



Inside the inferno—understanding the fundamental processes of a bushfire

A raging high intensity bushfire is one of the most spectacular and dangerous natural phenomena in the world. Understanding the processes involved in the sustained combustion of vegetation is essential to developing systems to predict the behaviour and spread of bushfires over the landscape. A recent two-part synthesis provides insight into the current state of our understanding and highlights many of the processes that contribute to the difficulties in obtaining accurate predictions of fire spread.

The need to predict bushfire behaviour

Understanding the factors that influence the behaviour and spread of a bushfire is essential to predicting how fast and in which direction it will move. Reliable predictions of the future location and arrival time of a fire front are critical to support operational decision making and for ensuring the safety of both firefighters and the general public. A number of approaches have been developed to carry out such predictions, ranging from simple rules of thumb through to process-based, computationally intense, numerical models of fire behaviour. No single approach satisfactorily provides all the necessary information under all situations in the time required. However, our efforts to understand this phenomenon are improving the reliability of predictions, resulting in safer and more effective firefighters and enabling better prepared and safer communities to live in fire-prone landscapes.

What is a bushfire?

While this may seem obvious, the question has different answers depending on the scale at which it is being asked. At its most basic, a bushfire is a complex combination of highly chaotic chemical reactions and physical processes that continually and freely propagate through spatially-variable biomass fuels across variable terrain influenced by spatially and temporally varying atmospheric conditions. The chemical and physical processes involved in the

combustion of vegetative fuel are the same as those for other biomass fuels such as a bonfire or coal-fired power station. The difficulty in understanding and predicting a bushfire arises from the fact that it is free-burning (i.e. unconstrained) and that it is open to vagaries of the prevailing conditions.

These difficulties are exacerbated by the broad range of spatial and temporal scales over which the combustion and heat transfer processes occur and interact (ranging from millimetres to kilometres and milliseconds to hours) and our inability to know precisely the conditions in which the fire is burning. But the apparent unpredictable nature of a bushfire is also a result of the nature of the fuels in which that bushfire burns.



Figure 1. Aerial photo of a large experimental grass fire illustrating the changes in combustion behaviour around the perimeter as a result of different localised burning conditions.

The nature of bushfire fuel and its combustion

An important source of the complexity of the behaviour of a bushfire resides in the fuel through which it burns—a combination of the broad range of chemical and physical structures present in the mix of live and dead vegetation that comprise bushfire fuels, and the chemistry that is unique to the combustion of biomass fuels.

The chemistry involved in the thermal degradation of biomass fuels is highly sensitive to the temperature of the fuel and the rate of heating which results in two possible pathways that are controlled by thermal and chemical feedbacks (Sullivan and Ball 2012). These pathways are mutually exclusive and compete to dominate combustion. The first is a rapid, high activation energy but endothermic volatilisation pathway that leads to flaming combustion. This competes with a slower, lower activation energy but exothermic charring pathway that leads to glowing and smouldering combustion.

The extent to which one thermal degradation pathway dominates the other is determined by the transfer of the heat released from the combustion reactions (in the form of light and heat seen as flames and heated gas) to adjacent fuel. At the rear of a fire the lower activation energy charring pathway and glowing combustion dominates over volatilisation. At the head volatilisation and flaming combustion dominates over charring (Fig. 1).

Heat transfer and fire spread

The transfer of heat released from the thermal degradation and oxidation reactions in combustion occurs by the combination of advection (incorporating buoyancy, convection and turbulence), thermal radiation, direct flame contact and transport of burning solid material such as embers and firebrands (i.e. spotting). The efficiency of these may be moderated or compounded by interactions with the surrounding atmosphere, topography and vegetation condition and the interactions of these with the fire itself.

While thermal radiation is widely recognised as a key heat transfer process in fire, it is direct flame contact with adjacent fuel that drives the spread of a bushfire (Fig. 2). A key characteristic of direct flame contact in a fire front is its intermittent nature—the periodic flicker of flame that alternately engulfs and then quits the fuel. This intermittency is driven by turbulence in the buoyant convective flow resulting from flow instabilities.

The interactions of the combustion chemistry and transfer of heat to adjacent fuel determines the overall behaviour of a fire, including ignition sustainability, the transition from glowing to flaming combustion and the fire's response to changes in prevailing wind and moisture conditions.



Figure 2. Fire spreading through mallee-heath fuels illustrating the ignition of fuels through direct flame contact.

Further reading

Sullivan AL (2017) Inside the Inferno: Fundamental processes of wildland fire behaviour. Part 1: Combustion chemistry and energy release. *Current Forestry Reports* 3, 132–149.

Sullivan AL (2017) Inside the Inferno: Fundamental processes of wildland fire behaviour. Part 2: Heat transfer and interactions. *Current Forestry Reports* 3, 150–171.

References

Sullivan AL, Ball R (2012) Thermal decomposition and combustion chemistry of cellulosic biomass. *Atmospheric Environment* 47, 133–141.

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