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EFFECT OF RELATIVE HUMIDITY ON GRASSFIRE PROPAGATION

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ABSTRACT

The relative humidity of air is directly related to fuel moisture. Fuel moisture is often considered as the index of flammability in the context of bushfires. Variation of relative humidity and fuel moisture is considered to have a significant effect on the rate of spread of grassfire propagation and fire intensity. In this study, two sets of grassfire simulations have been conducted: one set with 0.21m grass and another set with 0.175m grass. For both sets the ambient temperature was kept constant while the relative humidity and fuel moisture were varied, with fuel moisture deduced from the McArthur MKIII-V GFDI model. A lower relative humidity was observed to lead to higher fire intensity and a faster rate of spread, which are intuitively expected. Froude number analysis showed that relative humidity can lead to change in the fire propagation mode (wind driven vs buoyancy driven), but the greater factor appears to be grass height (fuel load).

INTRODUCTION

The relative humidity of air is considered to have a significant effect on the rate of spread (RoS) of grassfire propagation. Sharples and McRae [1] in their simple index model proposed to use only temperature, wind speed and relative humidity to predict a fire danger index (FDI). The argument is one of model parsimony. That is, many other empirical models use too many parameters, parameters that may be deduced from other models, and have only small effects on the predicted FDI. Ambient temperature (*T*), relative humidity (*RH*) and curing (*c*) are a proxy for fuel moisture. For GFDI MK-III and MK-V [2], fuel moisture content (MC) is determined as:

$$MC = \frac{97.7+4.06RH}{T+6} - 0.00854RH + \frac{3000}{C} - 30 \qquad \textbf{Equation (1)}$$

Moinuddin et al [3] investigated the effect of wind speed and grass height, separately, on the rate of spread (RoS) of grassfire, using a physics-based model, Wildland0urban interface Fire Dynamics Simulator (WFDS). The RoS obtained from the physics-based model was found to be linear with wind speed in the parameter range considered. When the grass height was increased to keep the bulk density constant, the fire front changed from a boundary layer flame mode to a plume flame mode. The present study investigates the effect of relative humidity and fuel moisture content on the RoS.

MODELLING METHODOLOGY

The simulations presented here use domain size, configuration and grid resolutions identical to Moinuddin et al. [3]. The simulations were performed over a domain that was 960m long, 640m wide and 100m high. From the inlet to 660m, there is a non-burning subdomain, followed by a 104m x 108m burnable grass plot and finally there was a 200m long non-burning subdomain. Bordering subdomains, 270m wide, are placed on either side of the burnable plot. A sketch of the domain is shown in Figure 1. Because the setup is identical to Moinuddin et al. [3], there is no need to repeat the careful grid and domain convergence studies here.

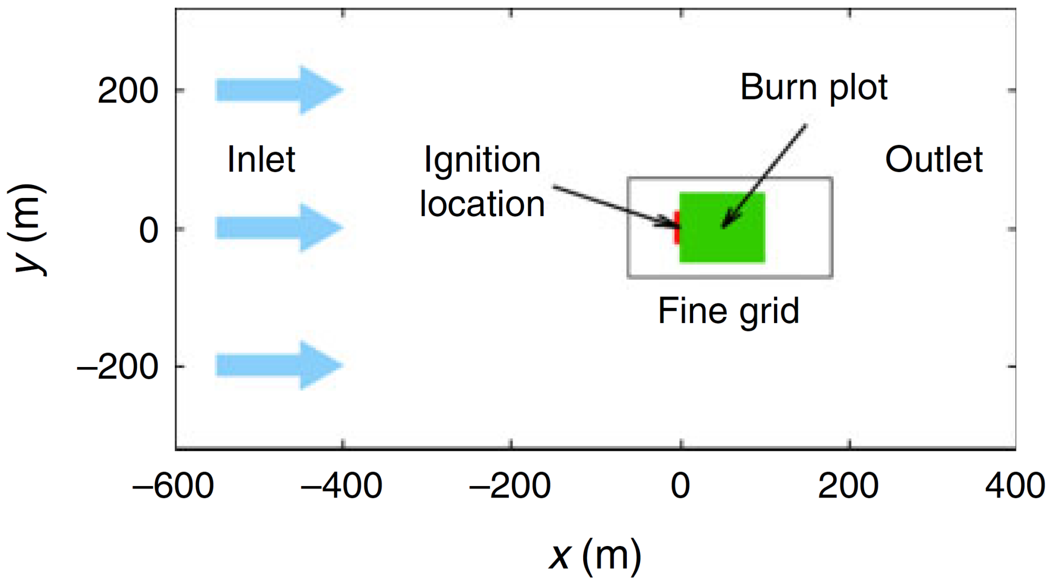


FIGURE 1 – SIMULATION DOMAIN PLAN VIEW (TAKEN FROM SUTHERLAND ET AL. [4]). THE RECTANGLE REPRESENTS AREA WITH FINE RESOLUTION OF 0.25M X 0.25M X 0.25M GRID UP TO 6M HEIGHT FROM THE GROUND.

Moinuddin et al. [3] investigated two modes of fire propagation: wind driven and buoyancy driven [5]. They found that "for the kind of grass was modelled", based on Froude Number (Fr), fire becomes buoyancy driven when grass height raises from 0.175m to 0.21m and above, when temperature and relative humidity (RH) were set at 32°C and 40% respectively.

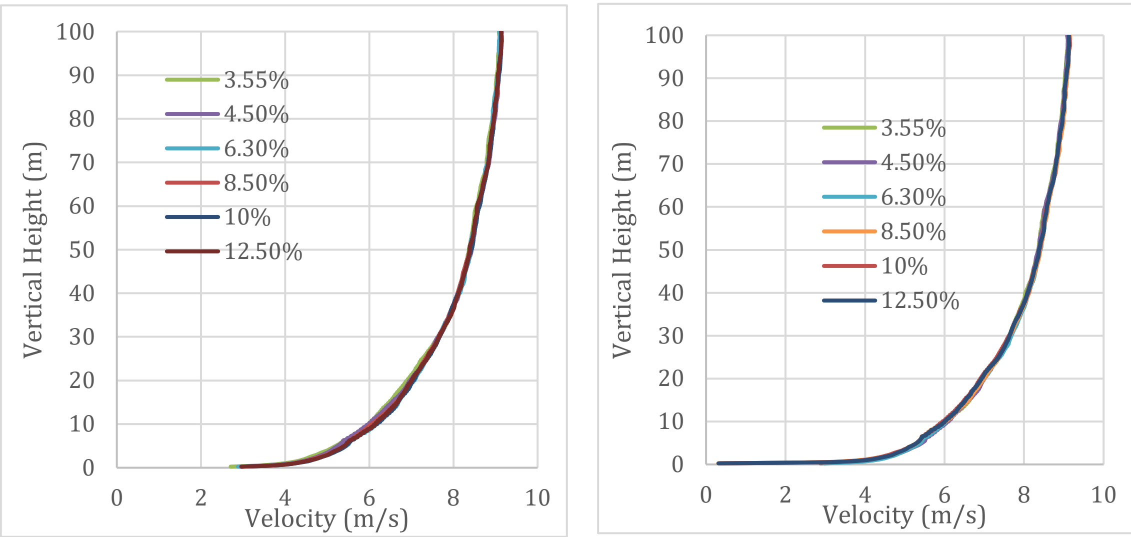
As the temperature, RH and MC are interlinked as per Equation (1), in this study, we have kept the temperature at 32°C for all simulations and RH was varied, and therefore MC also varied. Intuitively, if RH and MC are reduced, the fires with 0.175m grass may produce a higher fire intensity and will become buoyancy driven. On the other hand, for 0.21m, a higher RH and MC may lead to transition from buoyancy driven to wind driven propagation.

Therefore, fire propagation simulations with two grass heights: 0.21m and 0.175m have been conducted with varying RH (and MC). Scenarios modelled in this study are given in Table 1.

U_2 (m/s)	Grass height (m)	MC (H%)	RH (%)
4.6 ± 0.15	0.21 and 0.175	3.55	10
		4.5	20
		6.3	40
		8.5	60
		10	75
		12.4	100

TABLE 1 – SCENARIOS MODELLED

The inlet was prescribed as (1/7) power law model of the ABL following Morvan et al. [6], with a wind speed of 5.6m/s at 2m above the ground, U_2. Turbulence is introduced as the domain inlet using synthetic eddy methodology (SEM) proposed by Jarrin et al. [7]. In addition, a surface roughness parameter of 0.15 is used. Over the non-burning domain, the wind speed slows down and settles to $U_2 = 4.6 \pm 0.15$m/s before the ignition location. This wind flow condition is to match the scenario of Case 064 of Cheney et al. [8] which was the base case for simulations of Moinuddin et al. [3] and Sutherland et al. [4].



(a) 0.21m high grass (b) 0.175m high grass

FIGURE 2 – VELOCITY PROFILES PRIOR TO THE IGNITION LOCATION FOR VARIOUS SIMULATIONS WERE RUN FOR DIFFERENT MC (FROM 3.55% TO 12.5%)

Figure 2(a) represents the velocity profiles prior to the ignition location. Seven simulations were run for different RH and fuel MC cases with a grass height of 0.21m. Air temperature was fixed at 32°C, while RH ranged from 10% to 100%, and the MC followed the GFDI model (equation 1). The wind velocity profiles at similar locations for corresponding simulations from 0,175m high grass are presented in Figure 2(b). As expected, the velocity profiles are identical. Therefore, the wind profile is well developed over the burnable plot and the relative humidity makes little difference to the wind speed profiles.

RESULTS

In this section, first we present the RoS and heat release rate (HRR) data for the two sets of simulations (first set with 0.21n high grass, and a second set with 0.175m high grass). Then we assess the data in terms of a non-dimensional parameter Froude number (Fr) to see the transition from wind driven to buoyancy driven mode and vice versa.

To obtain the RoS, the fire front location is determined by examing the boundary centerline temperature as the fire moves through the regions of burning grass. Once the propagation has reached a quasi-steady state, as judged by a linear increase in the fire front location, the RoS is determined by applying a straight line fit to the fire front location using a least-squares regression method. The HRR is computed by WFDS by first determining the combustion rate of the fuel, and then multiplying the combustion rate by the calorific value (or heat content) of the fuel.

0.21M HIGH GRASS CASES

The fire front locations are presented in Figure 3 for a grass height of 0.21m. Only the quasi-steady period data is presented. The fire front moves faster with a decrease in RH and MC. The slope of each linear fit is the RoS for each RH case. For all cases, for a quasi-steady region, the R^2 value is found to be ~0.999, indicating the fire is indeed quasi-steady.

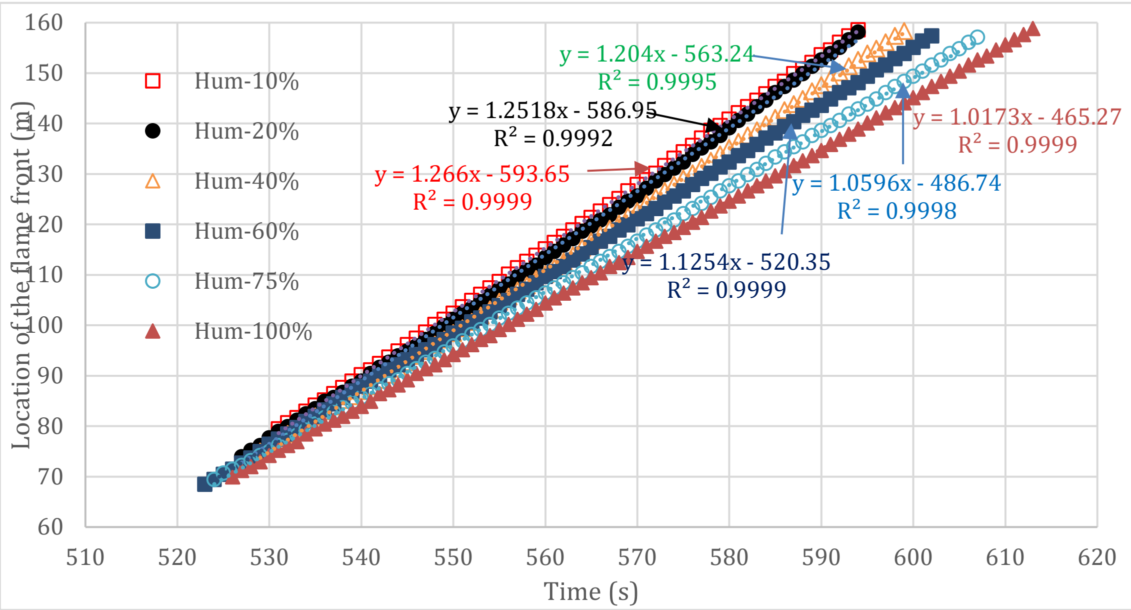


FIGURE 3 – FIREFRONT LOCATIONS VS TIME FOR CASES WITH GRASS HEIGHT OF 0.21M

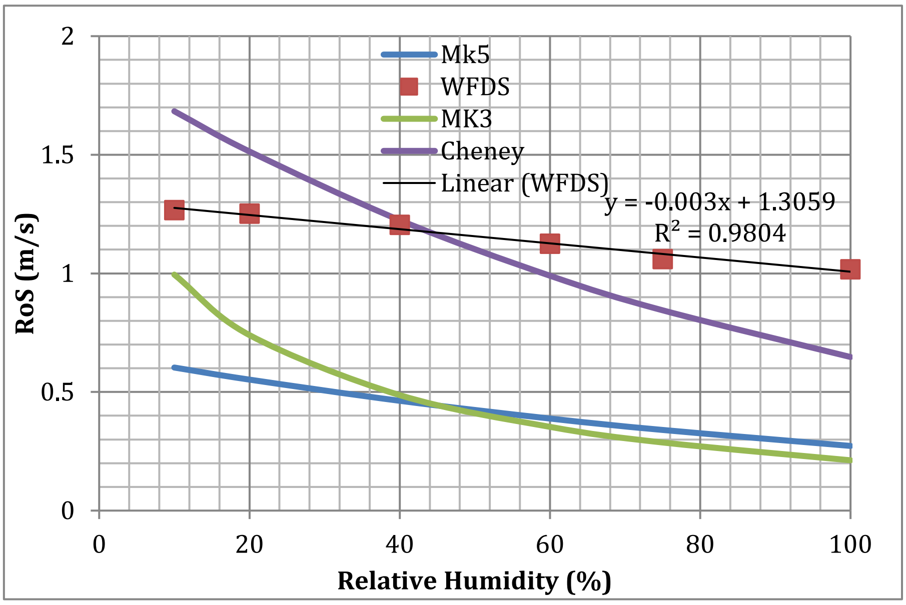


FIGURE 4 – ROS-RH CORRELATIONS GRASS HEIGHT OF 0.21M

In Figure 4, the RoS as a function of RH is presented. The correlation appears to be linear and is compared with operational models: Mk3 and Mk5 [2] and Cheney et al. [9]. The comparison of a simulated RoS with the operational models shows that the RoS is in quantitative agreement with the RoS values predicted by the operational models and the decreasing trend is similar. The simulated RoSs are closest to the predicted of the Cheney et al. [9] model.

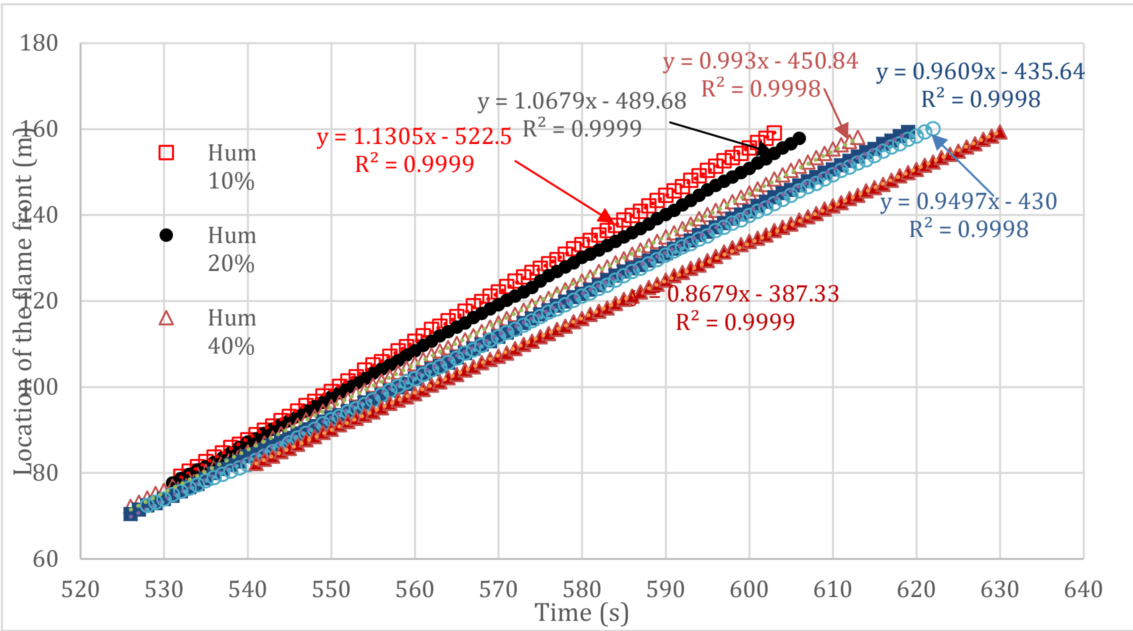


FIGURE 5 – FIREFRONT LOCATIONS VS TIME FOR CASES WITH GRASS HEIGHT OF 0.175M

0.175M HIGH GRASS CASES

Similar to Figure 5, the fire front locations during the quasi-steady period are presented for a grass height of 0.175m. Once again, we can observe that the fire front is moving faster with decreasing RH (MC). The RoS for each RH case is represented by the slope of each linear fit (with R^2 ~0.999).

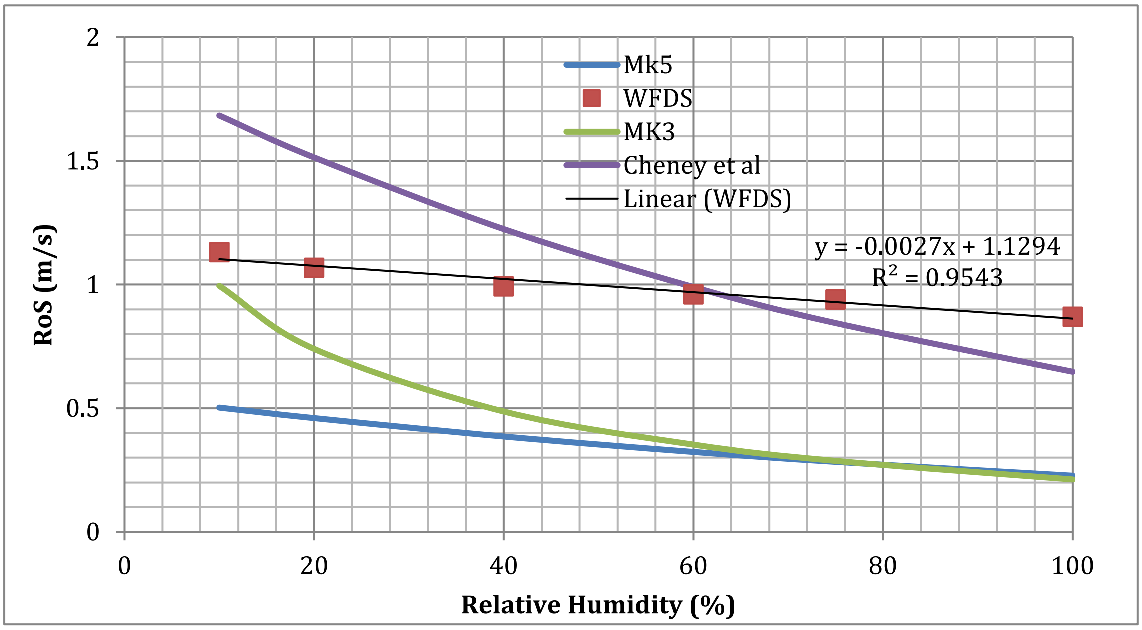


FIGURE 6 – ROS-RH CORRELATIONS GRASS HEIGHT OF 0.175M

In Figure 6, we present the RoS for six simulation cases with 0.175m grass, along with the operational model profiles. Mk5 and Cheney et al. [9] model predictions did not change with the fuel height (in turn, fuel load) from Figure 4. It can be seen again that the differences between simulated RoS with the operational models are not big.

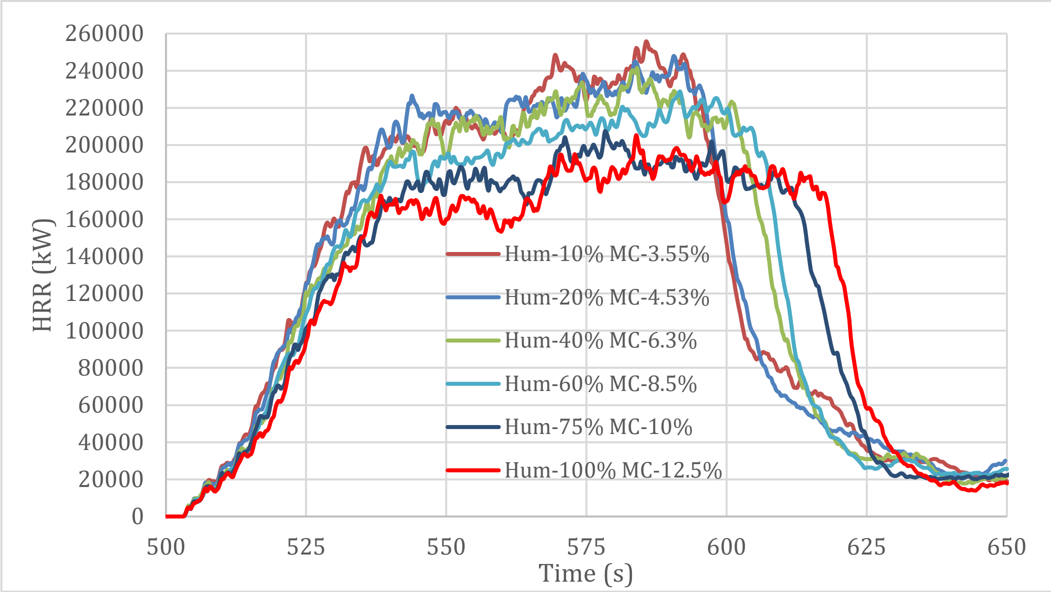
MODE OF FIRE PROPAGATION

We are interested to learn if the fire propagation mode changes if the RH increases/decreases using Froude number (*Fr*). Apte et al. [5] proposed to use *Fr* as shown in Equation (2) to distinguish two modes of fire propagation. Moinuddin et al. [3] used the same methodology.

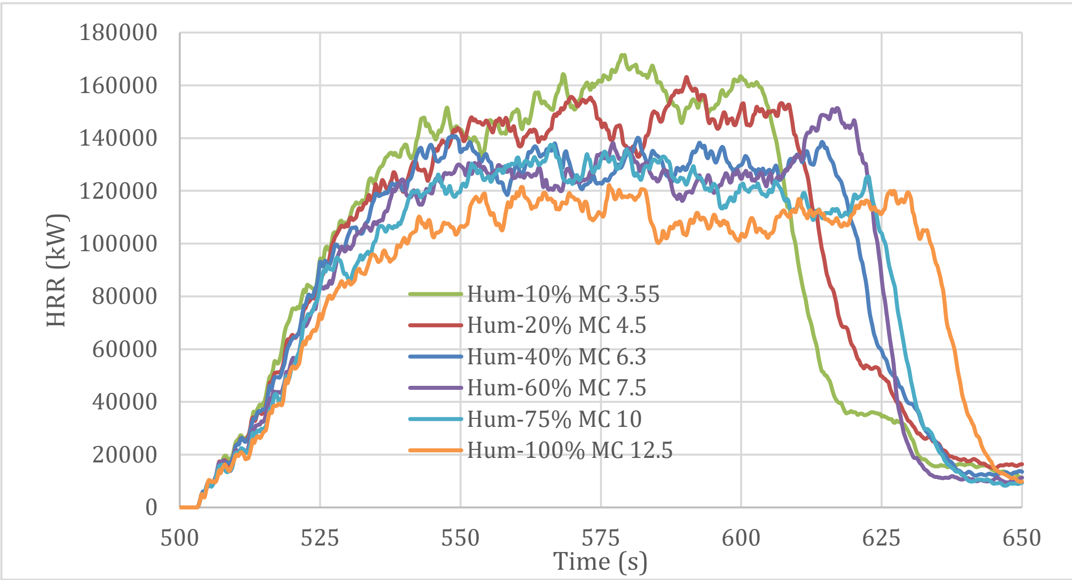
$$Fr = \frac{U_{10}}{\{gHRR/(\rho C_p T_s)\}^{1/3}} \qquad \textbf{Equation (2)}$$

Hence, U_{10} is a velocity above 10m (can be obtained from Figure 2), HRR is in kw, c_p in kJ/kg/K and T_s is the surface temperature taken as 450K. The other parameters used to compute Fr are g = 9.8m/s, which is the acceleration due to gravity, and the density ρ = 1.2kg/m^3.

From 0.21m and 0.175m high grass fire simulations, the HRR values are presented in Figure 5(a) and 5(b), respectively. Ignition occurs at 504 sec. It can be observed that when the grass height is constant, with the reduction of RH, the HRR (hence fire intensity) increases.



(a) 0.21m grass height



(b) 0.175m grass height

FIGURE 7 – HRR FROM GRASSFIRE SIMULATIONS; IGNITION OCCURS AT 504 SEC

To calculate *Fr* values, HRR values are averaged between 540 and 595 sec for 0.21m high grass cases and between 545 and 605 sec for 0.175m high grass cases. In these time periods, the HRR (hence the intensity) is quasi-steady. *Fr* values calculated using Equation (2) for all cases are presented in Figure 8. Due to different boundary conditions used in this study, the threshold value is set as 0.46, above which the fire propagates as wind driven.

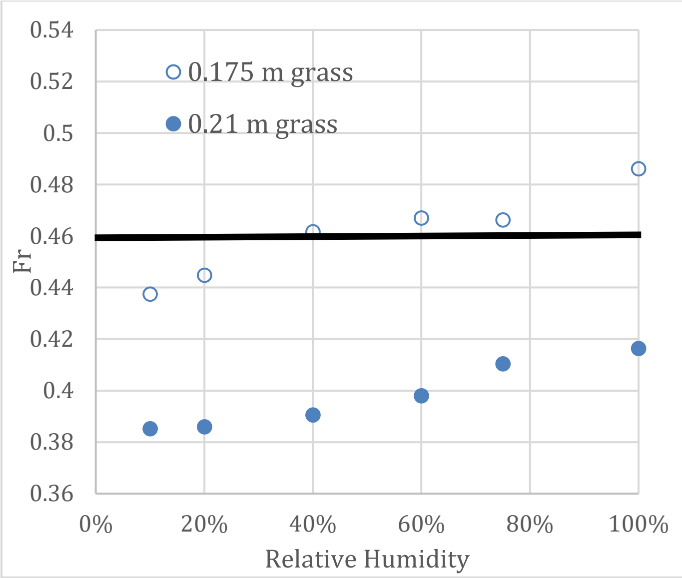


FIGURE 8 – FR VS RH FOR ALL SIMULATION CASES

For a 0.21m grass height, with the change of RH, fire propagation remains in a buoyancy driven mode. However, for a 0.175m grass height, with low RH (40%<), Fr values fall below the threshold line. This indicates a transition from wind driven mode to buoyancy driven mode due to increased HRR (Figure 7(b)). An important finding of this study is that RH can contribute to different modes of propagation. However, comparing data in Figure 8, it appears that whilst RH can lead to a change in propagation mode, a greater factor appears to be the grass height (fuel load).

CONCLUSIONS

To understand the role of relative humidity of air in grassfire propagation, two sets of grassfire simulations have been conducted: one set with 0.21m grass and another set with 0.175m grass. If the ambient temperature is kept constant, fuel moisture is directly correlated. Therefore, in this study, fuel moisture (and relative humidity) was varied by keeping air temperature constant at 32°C. The driving velocity (U_{10}) was also kept constant at 6m/s. The relative humidity range was 10% to 100% corresponding to a fuel moisture range of 3.55% to 12.5%. As expected, lower relative humidity leads to higher fire intensity and a faster rate of spread.

Froude number analysis has been conducted to see the effect of fuel moisture and relative humidity on the fire propagation mode (wind driven or buoyancy driven). Fires involving 0,21m high grass are found to be in a buoyancy driven mode irrespective of the relative humidity. On the other hand, fires involving 0.175m high grass are in the wind driven mode when relative humidity is greater than 40%. With the decreased relative humidity, fire changes to buoyancy driven mode. However, a more significant factor accounting for different modes appears to be the grass height (fuel load).

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