

Study of the Pine Tree Thermal Behaviour Nearby a Forest Fire Environment

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Abstract—In this work a numerical model of the pine tree thermal behaviour, nearby a forest fire environment, is developed and applied. The pine tree thermal behaviour numerical model is based on energy balance integral equations for the tree elements and mass balance integral equations for the water in the tree elements. The numerical model considers the heat conduction through the tree elements, heat exchanges by convection between the external tree surfaces and the environment, heat exchanges by radiation between the flame and the external tree surfaces and water heat loss by evaporation from the tree to the environment. The numerical simulation applied in this study considers the mean fire front temperature of 500°C, the air temperature of 40°C, the air velocity of 10 m/s and the air relative humidity around the pine tree of 50%. The Mean Radiant Temperature (MRT) and the external surface temperatures, that each element (trunks, branches and leaves) of the pine tree is subjected, were calculated. The values of the MRT and surface temperatures of the pine tree are highest in the side of the fire front and decrease from the first level, located near the ground, to the last level, corresponding to the top of the pine tree.

Keywords— Pine Tree, Fire Front; Thermal Response; Heat Fluxes; MRT; Numerical Simulation.

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I. Introduction

This work is a continuation of the previous paper when was develop a virtual pine tree geometry used in the radiation heat exchanges with a fire front [1]. In the previous paper the geometry of the maritime pine tree was developed, the outer surfaces of the maritime pine tree and the fire front were meshed and the view factors were calculated. From the information obtained previously, in this work the Mean Radiant Temperature (MRT) and the distribution of surface temperatures in the maritime pine tree are calculated.

The model presented in this work is used in the evaluation of the thermal response of the maritime pine tree initially developed and applied in the simulation of the thermal response of buildings, thermal response of vehicles and thermal response of human thermo-physiology. The thermal response model of the maritime pine tree is based on the thermal and radiative models developed for vehicles [2,3], buildings [4] and human [5].

The thermal response model of the maritime pine tree takes into account convective, radiative, conductive and mass transfer phenomena. The sub-models of heat exchanges by radiation and solar radiation used in the thermal response model of buildings were validated in summer conditions in Conceição and Lúcio [6] and in winter conditions in Conceição et al. [7], and used in the thermal response model of the humans were validated in Conceição and Lúcio [8]. Radiative exchanges were analyzed in Conceição and Lúcio [9] and Conceição et al. [10]. The radiative exchanges, important in the case of forest fires, were applied in a similar way between the tree and the fire front. The mass transfer equations, verified for water vapor inside the maritime pine tree, are similar to those applied in the study of indoor air quality [11].

Applications of the thermal response model in buildings can be seen in Refs. [12-18] and applications of the human thermal response model can be found in Refs. [19-22].

Regarding the radiative heat exchanges taking into account the shading, the papers by Conceição and Lúcio [23] and Conceição and Lúcio [24] present, respectively, applications of the thermal response model in buildings and people.

The objective of this work is to apply a thermal response model of the maritime pine tree in front of a forest fire and to analyze the values obtained from the MRT and the surface temperatures of the various elements (trunks, branches and leaves) integrating the virtual maritime pine tree.

II. Numerical Model

The three-dimensional pine tree numerical model is developed from the numerical model of the human thermal response conceiving a new geometric structure, adapting the water circulation paths and removing the thermoregulation system. The human thermal response numerical model was validated in the works of Conceição [25] and Conceição et al. [26]. The three-dimensional pine tree model consists of cylindrical elements that characterize the trunk, branches and leaves of the tree [27].

The pine tree thermal behaviour numerical model takes into account the phenomena of radiation, conduction, evaporation and convection and it is based on energy balance integral equations for the tree elements and mass balance integral equations for the water in the tree elements. The system of energy and mass balance equations is solved by the Runge Kutta Fehlberg method.

The radiation phenomena occur between all surfaces and the fire front and use the values of the Mean Radiant Temperature (MRT) obtained from the view factors values. The view factors are determined between the fire front and the surfaces of the elements.

The heat conduction phenomena are verified between each element layers of the pine tree. The heat exchanges by convection and water heat loss by evaporation phenomena, verified between the surfaces of the pine tree and the air, are obtained by empirical expressions.

III. Numerical Methodology

The virtual three-dimensional pine tree is 7.5 m high. It is constituted by 8863 cylindrical elements divided by 36 trunks, 97 branches and 8730 leaves. These elements can be structured according to four levels. The first level is at the height closest to the ground. The fourth level corresponds to the top of the pine tree.

The fire front is characterized by a height of 1 m and a length of 10 m. The pine tree is placed perpendicular to the central area of the fire front and at a distance of 5 m (Fig. 1).

The input data of the numerical simulation are the following:

- Flame mean temperature of 500°C;
- Air temperature of 40°C;
- Air relative humidity of 50%;

- Air velocity of 10 m/s.

The MRT and surface temperature of the different elements of are numerically obtained and used to analyse the pine tree thermal behaviour.

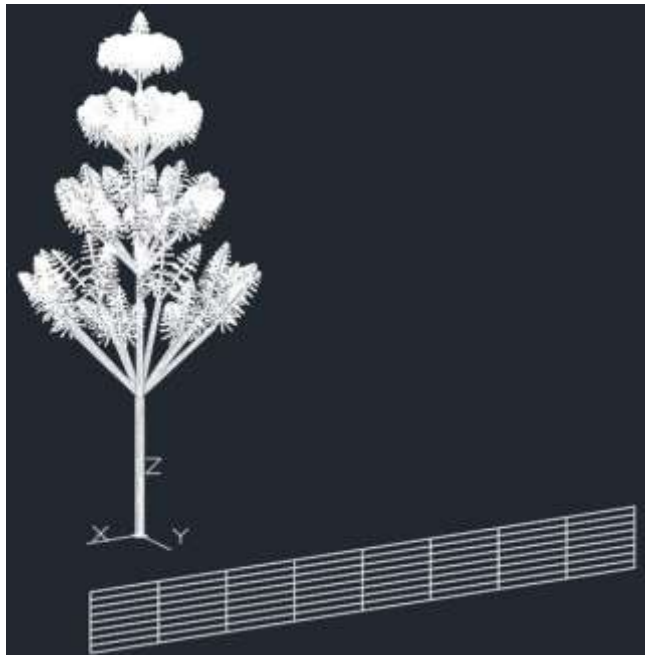


Figure 1. Three-dimensional pine tree located at a 5 m distance perpendicular to the fire front.

IV. Results and Discussion

In this section the results obtained for MRT (Fig. 2 and Fig. 3) and external surface temperatures (Fig. 4 and Fig. 5) of the pine tree elements are presented and discussed. In Fig. 3 and Fig. 5 the results of first, second, third and fourth levels are represented. These results were obtained for a 5 m distance of the pine tree from fire front.

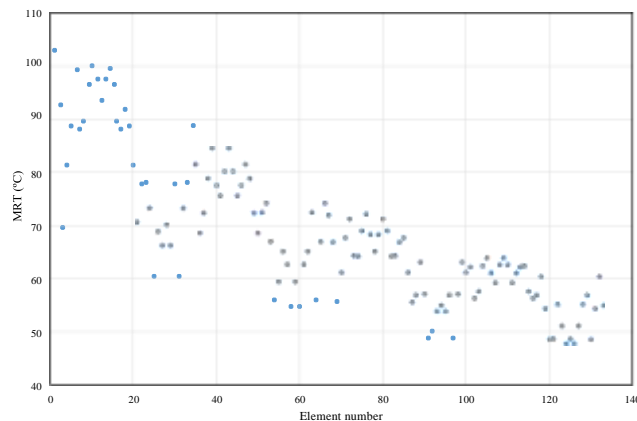


Figure 2. MRT of the pine tree trunks elements.

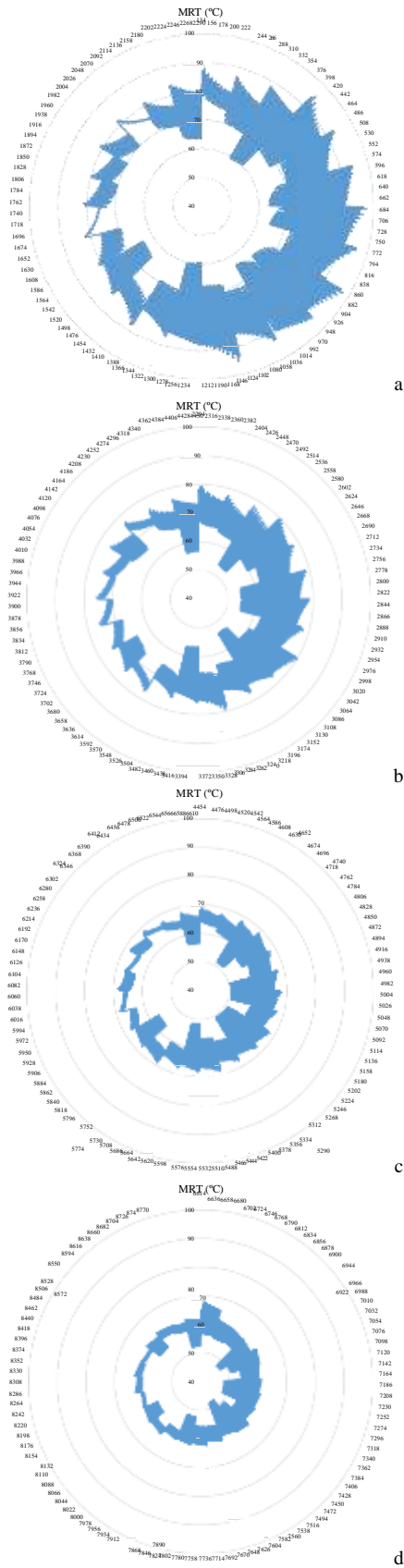


Figure 3. MRT of the pine tree leaves elements: a) first level; b) second level; c) third level; d) fourth level.

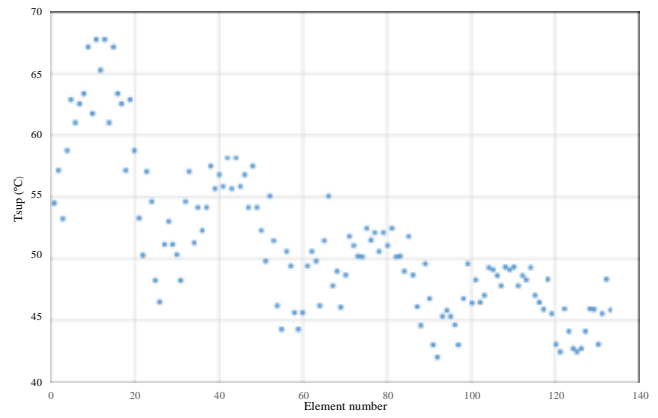


Figure 4. Surface temperatures (Tsup) of the pine tree trunks elements.

The results show that there is a direct relation between the values obtained for the MRT and surface temperatures of the pine tree elements. The highest values are obtained in the trunk section close to the ground facing the fire front and the lowest values are obtained in the upper branches of the pine tree facing in the opposite direction to the fire front. Regarding the leaves, the highest values are obtained at the first level of the pine tree and the lowest values at the fourth level of the tree. By level of leaves, as for the trunks and branches, the highest values are obtained on the leaves on the fire front side and the lowest on the opposite side.

Comparing the temperature values in each element of the pine tree, in general it verifies that the MRT values are greater than the surface temperature values.

The MRT values in the trunks and branches vary between the minimum value of 47°C obtained in the upper branches of the tree and the maximum value of 103°C obtained in the lower section of the main trunk. Namely:

- For the first leaf level, the MRT values vary between 59°C and 97°C;
- For the second leaf level, the MRT values vary between 53°C and 80°C;
- For the third leaf level, the MRT values vary between 50°C and 68°C;
- For the fourth leaf level, the MRT values vary between 48°C and 67°C.

The values of surface temperatures in the trunks and branches vary between the minimum value of 42°C, obtained in the upper branches of the pine tree, and the maximum value of 68°C, obtained in the lower section of the main trunk.

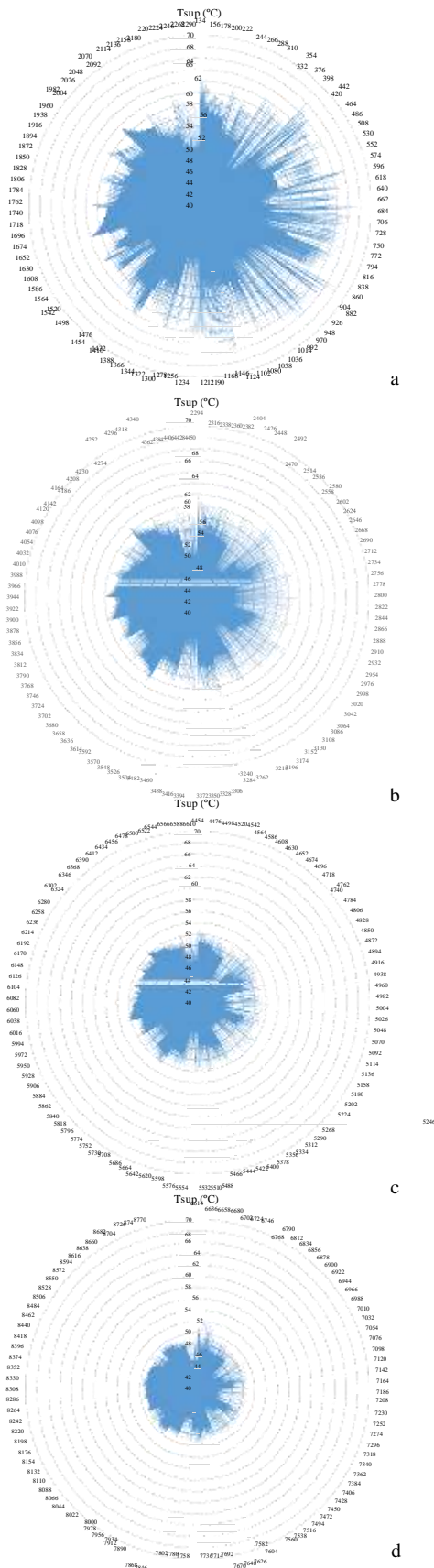


Figure 5. Surface temperatures (Tsup) of the pine tree leaves elements: a) first level; b) second level; c) third level; d) fourth level.

Namely:

- For the first leaf level, the surface temperature values vary between 48°C and 68°C;
- For the second leaf level, the surface temperature values vary between 46°C and 68°C;
- For the third and fourth leaf level, the surface temperature values vary between 44°C and 52°C.

As can be seen, the upper levels of the pine tree are slightly affected by the fire front because the surface temperatures obtained are just above the air temperature (40 °C). The areas most affected by the fire front are located in the lower sections of the trunk and in the first and second level of the leaves facing the fire front. For the upper levels of the pine tree there is a more uniform distribution of the values of MRT and surface temperatures.

v. Conclusions

In this work, a numerical model of the pine tree thermal behaviour, nearby a forest fire environment, was developed and applied. The numerical simulation carried out made possible to obtain the values of the MRT and the surface temperatures of the various constituent elements (trunks, branches and leaves) of the pine tree when a fire front, 1 m high and 10 m long, is located 5 m away from the pine tree. These values were obtained for each of the four levels at which the pine tree was divided.

The main conclusions are that the values of MRT and surface temperatures are higher on the fire front side and on the elements (trunks, branches and leaves) located closer to the ground, and that these values decrease between the first level (lower zone) and the last level (top) of the pine tree. It turns out that the most exposed elements of the pine tree to forest fire (with a relatively low height) are the leaves on the lower branches of the tree and turned in the direction of the fire front. These are the elements which will tend to ignite first.

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