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Numerical and experimental study on the moisture content of a pine tree

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Abstract

This article presents a validation study of the numerical model for assessing the moisture content of a pine tree based on experimentally obtained results, considering the surrounding external environmental conditions. In this work, the moisture content of the leaves of a pine tree is evaluated, taking into account the air temperature and the relative humidity conditions around the tree. The experimental work consisted of collecting maritime pine leaves, measuring their moisture content with a moisture analyzer and recording the environmental conditions, obtained by a meteorological station, at the time of this collection. In this work, data obtained during the year 2021 are considered. The experimental results obtained in the meantime were compared with the results obtained numerically. The numerical simulation was done by a research software developed by the authors called Hygrothermal Tree Modelling. In the conceiving of the numerical model, the processes of water circulation and energy transmission were included. The values of leaf moisture content predicted by the numerical model differ slightly from the values obtained experimentally, whose relative error calculated was 1.45%.

1. Introduction

Mass and heat transmission processes must be known when evaluating the thermal response and existing water circulation in trees. Phenomena such as water distribution, diffusion, transpiration and temperature are taken into account in this type of process.

Studies carried out by Janott et al. (2011), Wang et al. (2012), Simon et al. (2018), and Green et al. (2003) present very relevant models for understanding and simulating phenomena concerning the way in which mass transmission takes place in trees. Janott et al. (2011) proposed a concept of water flow in soil-plant systems. Wang et al. (2012) defined a model of tree structure and functioning to include biomass production, organ sharing and water availability solutions to simulate plant and environment interaction. Simon et al. (2018) developed a model to evaluate leaf temperatures and transpiration rates of trees. Green et al. (2003) presented a soil water balance numerical model.

Vegetation moisture and dry matter content can be used as important indicators in fire spread models and also to predict how fire evolves (Adab et al., 2016). For example, Adab et al. (2016) concluded that the scaling up of moisture content indices could be useful to apply as a previous forest fire alert system. Evaluating forest fire risk is a challenge task due to several uncertainties such as fuel flammability and ignition potential (Rao et al., 2020). In research works of Lifang et al. (2019) and Nolan et al. (2020) and Rao et al. (2020) the application of moisture content indices, their implications, challenges and details of use in this type of forecast were evaluated.

The model of water transfer, used in the study presented in this paper, includes the distribution, diffusion and transpiration processes. This model was developed from models of blood and water flow processes in the human body (Conceição and Awbi, 2021).

The grid generation is important to evaluate the temperature distribution and to feature the thermal phenomena (by conduction, evaporation, radiation and convection) that occur in the tree. The grid generation theory applied in this is founded on that used to obtain the geometries of buildings, vehicles or human bodies, utilized to assess the radiative exchanges (Conceição and Lúcio, 2010; Conceição et al., 2010).

The thermal response model of the pine tree used here is founded on thermal and radiative numerical models applied to other type of geometries, such as buildings (Conceição et al., 2018) and vehicles (Conceição et al., 2000).

The objective of this study is to validate the sub-model of the Hygrothermal Tree Modelling numerical model used to calculate the moisture content, mainly in the leaves, of a pine tree. Therefore, a periodic collection of pine leaves and subsequent measurement in the laboratory of their moisture content were carried out over the last two years. The experimental results obtained during the year 2021 were chosen to be compared with the results obtained numerically, maintaining the same external environmental conditions as those recorded experimentally.

2. Numerical Model

The numerical model is based on a system of equations of mass and energy transmission. The conduction, convection, radiation and transpiration phenomena are considered when establishing the system of energy transmission equations. The water mass evaluation, the water distribution, and the processes of diffusion and transpiration are considered when establishing the system of mass transmission equations.

The pine tree three-dimensional (3D) geometry model consists of cylindrical elements used to define the trunks, branches and leaves. The dimensions of each cylindrical element, consisting of several layers, are given by its length and diameter. This 3D geometry model will be an input of the pine tree thermal response numerical model.

The pine tree thermal response numerical model is founded on the human thermal response numerical model (Conceição and Lúcio, 2001), removing the thermoregulatory system and arising new pathways for water circulation. This numerical model considers a set of balance integral equations of energy for the pine tree body tissues and of mass for the water in the pine tree. The solution of the system of equations thus constituted is obtained by applying the Runge-Kutta-Fehlberg algorithm with error control.

The following phenomena are considered by the tree thermal response numerical model:

- Heat conduction existing between the various layers of each element of the tree;
- Heat convection existing between the outer surface of the elements and the surrounding air environment;
- Heat evaporation, assuming simultaneously the mass and heat transfer and the water phase change, existing between the outer surface of the elements and the surrounding air environment.

The following phenomena are considered in the mass transmission:

- Water distribution: the water is conveyed from the trunk to the branches and leaves;
- Water diffusion: water is conveyed within the trunk from the internal tissues to the external tissues; in this calculation, the cylindrical elements that constitute the trunk are divided into several layers (one inner, one outer, and a set of central layers located between them);
- Water transpiration: water is evaporated by convection from the outer layer to the environment, considering evaporative phenomena.

3. Methodology

Numerical simulation was carried out considering only one pine branch and its 90 leaves. Figure 1 presents the grid generation of this branch with its leaves. As input data for the numerical simulation, the average values of wind speed, ambient air temperature and ambient air relative humidity were considered, corresponding to the average of values recorded experimentally throughout the year 2021. These values are as follows:

- Average ambient air temperature: 20.60ºC;
- Average air relative humidity: 58.39%;

- Average wind speed: 4.29 m/s.

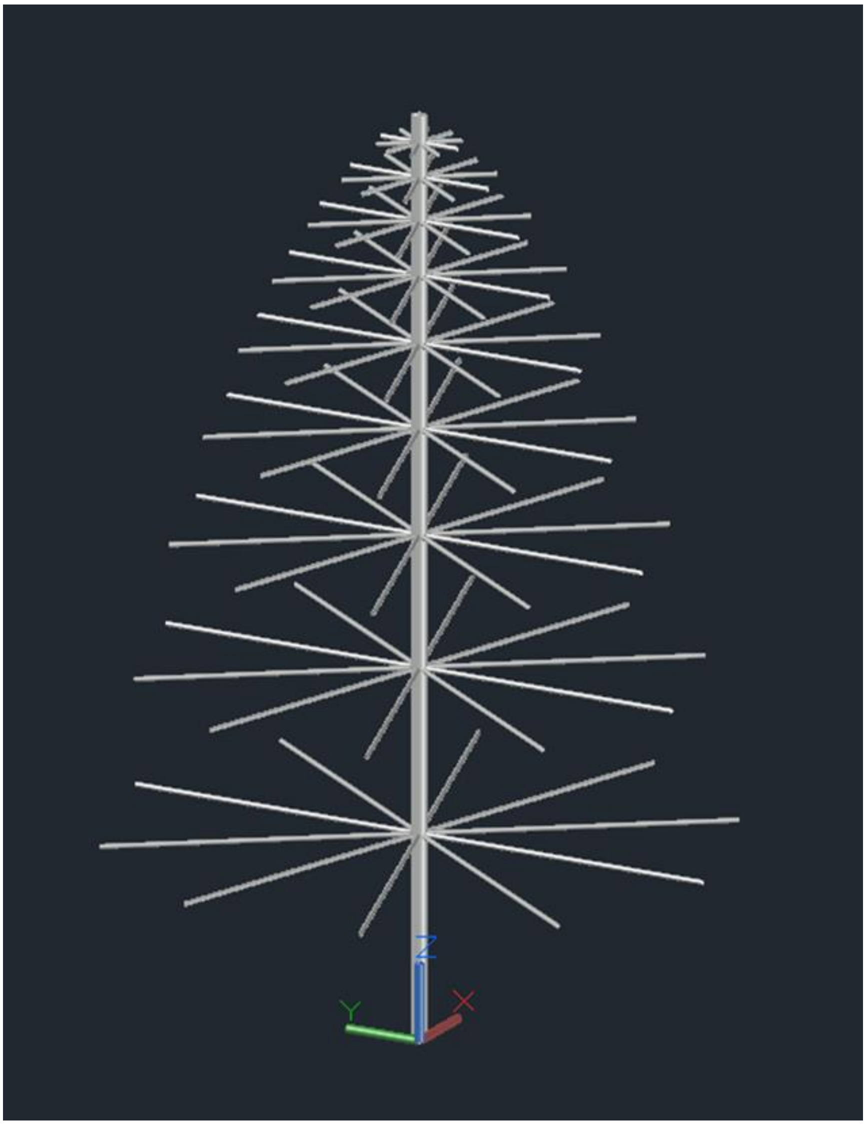

Figure 1 – Grid generation of the pine branch with its leaves.

The experimental work involves a periodic collection of a sample of maritime pine leaves, among other tree species, in a previously delimited area. This collection work has been going on since June 2019. This sample is taken to the laboratory in a closed environment for experimental tests. Upon arrival at the laboratory, its moisture content is measured. The tests carried out later are not presented in this work. Moisture content measurement is done using a Kern moisture analyzer. During this process, records of air temperature, relative humidity and wind speed measured on the day of collection are obtained by a weather station located in the vicinity of the collection area.

4. Results and Discussion

The experimental data obtained are shown in Table 1. The experimental results chosen to be analyzed and compared with the numerical results refer to the year 2021. From the measurements carried out, 61 were selected to be analyzed. Table 1 shows the monthly average values obtained from the measured moisture content of maritime pine leaves, as well as the monthly average of air temperatures and relative humidity recorded on the days of leaf sampling.

The average numerical moisture content obtained in the leaves of the pine branch was 56.41%. Note that this value corresponds to the numerical simulation carried out considering the mean values of air temperature and relative humidity obtained experimentally (see Table 1).

The numerical average results of the moisture content in the leaves are very similar to the monthly average results obtained experimentally in the measurement of the moisture content in the leaves. Comparing the numerically calculated value of the moisture content of the leaves with the annual mean value of the experimental measurements, it appears that the relative error is 1.45%. It can be concluded that the numerical model implemented in the calculation of the moisture content of the leaves of a pine tree allows to obtain results very close to the real ones, so the use of this numerical model is considered valid.

Table 1 – Experimental data obtained during 2021 (average monthly results).

Month	Moisture content (%)	Air temperature (ºC)	Relative Humidity (%)
1	55.20	15.10	83.00
2	55.29	16.03	78.29
3	54.76	17.54	62.20
4	55.32	17.95	65.50
5	54.24	21.10	55.00
6	54.06	25.82	44.00
7	57.87	26.71	38.11
8	56.60	26.42	53.67
9	54.53	26.50	48.00
10	61.85	22.74	50.60
11	54.14	17.70	53.00
12	53.38	13.63	69.33
Average	**55.60**	**20.60**	**58.39**

5. Conclusions

This article introduced a numerical model developed to calculate the moisture content available in the leaves of a tree, considering the surrounding external environmental conditions given by air temperature, relative humidity and wind speed. In this study, in particular, maritime pine leaves were used. The results obtained numerically were compared with experimental measurements done under similar environmental conditions. Experimental data used throughout the year 2021 were used.

The main conclusion reached is that the numerical model proposed here allows obtaining results on the moisture content of maritime pine leaves very close to those obtained experimentally. Comparing the numerical result with the annual average value of the experimental results, it is verified that there is a relative error of 1.45%.

Therefore, the authors consider that the numerical model proposed in this work can be effectively used to calculate the moisture content of tree leaves and, particularly, of maritime pine.

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