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Limiting Distances for Flame Merging of Multiple n-Heptane and Di-tert-Butyl Peroxide Pool Fires

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Experiments to determine the limiting distances for flame merging of multiple pool fires are presented. As model substances n-heptane and di-tert-butyl peroxide are used. Laboratory scale tests with a diameter d = 6 cm and relative distances between the pools of $0.08 \le D/d \le 4$ are described and complemented with field experiments with a diameter d = 1.5 m and relative distances between the pools of $0.17 \le D/d \le 1$. Three regions for flame merging are observed and limiting distances are determined. A merging region with the limiting distance D_{merg}/d within which all flames merge together over the complete burning time. A transition region with the limiting distance D_{tran}/d within which some flames merge together while other flames are separated from each other. A separated region within which all flames are completely separated from each other. A correlation against the number of burning pools is presented to predict the limiting distances D_{merg}/d und D_{tran}/d.

1. Introduction

Accidental fires in process industries often occur as pool fires which are hazardous to people and adjacent objects due to thermal radiation (Persson and Lönnermark, 2004; Mannan, 2005). Beside single pool fires multiple pool fires are of interest in safety science, particularly with regard to flame merging which is supposed to increase thermal radiation. As model substances on the one hand n-heptane (hc) is used as a liquid flammable typical and on the other hand experiments (Mudan, 1984; Muñoz et al., 2004; Schönbucher, 2012) are conducted with di-tert-butyl peroxide (DTBP) as a flammable self decomposable substance (Wehrstedt and Wandrey, 1993; Chun, 2005; Schälike et al., 2012). For the discussion of the flame merging the geometric configurations in Figure 1 are used.

First investigations on multiple fires were conducted by Putnam und Speich (1963) on propane and hydrogen burner flames where high Reynolds numbers Re > 5000 were used. Putnam and Speich (1963) used a diameter of d = 0.3 cm and relative distances between the burner of D/d < 2. The limiting distances for flame merging is given to be D/d = 2d. Other researchers like Thomas et al. (1965) and Baldwin (1968) proposed analytical solutions for the flame heights of multiple fires based on the relative distances between the pools. Further investigations on the flame height of multiple n-hexane pool fires use a correction factor relating to the geometric configuration (Sugawa and Takahashi, 1993). A flame height correlation for multiple propane and wood crib burners using a dimensionless parameter similar to the Froude number is described by Kamikawa et al. (2005). Fukuda et al. (2006) showed, that the pulsation frequency of two n-heptane and methanol pool fires change with the relative distance between the pools. Investigations on the burning times and maximum flame heights of multiple n-heptane pool fires are presented also in literature (Liu et al., 2007; Liu et al., 2009). The limiting distance for flame merging was found to be D/d = 6.7.

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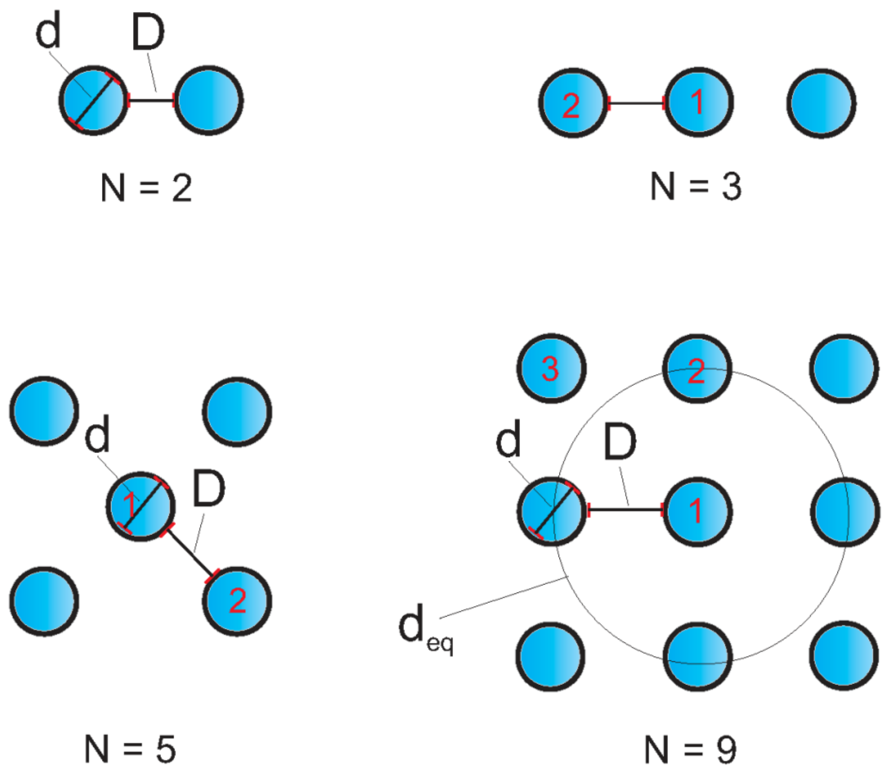

Figure 1: Experimental arrangements for the investigation of multiple fires

2. Experimental section

The laboratory scale tests were carried out in a test bunker (10 m x 5 m x 5 m). Air ventilation was used to get ambient conditions after each fire test. The ventilation was stopped during the tests to achieve wind still conditions. Steel pools with a diameter d = 6 cm were chosen for the experiments on laboratory scale. The experiments were conducted with a number of burning pools of $2 \leq N \leq 9$. The distance between the pools was chosen depending on the flame interaction between $0.08 \leq D/d \leq 4$.

The field experiments were conducted at BAM test site technical safety. Wind still conditions were awaited and low thermal lift was achieved by starting the tests at still air. Steel pools with a diameter d = 1.5 m were chosen. The experiments were conducted with two burning pools (N = 2). The distance between the pools was chosen depending on the flame interaction between $0.17 \leq D/d \leq 1$.

The flame merging during the stationary burning time was recorded using three VHS cameras positioned perpendicular to each other.

3. Results and discussion

If the relative distance between at least two fires falls below a limiting distance the flames lean together forming a multiple fire. A multiple fire is characterized by the formation of one single flame column from different fire sources. For both hydrocarbon and peroxide pool fires three regions with characteristic limiting distances are observed. The so called merging region is the first region within which the flames of all fire sources merge together over the complete burning time (figure 2(a) for n-heptane and figure 3(a) for DTBP). The limiting distance for the merging region D_{merg}/d can be taken from Table 1. In the transition region (figure 2(b) for n-heptane and figure 3(b) for DTBP) not all flames from the fire sources merge together over the complete burning time. There are always some flames merged together while other flames are separated from each other.

Table 1: Limiting distances of the merging region D_{merg}/d and transition region D_{tran}/d of multiple pool fires

	n-Heptane		*DTBP*	
N [−]	*D_{merg}/d [−]*	*D_{tran}/d [−]*	*D_{merg}/d [−]*	*D_{tran}/d [−]*
2	*0.17*	*0.33*	*0.5*	*1*
3	*0.25*	*0.42*	*0.67*	*2*
5	*0.33*	*0.67*	*0.83*	*2.33*
9	*0.5*	*1.33*	*0.83*	*2.67*

The limiting distance for the transition region D_{tran}/d can be taken also from Table 1. The third region is the separated region (figure 2(c) for n-heptane and figure 3(c) for DTBP). In this region the flames are separated completely from each other and no interaction between the flames is observed. It should be noted, that the figures 2 and 3 show fires within a special region, while the Table 1 gives the limiting distances separating the defined regions from each other.

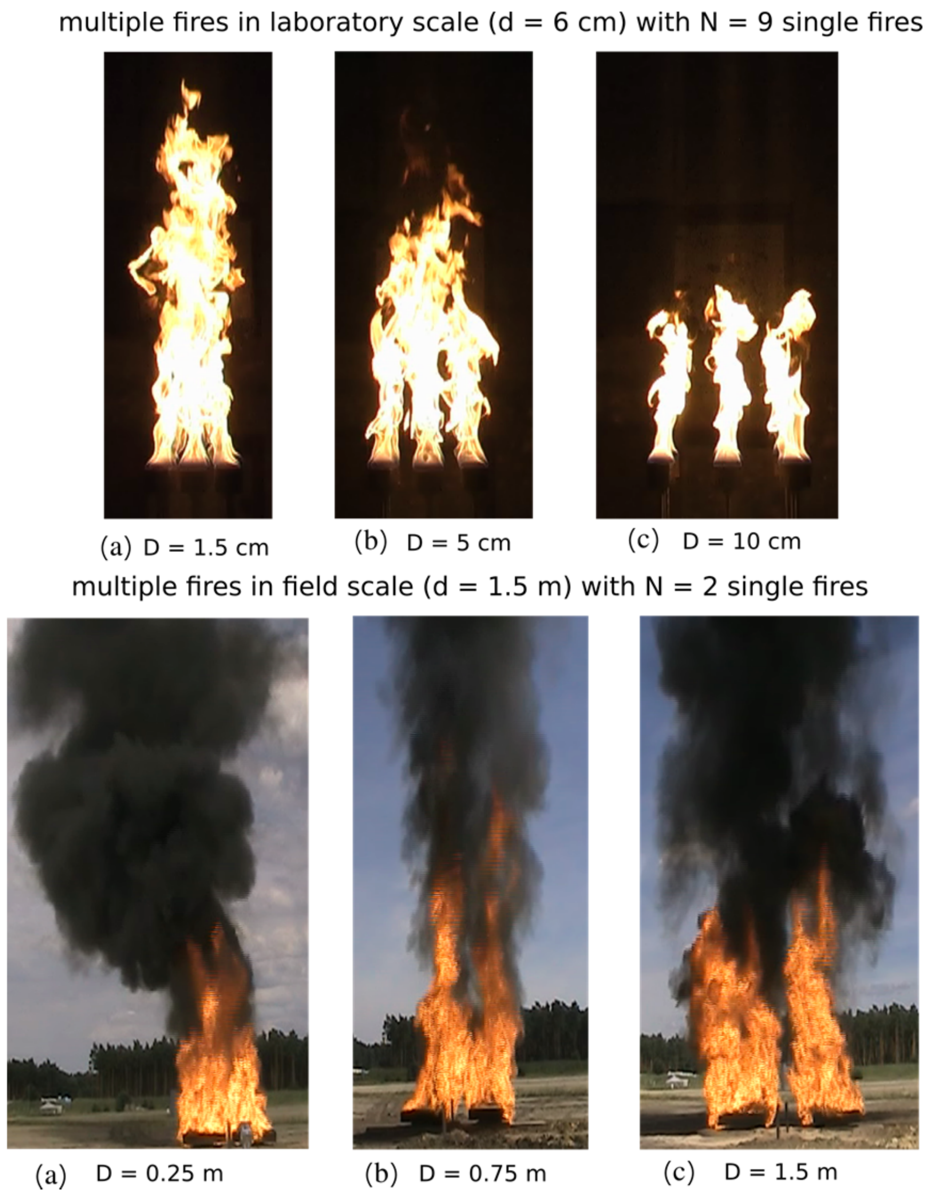

Figure 2: Flame merging of multiple hydrocarbon pool fires in laboratory scale and field experiment

It is interesting to note, that the transition region is much broader for multiple DTBP pool fires in comparison to multiple n-heptane pool fires. Besides, it has to be mentioned that during the merging process the flames do not touch each other at the flame tip. In the laboratory scale the flames merge together over almost the complete flame length, starting for n-heptane in a region of 0.05 $\overline{\mathrm{H}}$ for D/d = 0.1 (N = 9) and 0.2 $\overline{\mathrm{H}}$ for D/d = 0.5 (N = 9). For DTBP merging starts in a region of 0.05 $\overline{\mathrm{H}}$ for D/d = 0.1 (N = 9) and 0.25 $\overline{\mathrm{H}}$ for D/d = 0.5 (N = 9).

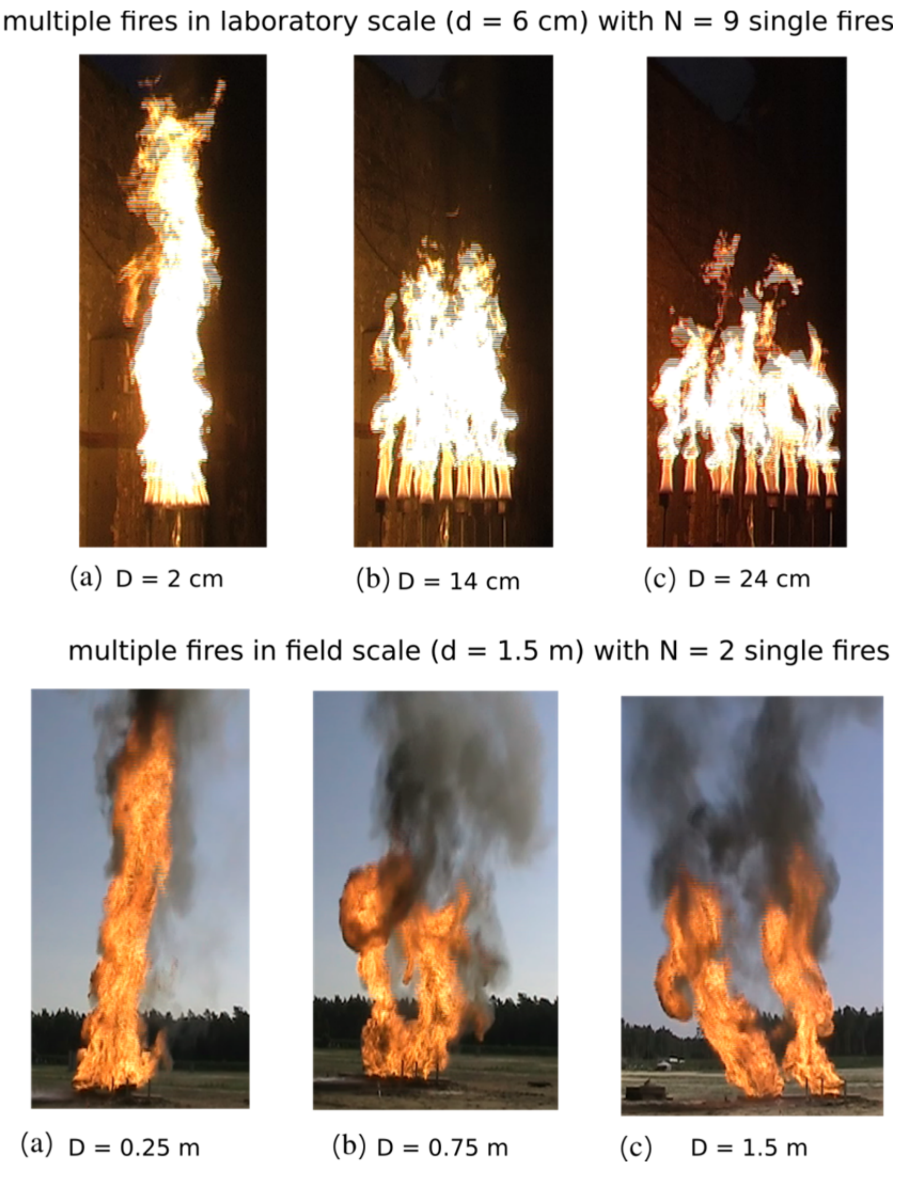

Figure 3: Flame merging of multiple DTBP pool fires in laboratory scale and field experiments

In the field experiments both fuels show a flame merging short above the fuel surface. For the hydrocarbon fuel merging starts at a height of 0.12 $\overline{H}$ (H; flame height) and for DTBP at a height of 0.05 $\overline{H}$. Both fires show for small relative distances (D/d = 0.17) between the pools one single flame column. With increasing relative distance between the pools (D/d = 0.75) two independent flames are formed in the upper region of the flame whereas the flame basis remains merged.

A comparison between the results of laboratory scale tests and field experiments shows that the limiting distances for the merging region and the transition region are independent from the pool diameter. Hence, the limiting distances can be correlated in a good approximation against the number of burning pools N:

$$\frac{D_{merg,hc}}{d} = 0.11\ N^{0.68} \tag{1}$$

$$\frac{D_{tran,hc}}{d} = 0.14\ N^{1.03} \tag{2}$$

$$\frac{D_{merg,DTBP}}{d} = 0.46\ N^{0.29} \tag{3}$$

$$\frac{D_{tran,DTBP}}{d} = 1.01\ N^{0.47} \tag{4}$$

The limiting distances for flame merging of n-heptane pool fires observed in this study are much smaller in comparison to the values of Liu et al. (2009). One reason for this could be the missing application of an exact definition for the merging and the transition region.

4. Conclusions

1. If the relative distance between at least two fires falls below a limiting distance a multiple fire with flame merging is observed.
2. Three regions for flame merging are defined und limiting distances are determined. A merging region with the limiting distance D_{merg}/d within which all flames merge together over the complete burning time. A transition region with the limiting distance D_{tran}/d within which some flames merge together while other flames are separated. A separated region within which all flames are completely separated from each other.
3. A correlation against the number of burning pools can be used to predict the limiting distances D_{merg}/d und D_{tran}/d.

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