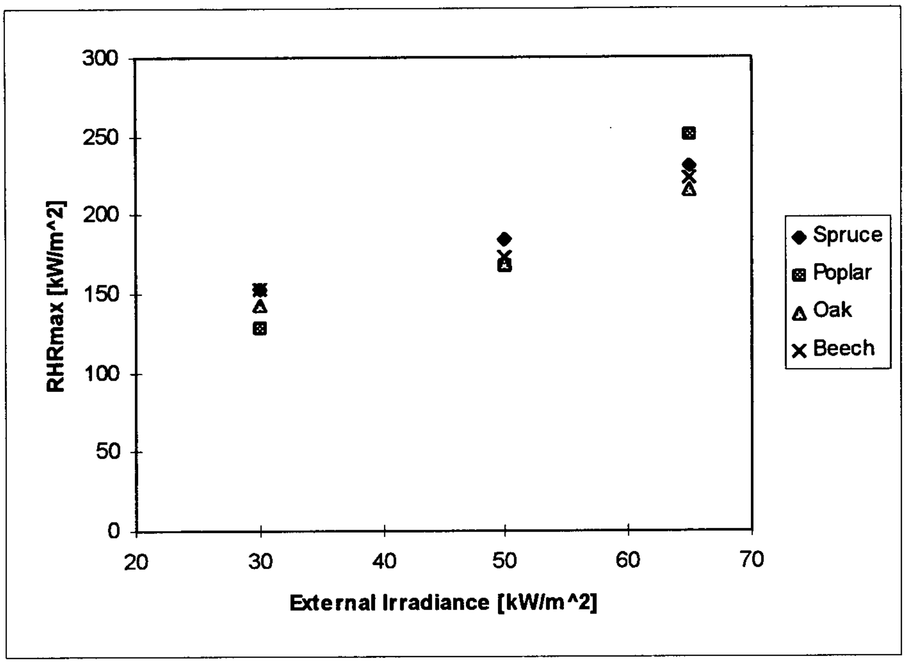

Fig. 3 First peak heat release rate as the function of external irradiance for tested wood species.

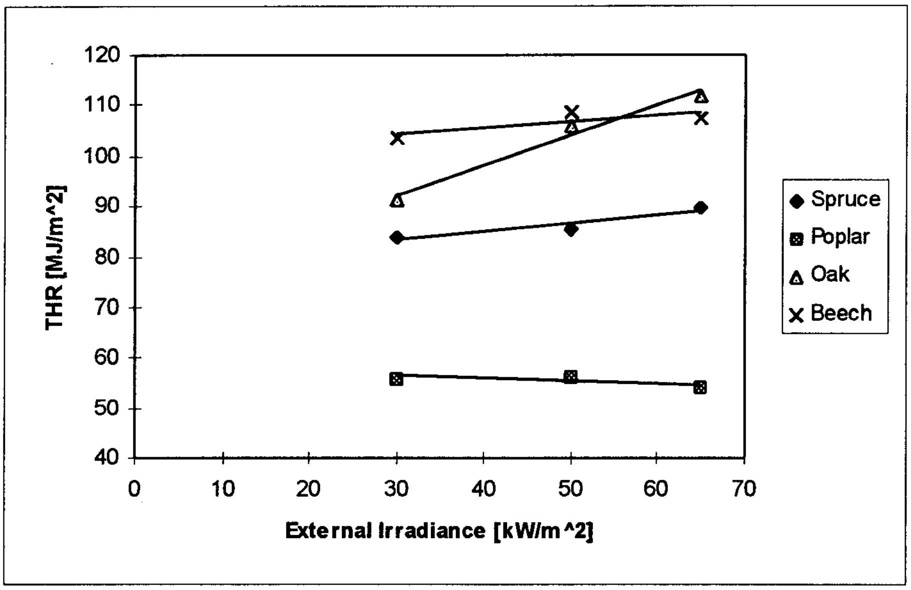

Fig. 4 Total heat released as the function of external irradiance for tested wood species.

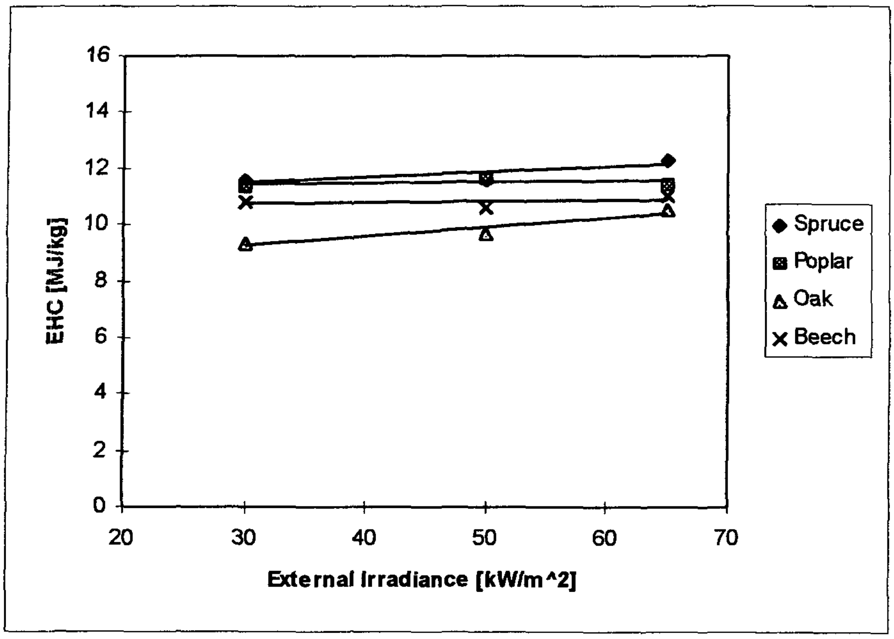

Fig. 5 Effective heat of combustion as the function of external irradiance for tested wood species.

Ignition Data

The time to ignition as the function of external irradiance (in a linearized form [12]) for tested wood species is presented on Fig. 6. The ignition time shortened with increasing external irradiance. Concerning the different wood species it can be seen, that at the same irradiance level the time to ignition was longer for higher wood density.

From the measurements of time to ignition as the function of external irradiance the thermal inertia and ignition temperature can be calculated. There are several ways of calculation of ignition parameters suggested by various authors [12, 13, 14]. For the illustration we present the calculated ignition temperature, T_{ig}, thermal inertia, kρc and ignition irradiance, $\dot{q}''_{ig}$ in the Table 2. Calculations were done the way suggested by Dietenberger [14].

Table 2: Calculated Ignition Parameters for Tested Materials

Material Name	$\dot{q}''_{ig}$ [kW/m^2]	T_{ig} [K]	kρc [kJ^2/m^4.K^2.s]
Spruce	14.1	625	0.181
Poplar	14.5	629	0.101
Oak	10.6	574	0.447
Beech	7.5	519	0.783

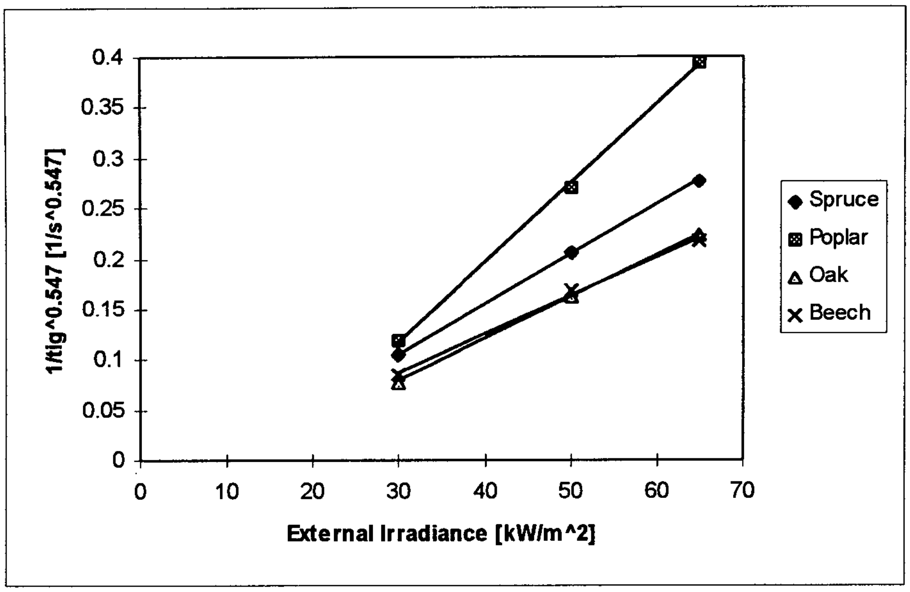

Fig. 6 Time to ignition as the function of external irradiance for tested wood species.

CONCLUSIONS

Cone calorimeter measurements were done at three irradiance levels on four wood species. The first peak of the heat release rate did not differ much for various wood species at the same irradiance level. The strong influence on the heat release rate had the level of external irradiance. Total heat release was slightly increasing with the external irradiance except for the poplar. The external irradiance had little effect on the average effective heat of combustion calculated for flame burning. The average values of total heat released increased with the increasing density of wood. The time to ignition was also increasing with the increasing density of wood at the same irradiance level.

NOMENCLATURE

EHC - Effective heat of combustion (MJ/kg)
RHR - Heat release rate (kW/m^2)
RHR_{max} - Peak heat release rate at the beginning of burning (kW/m^2)
$\dot{q}''_{ig}$ - ignition irradiance [kW/m^2]
T_{ig} - Ignition temperature [K]
t_{ig} - Time to ignition (s)

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