Lignocellulosic Material's Mass Flux Rate at the Moment of Ignition

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Abstract

The contribution deals with monitoring of lignocellulosic material's mass loss rate at the moment of ignition by external ignition sources. Experiment was performed in a electrically heated hot-air furnace according to ISO 871 standard (Setchkin furnace) in conjunction with precision scales. Like an ignition source was used kanthal wire. The mass loss rate in dependance of time was monitored under isothermal conditions. For a given temperature were used speeds of air-flow in the oven 30, 20, 10, 0 mm.s^{-1}.

Keywords Critical mass flux rate· air-flow lignocellulosic material time to ignition·setchkin furnace.

Introduction

Based on experimental observations, in order to determine the moment of ignition led to create the criteria of ignition on the base of experimental results of convection thermal stress of defined geometry wood samples and numerical solutions of conduction heat transfer equation. For wood was determined a minimum rate of formation of volatile combustible products $2,5. 10^{-4}$ g.cm^{-2}s^{-1} near the surface of the condensed phase[1].

Methodology

Experiment: Used materials: For verification of Bamford criteria, we selected a sample of spruce wood. We used cellulose like a model compouds from the reason that, it is the main component of wood and are released the most flammable products from it. We used water solution of retardants $KHCO_3$ and $(NH_4)_2HPO_4$ in concentrations 5%, 10%, 15%, becouse they cause modification of active thermal decomposition such

catalyze the reaction going at lower temperatures (dehydration, thermal-oxidation). Flax is not good explored cellulosic material, so we have also focused on it.

Equipment and measurement procedure: The basis of test equipment (figure. 1) is electrically heated hot-air furnace according to STN ISO 871 standard[2] (Setchkin furnace)[1], in the furnace is placed a sample in a steel sieve[3] to better monitoring of the air flow effect. In the furnace are placed two thermocouples[4], one is about two centimeters above the sample and the second approximately centimeter below the sample. With air pump is air forced to the furnace, the flow is regulated by flowmeter[5]. Under the furnace is weight (KERN PLT 450-3M)[2]. Sieve with the sample in the furnace is linked with weight using a glass rod[6], which is on both sides flat extensioned, for stability. Four centimeters above the sample is a source of ignition. As a source of ignition was used electrical coil from kanthal wire[7].
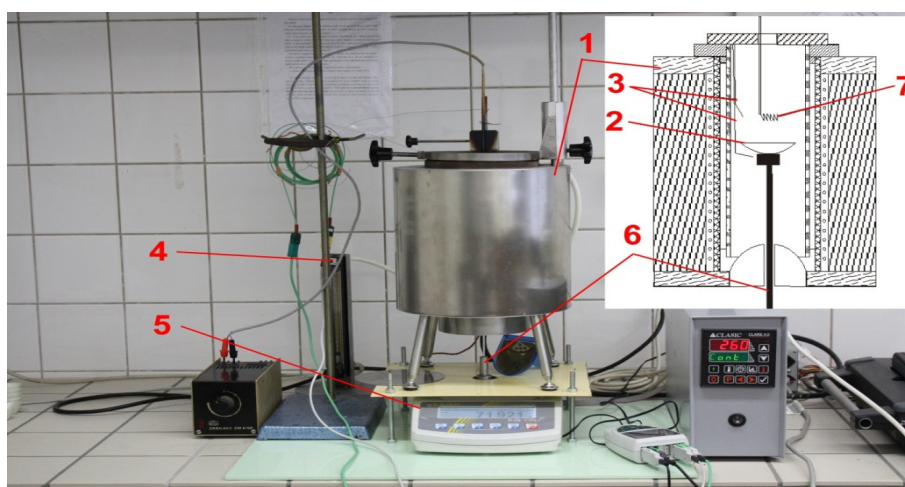

Figure-1
Testing equipment

The temperature for determining the critical rate for the formation of degradation products of different samples was determined from the thermogram[6] in condition of dynamic heating 5 °C.min^{-1}, when the highest rate of weight loss was observed. For each sample were made four measurements at a given temperature and speed of air-flow in the oven 30, 20, 10, 0 mm.s^{-1}, (calculation according to standard[2]. From the record of temperature course were determined time of ignition.

Results and Discussion

Bamford suggested the critical rate of flammable gases creation, as a condition for ignition of wood degradation products. The value of this critical rate is $2,5.10^{-4}$ g.cm^{-2}s^{-1} near the surface of the condensed phase. The mass loss rate for spruce wood was measured at a 320 °C. The mass loss rate in the moment of initiation of flame combustion was approximately 0.0035 g.s^{-1}. Used samples had the shape of cubes with side 1,5 cm and weight approximately 2 grams. After the conversion of mass loss rate per unit area consequential mass flux rate was $2,49.10^{-4}$ g.cm^{-2}s^{-1} that coinciding with Bamford criteria. The samples were burning at the speed of air flow 30, 20, 10 mm.s^{-1}.

The mass loss rate of pure cellulose was measured at a 320 °C. The ignition of degradation products in samples of pure cellulose occurred at a mass flux rate $2,63.10^{-5}$ g.cm^{-2}s^{-1} from the sample, which is about 10 times less than for a sample of spruce wood. After the initiation of sample, fire occurred for more than 5 seconds at speeds of air-flow 30, 20, 10 mm.s^{-1}..

Table-1
Measured values of mass loss rate of tested samples (MLR - mass loss rate)

Sample	Temperature (°C)	Speed of air-flow (mm.s^{-1})	Time to ignition (s)	Mass loss rate (g.s^{-1})	Ignition method	Average value of MLR (g.s^{-1})	Square density (g.cm^{-2})	Mass flux rate (g.cm^{-2}s^{-1})
Spruce wood	320	30	264	0,004	Burning	0,0035	0,142	0,000249
	320	20	251	0,003	Burning			
	320	10	287	0,004	Burning			
	320	0	293	0,003	Ignition			
Pure Cellulose	320	30	236	0,006	Burning	0,00525	0,01	2,63E-05
	320	20	242	0,007	Burning			
	320	10	250	0,004	Burning			
	320	0	268	0,004	Ignition			
Flax	270	30	243	0,008	Burning	0,008	0,0186	7,44E-05
	270	20	215	0,009	Burning			
	270	10	247	0,008	Ignition			
	270	0	281	0,007	Ignition			
Cellulose + 5% KHCO$_3$	230	30	268	0,008	Burning	0,00825	0,0108	4,46E-05
	230	20	258	0,009	Burning			
	230	10	287	0,008	Ignition			
	230	0	327	0,008	Ignition			
Cellulose + 10% KHCO$_3$	220	30	258	0,009	Burning	0,00875	0,0116	5,08E-05
	220	20	262	0,008	Burning			
	220	10	301	0,01	Burning			
	220	0	368	0,008	Ignition			
Cellulose + 15% KHCO$_3$	220	30	157	0,012	Ignition	0,01225	0,0126	7,72E-05
	220	20	157	0,012	Ignition			
	220	10	217	0,012	Ignition			
	220	0	248	0,013	Ignition			
Cellulose + 5% (NH$_4$)$_2$HPO$_4$	260	30	215	0,013	Burning	0,012	0,0108	6,48E-05
	260	20	227	0,012	Ignition			
	260	10	272	0,012	Ignition			
	260	0	298	0,011	Ignition			
Cellulose + 10% (NH$_4$)$_2$HPO$_4$	300	30	-	Nothing	-	0,0125	0,0116	<7,25E-05
	300	20	-	Nothing	-			
	300	10	-	Nothing	-			
	300	0	-	Nothing	-			
Cellulose + 15% (NH$_4$)$_2$HPO$_4$	300	30	-	Nothing	-	0,0105	0,0126	<6,62E-05
	300	20	-	Nothing	-			
	300	10	-	Nothing	-			
	300	0	-	Nothing	-			

Behaviour of flax sample was monitored at a 270 °C. The ignition of degradation products occurred at mass flux rate $7,44.10^{-5}$ g.cm^{-2}s^{-1} from the sample. After the initiation the sample burnt more than 5 seconds at speeds of air-flow 30, 20 mm.s^{-1}.

For samples of cellulose impregnated by water solution of KHCO$_3$ was observed a significant reduction of the temperature at which was on thermogram observed the maximum mass loss rate against the pure cellulose, 5% solution temperature dropped at 230°C and 10%, 15% solution temperature dropped at 220 °C. The minimum mass loss rate needed for ignition increase compared to pure cellulose which was also reflected at the minimum mass flux rate, in the case of 5% solution it was $4,46.10^{-5}$ g.cm^{-2}s^{-1} at 10 % solution it was $5,08.10^{-5}$ g.cm^{-2}s^{-1} and 15% solution it was $7,72.10^{-5}$ g.cm^{-2}s^{-1}.

For samples of cellulose impregnated by water solution of (NH$_4$)2HPO$_4$ also was observed reduction of the temperature at which was on thermogram observed the maximum mass loss rate. The temperature for 5% solution dropped to 260°C and for 10%, 15% solution temepreature dropped at 240°C. The minimum mass loss rate for ignition of 5% solution of (NH$_4$)$_2$HPO$_4$ compared to pure cellulose increased. The minimum mass flux rate increased on $6,48.10^{-5}$ g.cm^{-2}s^{-1}. For samples impregnated by 10% and 15% solution of (NH$_4$)$_2$HPO$_4$ at temperature 240°C, mass loss did not achieve rate needed to initiation of flame combustion, even after the temperature was

increased to 300°C, the necessary mass loss rate to ignition was not achieved. Mass flux rate was calculated at the maximum mass loss rate and it can be assumed that the initiation would occur at rates greater than $7,25.10^{-5}$ g.cm^{-2}s^{-1} for 10% solution of (NH$_4$)$_2$HPO$_4$ and $6,62.10^{-5}$ g.cm^{-2}s^{-1} for 15% solution of (NH$_4$)$_2$HPO$_4$.

All measured values are more clearly presented in Table 1

Conclusion

Use of KHCO$_3$ and (NH$_4$)$_2$HPO$_4$ water solutions reflected on significant decrease in temperatures which were observed maximal mass loss rate on thermograms and increase the critical mass flux rate for the initiation of a flame combustion. In the case of using 10% and 15% solution of (NH$_4$)$_2$HPO$_4$ was not achieve the necessary mass loss rate for initiation.

In Figure. 2 is a comparison of the critical mass flux rate for tested samples. The difference between the mass flux rate of spruce wood and other samples is due to the shape of the sample, while spruce wood was used in a cube of side 1,5 cm, other samples have a flat shape and therefore greater surface from which the pyrolysis products were released. Confirmation of Bamford criteria gives the possibility of using this measurement procedure to determine the critical mass loss rate also for other materials.
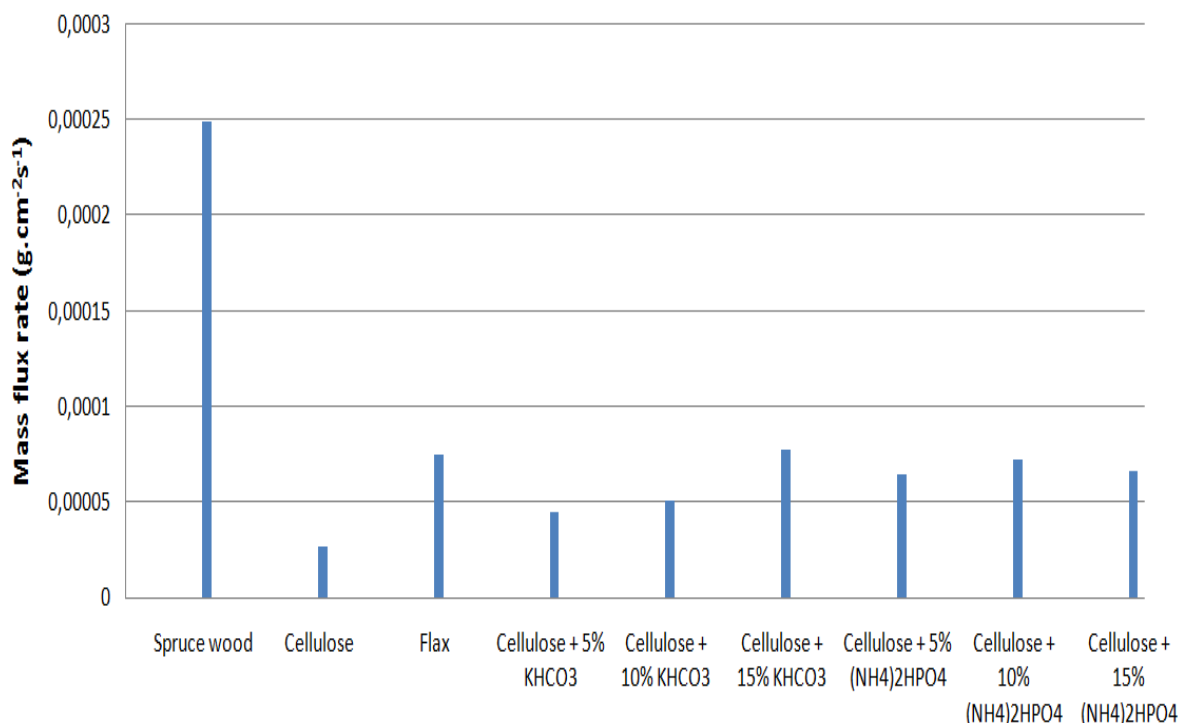

Figure-2
Minimum mass flux rate for ignition of tested materials

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