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Selection justification of the wood pulp and crown combustion parameters for the calculation of the crown forest fires impact on Vietnamese energy facilities

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Abstract. The selection of specific carbon monoxide generation rate and specific mass gasification rate values is necessary for mathematical modeling of crown forest fires and their thermal effects on Vietnamese energy facilities. The study presents results from experiments on burning trunk wood pulp and crown samples of the most common deciduous and coniferous trees in Vietnam. Specific carbon monoxide generation rate and specific mass gasification rate were measured for wood and crown samples under flame combustion mode. The experimental results were compared with literature values, and it was found that the time-average experimental values of specific mass gasification rate fell within the range specified in the fire load database by Koshmarov 2000 for both coniferous and deciduous trees.

1 Introduction

The destruction of vital energy facilities due to forest fires can have catastrophic consequences for a country's economy and security, disrupting human activities. Modeling forest fires is a complex and unresolved problem, with non-linear and multifactorial aspects [1]-[8]. Due to the uncertain properties of combustible materials in forests, it is difficult to accurately calculate the heat flux from a forest fire affecting energy facilities such as electrical substations, thermal power plants, hydroelectric power plants, and power lines in Vietnam [9]-[19].

Therefore, it is urgent to study the burning of wood pulp and crown samples of Vietnamese trees [20]-[26] in order to address this scientific and practical problem.

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The aim of the article is to provide evidence for the source data used in the mathematical modeling of the parameters of high forest fires and their thermal effects on energy facilities in Vietnam.

This was achieved through conducting experimental studies on the burning of trunk wood pulp and crown samples of the most common deciduous and coniferous trees in Vietnam.

2 Experimental set-up and experiments procedure

Fig. 1 shows the diagram of the experimental set-up proposed for works [27]-[33].

The set-up consists of a combustion chamber 1, which is connected to the exposure chamber 2 by means of a transition sleeve 3.

The combustion chamber has a volume of 3×10-3 m3 and its walls consist of stainless-steel sheets that are 2.0 ± 0.1 mm thick. To observe the testing of materials, a quartz glass window is present. The chamber's mode of testing can be changed by exchanging air between the chamber and the room through the six gate holes on the side wall.

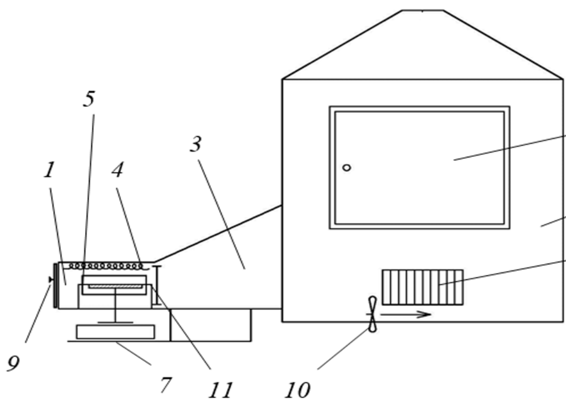

Fig. 1. Basic diagram of the pilot plant 1 – combustion chamber; 2 – exposure chamber; 3 – transition sleeve; 4 – electric-heating radiant; 5 – sample holder; 6 – gate holes; 7 – table for scales; 8 – exposure chamber door; 9 – combustion chamber door; 10 – fan; 11 – gate (partition) of the transition sleeve [34]-[37].

A device that thermally blocks the exposure chamber from the combustion chamber is situated in the transition sleeve. The exposure chamber has a cubic volume of 0.5887 m^3 and a cone-shaped upper part, with gate holes located on the sidewall.

The combustion chamber contains a shielded electric-heating radiant 4 and a sample holder 5. Electronic scales 7, with an error value not exceeding ± 1 mg, are used to measure the sample mass and are placed on a table with adjustable height.

Low-inertia armored thermocouples were used to carry out continuous temperature measurements in the exposure chamber. There were 32 thermocouples with a temperature range of -40 °C to +1100 °C and a measurement error of not more than ± 1.5 °C.

The density of the heat flux, which comes from the shielded electric-heating radiant to the surface of the material sample, is measured by a water-cooled Gordon sensor. The measurement error did not exceed ± 8%.

A water-cooled Gordon sensor was used to measure the density of heat flux from the shielded electric-heating radiant to the material sample surface, with a measurement error not exceeding ± 8%. The gas-air medium composition in the exposure chamber was measured using a multichannel gas analyzer with measurement ranges for gas concentrations and maximum errors, respectively: CO - 0 to 1% vol. and ±10%, CO2 - 0 to 5% vol. and ±10%, O2 - 0 to 21% vol. and ±10% vol.

The tests were conducted in flame combustion mode with an incident heat flux density of 60 kW m-2 and a radiant surface temperature of 750 °C.

The experimental procedure can be summarized as follows:

First, a sample of the material at room temperature and pre-weighed was placed in the sample holder insert.

Once the electric radiant stabilized operating mode was set, the door to the combustion chamber was opened, and the sample insert was placed in the holder. The valve of the transition sleeve was opened, and the combustion chamber door was closed, following which the sample was ignited. Throughout the experiment, measurements were taken continuously for CO (% vol.), CO2 (% vol.), O2 (% vol.), temperature, and weight of the sample.

The specific mass gasification rate is determined by the following formula:

$$\Psi_{sp} = \frac{1}{F}\frac{dM}{d\tau} \tag{1}$$

where Ψ_{sp} – specific mass gasification rate, kg m-2 s-1; M – current sample weight, kg; τ – time, s; F – sample surface area, m^2.

In order to anticipate the toxicological conditions during forest fires, it is crucial to have information about the concentration of carbon monoxide. Consequently, during the experiments, the specific factor for generating carbon monoxide (LCO) was measured at every time interval using the following equation:

$$L_{CO} = \frac{V}{\psi_{sp} F}\frac{d\rho_{CO}}{d\tau} \tag{2}$$

where V is the volume of the exposure chamber, m3; ρ_{CO} is the volume-averaged CO density in the exposure chamber, kg m-3.

To mathematically model the parameters of crown forest fires and their thermal effects on energy facilities, it is crucial to determine the lowest operational calorific value (Q) and the specific mass gasification rate of woody biomass.

According to the research conducted by Ivanov (2010) and Koshmarov (2000), the Q values for both deciduous and coniferous tree species range from 13.8 to 21.2 MJ kg-1. Therefore, taking an average value of 17.5 MJ kg-1 would result in an error of no more than 27% compared to the actual value.

Let's take measurements of the specific mass gasification rate of the trunk wood pulp samples of the Vietnamese trees, reflected in Table 1.

Table 1. Vietnamese tree species under consideration

Sample No.	**Name (English)**	**Tree class**	**Humidity, %**
1	Acacia auriculiformis	Deciduous	<5
2	Chinaberry	Deciduous	<5
3	Pine	Coniferous	<5
4	Eucaliptus camaldulensis dehnhardt	Deciduous	8
5	Dimocarpus longan	Deciduous	7

The wood samples had dimensions of 0.1×0.1×0.02 m, while the crown samples (leaves and branches) were 0.1×0.1×0.05 m. The leaves and branches had respective masses of 5.27 g and 12.3 g in a 3:7 proportion, which is typical for tropical forests in Vietnam.

The humidity of the samples was determined using a ZNT 125 Electronic humidity meter with a measurement range of 5% to 50% and a measurement error of ±2%. The moisture content of the samples was less than 8% (as shown in Table 1), which is consistent with the humidity of trees in Vietnam during the dry season when most forest fires occur.

3 Results

Fig. 2 shows the experimental time dependencies of the wood and crown samples specific gasification rate.

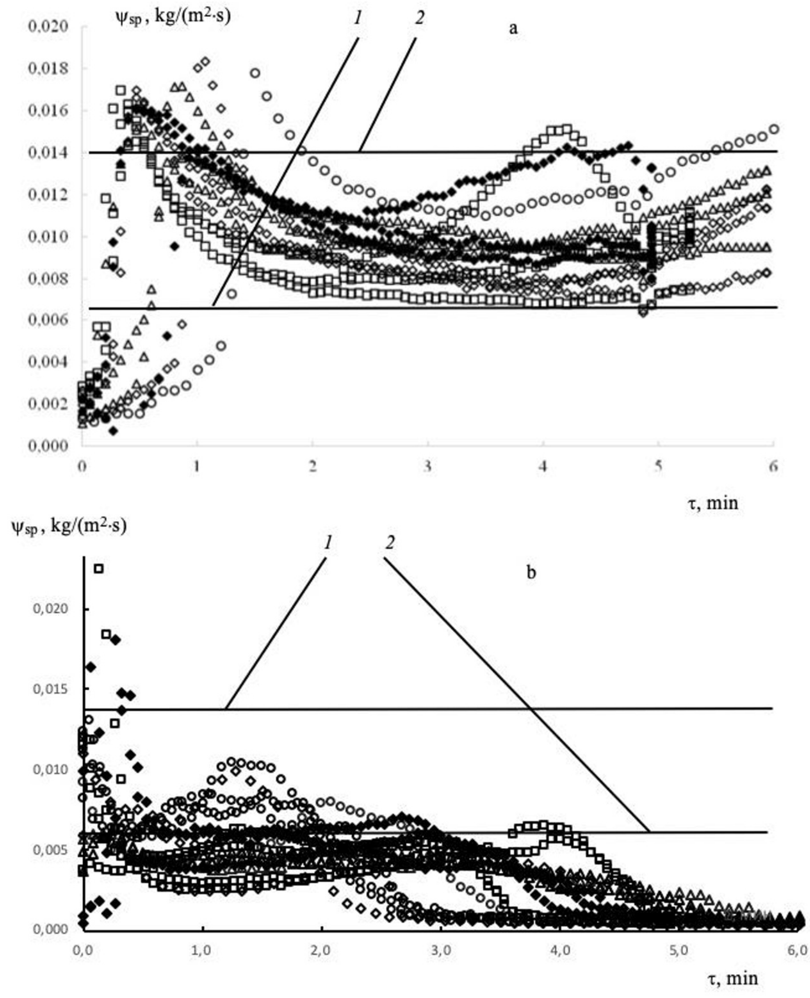

Fig. 2. The wood pulp (a) and the crown (b) specific mass gasification rate time depend ncies from the test beginning: □ — Sample No. 1; Δ — No. 2; ♦ —No. 3; ○ —No. 4; ◊ — No. 5; 1 – ψsp = 0.0063 kg m-2 s-1 (conifer species) (Koshmarov 2000); 2 – ψsp = 0.014 kg m-2 s-1 (deciduous ones) [38]-[39]

It is apparent from Fig. 2 that the time dependencies of the specific mass gasification rate of the wood pulp and the crown are maximal at the beginning of the gasification process. The time to reach maximum values does not exceed 0.5÷2 min, depending on the type of wood. After this, the process of wood gasification becomes relatively stabilized.

It is clear from Fig. 2:

— after 2 minutes of testing, the wood pulp samples show local ψsp values ranging from 0.0063 to 0.014 kg m-2 s-1. The lower limit corresponds to coniferous tree burning, while the upper limit corresponds to deciduous tree burning [40].

— on the other hand, the crown samples display local ψsp values lower than the lower limit after 3 minutes of testing [41]-[43].

The crown has a lower specific mass gasification rate mainly because its density is much lower than that of the wood pulp. Thus, in order to calculate the parameters of a crown forest fire more precisely, it is essential to consider the specific mass gasification rate of the crown.

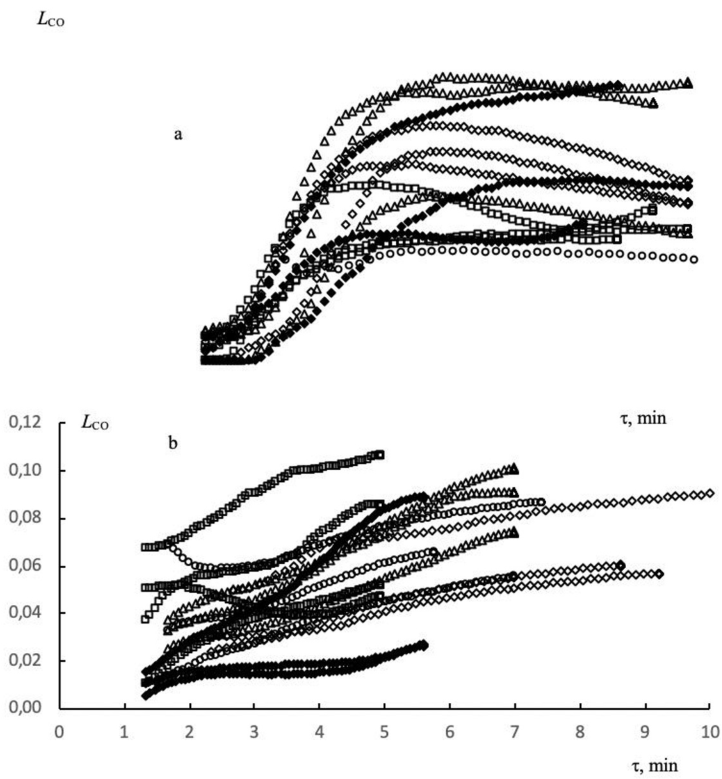

Fig. 3. The wood pulp (a) and the crown (b) CO generation specific coefficients time dependencies from the test beginning: □ — Sample No. 1; Δ — No. 2; ♦ —No. 3; ○ —No. 4; ◊ — No. 5.

Fig. 3 illustrates the time dependence of the specific mass coefficients of CO generation obtained from the experiment. As depicted in Fig. 3(a), the specific mass coefficients of CO generation are insignificant until approximately 2 minutes from the start of combustion. Afterward, there is a sudden rise in these coefficients, reaching their maximum values within 1 to 2 minutes, depending on the wood type. This phenomenon is attributed to the decrease of oxygen concentration in the combustion chamber 1 (as shown in Fig. 1), which leads to incomplete oxidation of carbon monoxide into carbon dioxide. As the oxygen concentration continues to decrease, the concentration of CO increases rapidly.

It is clear from Fig. 3 (b) that in case of the crown, CO generation specific mass coefficient increses monotonously.

The mean values of ψsp and LCO for the experimental period are listed in Table 2.

It is evident from Table 2 that in case of the wood pulp:

- experimental average values of Ψsp for all tree species under consideration are in the range from ψsp = 0.0063 kg m-2 s-1 (coniferous species) (Koshmarov 2000) to ψsp = 0.014 kg m-2 s-1 (deciduous ones)
- experimental average LCO values are significantly lower (more than 2 times) than the values specified in the database [45]-[48]

Table 2. Mean values of Ψsp and LCO for the experimental period

Sample No.	**ψsp , kg/(m2·s)**			**LCO**		
	The crown	**The wood pulp**	**Work**	**The crown**	**The wood pulp**	**Work**
1	0.0032	0.0093	0.014	0.0565	0.0052	0.024
2	0.0027	0.0102		0.0587	0.0107	
3	0.0036	0.0113	0.0063	0.0180	0.0073	
4	0.0029	0.0127	0.014	0.0472	0.012	
5	0.0016	0.0091		0.0524	0.008	

Work (Koshmarov 2000)

It is clear from Table 2:

- the experimental average ψsp values obtained from burning the tree crown are 2.7-5.7 times lower than those obtained from burning wood pulp;
- the experimental average LCO values obtained from burning the tree crown are 2.5-10.9 times higher than those obtained from burning wood pulp.

These average experimental values for mass gasification rate and CO generation coefficient specific values for wood pulp and crown samples of the most common deciduous and coniferous trees in Vietnam can be utilized to compute the characteristics of crown fires.

4 Conclusion

The experimental investigation of burning wood pulp and crown samples from common deciduous and coniferous trees in Vietnam supports the choice of specific CO generation rate and specific mass gasification rate required for mathematical modeling of thermal effects on Vietnamese energy facilities caused by crown forest fires.

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