Fire Safety Journal xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

An experimental study on backdraught: The dependence on temperature

Chia Lung Wu, Ricky Carvel*

BRE centre for Fire Safety Engineering, The University of Edinburgh, King's Buildings, Edinburgh EH9 3FG, United Kingdom

ARTICLE INFO

Keywords:
Backdraught
Temperature
Auto-ignition
Piloted ignition

ABSTRACT

This paper presents the results of a series of reduced scale experiments to investigate the temperature conditions leading to backdraught in a fire compartment (0.8 m×0.4 m×0.4 m), using solid polypropylene pellets as the fuel. The factors of primary interest are the pre-burn time, before the fire becomes oxygen limited, the duration of door closure, and the temperature distribution in the compartment. It is shown that the temperature inside the compartment is crucial for the occurrence of backdraught. Above 350 °C, backdraught by auto-ignition is possible. If a pilot spark is present, backdraught may occur at temperatures down to 300 °C. It is shown that backdraught conditions can be achieved in the early stages of a fire as long as a suitable temperature is reached, at considerably lower temperatures than those generated during flashover. Further investigation on gas concentration is essential to understand the chemistry of backdraught combustion.

1. Introduction

Despite being well known for several decades, backdraught remains one of the largely unresolved issues in fire science [1]. Research has demonstrated the mechanisms involved in backdraught, but a rigorous definition of instances where backdraught can occur is still elusive. This phenomenon generally occurs in conditions where a compartment containing a fire has a very limited fresh air supply, and the fire is considerably ventilation-controlled or extinguished. A backdraught may occur if there is a sudden supply of fresh air, e.g. due to a window or door opening or breaking, possibly due to the fire, or commonly due to the intervention of fire-fighters. Backdraught has led directly to fire-fighter injuries and fatalities, thus it is essential to study backdraught in order to mitigate or avoid its effects in future fire-fighting interventions.

Fundamental research into backdraught started in the 1990s. In the pioneering research into this field, Fleishmann *et al.* [2–4] conducted a series of experiments using a reduced-scale chamber (2.4 m×1.2 m×1.2 m). A methane burner was used as the fuel supply. They observed the propagating flame of backdraught, and identified the concentration of the unburned gases in the compartment as a critical factor leading to backdraught; they observed that a mass fraction of 10% unburned fuel in the compartment is required in order to have a backdraught. Later studies by Weng and Fan [5–7], using an apparatus half the size of Fleishmann's (1.2 m×0.6 m×0.6 m), produced similar results, with 9.8% of the unburned gas being the identified criterion. Both these studies suggest that the concentration of flammable gases is an import factor with regard to the occurrence of backdraught, when methane is the primary fuel used.

When a door is opened to a compartment full of hot gases, the hot gases will tend to spill out of the upper part of the opening, and cold air will flow into the lower part of the opening. This flow of air is known as a “gravity current” and is crucial in determining the occurrence and severity of a backdraught. The gravity current has been extensively observed and studied [2–4,8–18]. The opposed flow of the gravity current with respect to the hot gases drives the process of the mixing of the hot flammable gases with the fresh air. In situations where there is a fire source or pilot flame at the back of the compartment, it is often assumed that the time at which backdraught is initiated (delay time after opening the door) is due to the time taken by the gravity current to create the flammable mixture and drive it to the ignition source.

Our current understanding of backdraught suggests the gravity current and the concentration of unburned gases are the crucial factors. The former may be able to predict the time when a backdraught will occur, the latter is used as the determining factor for the possibility of backdraught occurrence. However, the gravity current travelling time related to backdraught was based on the tests using an artificial ignition source, such as an electric spark, but in real life, not every backdraught fire has such an ignition source. Another possibility is auto-ignition leading to backdraught. This involves various physical and chemical processes beyond questions of gas concentration. Current knowledge is considerably limited by the fact that the majority of backdraught studies have used methane gas as fuel, and very few real backdraught incidents involve this fuel.

In a typical backdraught scenario, the atmosphere in the compartment, before the door is opened, consists of a mixture of pyrolysis gases

* Corresponding author.

http://dx.doi.org/10.1016/j.firesaf.2017.04.003
Received 10 February 2017; Accepted 3 April 2017

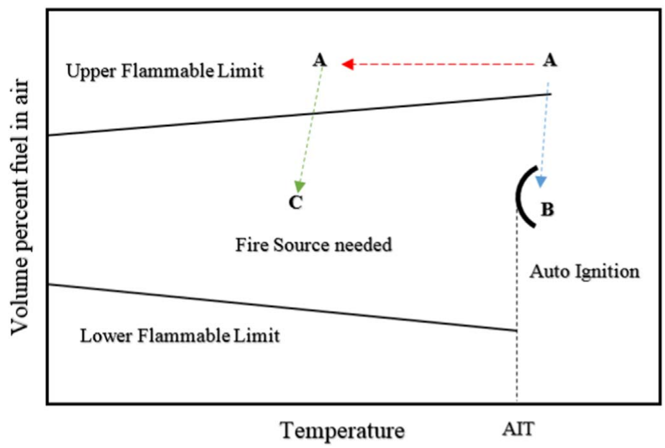

Fig. 1. Flammability limits change with temperature. (Adapted from Zabetakis [20]).

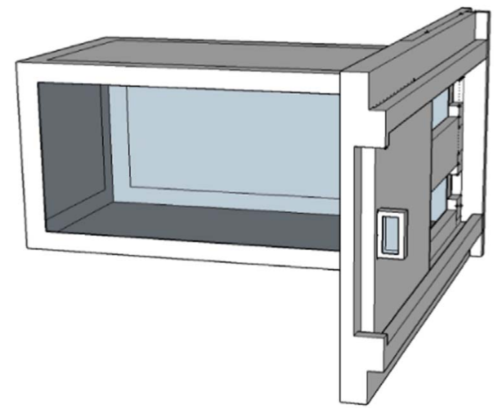

Fig. 2. Test compartment.

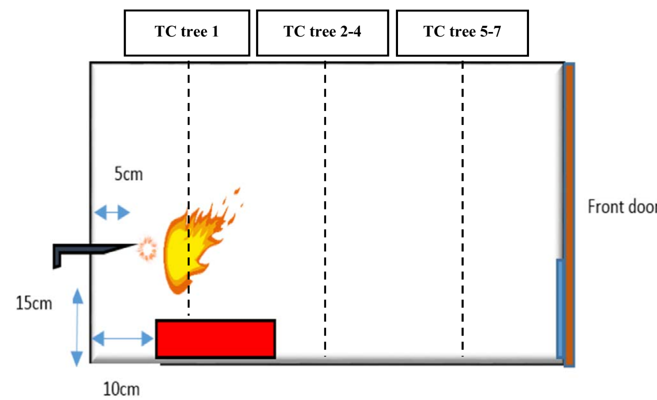

Fig. 3. Spark apparatus (side view).

and vitiated air at elevated temperature, generally above the upper flammability limit of the fuel-air mixture [19]. This initial set of conditions is represented conceptually by points A or A′ in Fig. 1. Opening the door allows cooler air into the compartment, resulting in both a decrease in gas temperature and the mixture being diluted with fresh air to form a flammable mixture, denoted by points B or C in Fig. 1. If the resulting mixture is sufficiently hot, auto-ignition can occur. If the resulting mixture is cooler, the flammable mixture will ignite only if an ignition source is present, or if the flammable mixture moves to where an ignition source is found.

Previous research is somewhat limited by the fact that methane-air mixtures are flammable at ambient temperatures (and below) so the dependence of pilot-ignited backdraught on temperature has not been adequately investigated. More realistic fuels must be selected for further studies [4,6,10]. This limitation is one of the drivers of the study described here.

This project aims to discover if there is a critical temperature for backdraught, using a fuel other than methane. Furthermore, this project aims to 'map out' the conditions of temperature and gas mixture under which backdraught does and does not occur. This paper describes experiments using polypropylene fuel, other fuels will be considered and published in the future.

2. Experimental setup and procedure

Most of the experimental research to date has been carried out at the laboratory scale, to minimise the risks due to explosive effects, and also because it has already been demonstrated that the general nature of backdraught is not depended on the scale of the compartment [21].

In the present study, a small scale fire compartment (0.8 m×0.4 m ×0.4 m) was designed and built for backdraught research, see Figs. 2 and 3. It is instrumented with 7 thermocouple trees (24 type K thermocouples in total). TC trees 3 and 6 are positioned on the centreline of the compartment, at 0.4 and 0.6 m from the back wall of the compartment. On these trees, there are TCs fixed at 0, 0.1, 0.2, 0.3, and 0.4 m below the ceiling. Trees 2 and 4 are positioned on either side of tree 3, halfway between the centreline of the compartment and the wall. Similarly, trees 5 and 7 are positioned on either side of tree 6. Trees 2, 4, 5 & 7 have TCs at 0.1, 0.2 and 0.3 m below the ceiling. Tree 1 is positioned in line with trees 2 and 5, not on the centreline, as this is the location of the fire, it only has TCs at 0.1 and 0.3 m. The fuel bed is contained in a steel tray, which is 0.2 m×0.2 m ×0.05 m, and was positioned 10 cm from the rear wall. The compartment was constructed out of two-layers of expanded insulating vermiculate boards, for which the maximum working temperature is 1100 °C. An electric spark apparatus was installed on the rear wall for some tests investigating the role of an ignition source. The influence of the position of the pilot spark has not yet been assessed; this will be investigated and reported in the future.

There are three removable baffles which may be positioned across the opening of the compartment, to investigate the effects of opening size. In all the experiments described here, the upper two baffles were kept in place, such that the opening was fixed at 0.13 m×0.4 m wide. Other door opening sizes and configurations will be tested in the future, and the findings will be published elsewhere. A sliding outer door is used to seal and open the compartment, this ensures that the experimenter is safely to the side of the compartment when the door is opened, and is well out of the way of any ejected flames.

2.1. Design fire

In order to simulate a realistic backdraught phenomenon, a solid fuel was used as a fire source. For the experiments described here, this was plastic pellets (Polypropylene, PP). To aid ignition and repeatability, a small quantity of n-Heptane (C_7H_{16}) was used as the accelerator to start the burning process. Initial tests were carried out to identify the optimum fuel load for these experiments. It was determined that 300 g of PP with 150 ml of n-Heptane was sufficient to achieve flashover conditions in the compartment (after about 13 min, from ambient initial conditions), and that all the liquid accelerant was consumed in the first 5 min of burning. From about 7–12 min after ignition, the heat release rate of the fire is quasi-steady and the temperature in the compartment rises in a steady and highly repeatable manner. During this time, the only fuel present is PP, so the primary focus of our research concerns what happens when the door is closed during this time-window, is kept closed for a variable period of time, and then opened again.

Fig. 4. Shows the temperature evolution in the compartment in 'free burn' conditions, that is, the door is never closed. The zone marked A is