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Multiple pool fires: Occurrence, simulation, modeling and management

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ABSTRACT

When two or more pool fires burn in such close proximity of one another that they can influence each other, they are termed ‘multiple pool fires’ (MPF). The characteristics and the structure of MPFs are significantly different from that of stand-alone pool fires. Even though MPFs have known to occur fairly often in chemical process industries, much lesser work has been done towards simulation, modeling and control of MPFs as compared to stand-alone pool fires.

This paper is perhaps the first-ever attempt at surveying the MPF state-of-the-art. It recounts MPF accidents and catalogs the controlled experiments that have been done to understand the mechanism and impact of MPFs. Attempts to model MPFs have been assessed and possible ways to manage MPFs have been touched upon.

1. Introduction

Pool fires are the most frequent of process industry accidents (CCPS, 2005; Lees, 2005). Pool fires are either the initiators, or the consequences, often both, of most process industry accidents involving fires or explosions (Abbasi & Abbasi, 2007a,b,c; Abbasi, Pasman, & Abbasi, 2010; Cozzani, Tugnoli, & Salzano, 2009; Crowl & Louvar, 2001; Lees, 2005). Even though *pool* literally means a small body of still liquid, or a collection of stakes/monies/professionals, the term pool fire has come to represent the pool of a fuel that has caught fire (Audouin, Kolb, Torero, & Most, 1995; Cetegen & Ahmed, 1993; Liu, Liao, Li, Qin, & Lu, 2003). According to Lees (2005) a pool fire occurs when a flammable liquid spills onto the ground and is ignited. A fire in a liquid storage tank is also a form of pool fire, as is a trench fire. Numerous other definitions have been given (Cowley & Johnson, 1992; Hamins, Kashiwagi, & Buch, 1996; Mudan & Croce, 1995; Nolan, 2010; Steinhaus, Welch, Carvel, & Torero, 2007; TNO, 1997) which emphasize one or the other of the characteristics common to all pool fires while stressing the main feature: ignition of pooled fuel. The term basically represents pool of liquid fuel catching fire, but it is also used to describe burning of solid fuels, for example poly methyl methacrylate (PMMA or Plexiglass) and polyethylene (Audouin et al., 1995; Cetegen & Ahmed, 1993; Liu et al., 2003), and forest fires (Hamins et al., 1996, pp. 15–41). Based on the medium on which the pool is formed, presence or absence of confinement, and the type of location, pool fires have been classified as in Fig. 1.

A review of the state-of-the-art of process industry accidents (Abdolhamidzadeh, Abbasi, Rashtchian, & Abbasi, 2011; Amendola, Contini, & Nichele, 1988; CCPS, 2005; HSE, 2012; Khan & Abbasi, 1999, 1998; Koivisto & Nielsen, 1994; Lees, 2005; Tauseef, Abbasi, & Abbasi, 2011; Tauseef, Rashtchian, & Abbasi, 2011) reveals that very elaborate and extensive studies have been done on stand-alone pool fires (SPF) but much less attention has been paid to MPFs. Blinov and Khudiakov (1961, p. 208) studied the flammability and ignition of liquids from burning of gasoline-like liquids in pans ranging in size from a fraction of a cm up to nearly 30 m in diameter to explain a number of phenomena observed in the ignition and burning of mixtures of liquids. They also investigated the problems connected with shapes and dimensions of the flames, pulsation, temperature, radiation and various combustion regimes. Their study reveals that thermal radiation heat transfer dominates real fires, not the pan conduction effects nor the convective heat transfer that characterizes smaller scale laboratory fires. For small-scale pool fires (diameter less than 1 m), the burning rate was found to be directly proportional to the diameter of the pool and the type of fuel feeding the SPF. The study also reveals that in SPF the burning rates per unit surface area tend to be relatively constant for pan diameters greater than about 1 m, independent of whether the flammable liquid is gasoline, kerosene, or diesel.

In contrast to the range and the depth of information available on SPFs, most studies on MPFs have been limited to pools of sizes

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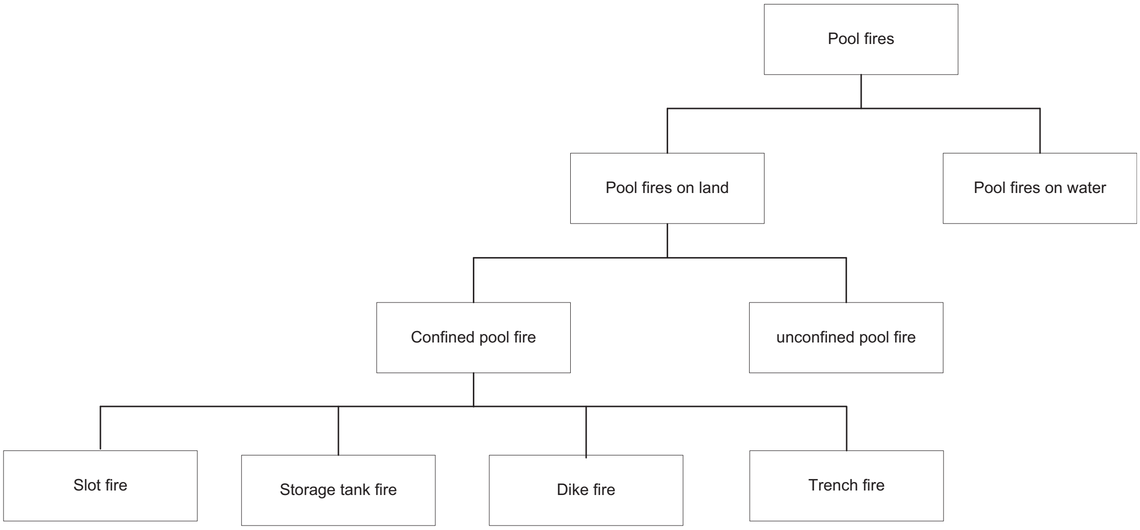

Fig. 1. Classification of pool fires.

ranging from just a few mm to a few cm. Very recently a report has appeared on MPFs involving pools of 1.5 m diameter (Schälike, Mishra, Wehrstedt, & Schönbucher, 2013) but this report does not alter the fact that studies on the MPFs arising in pools of diameters large enough to be relevant in the management of real-life tanks are yet to be conducted. For MPFs of size ranges studied so far, the burning rates were found to vary with diameters of the pools, and the types of fuels. Highly radiating pool fires such as the ones fueled by gasoline were found to interact more strongly than the ones fueled by low radiation fuels such as diesel (Vincent & Gollahalli, 1995).

Many of the past accident reports state that the interaction of flames from MPFs result in more intense radiation, and higher flame, than it would have resulted if the flames were not interacting. But in the absence of any experimental data on MPFs with pool diameters larger than 1.5 m, it is impossible to say if the burning rates and the flame interaction is a function of pool diameter and fuel type.

One of the first reports on multiple pool fires is due to Broido and Mccmasters (1960) who generated 70 fires with 2.1 m high 6.09 m × 4.5 m assorted scrap lumber piles spaced 3.6 m apart along three concentric rectangles. The resulting 15.2 m high flames were seen to merge at least part of the time. The authors felt that this happened because conditions were near to the critical for merging; after about 10 min when the quantity of fuel had been depleted, the merging flames separated into a group of individually burning fires.

Putnam and Speich (1963, pp. 867–877) studied different arrangements of fuel piles to generate MPFs and found that when the spacing factor given by $S/(Q_o^2/g)^{1/5}$ was about two, the individual diffusion flames began to interact.

Waterman, Labes, Salzberg, Tamney, and Vodvarka (1964) burned 0.91 m^2 wood cribs arranged in square arrays to find that the onset of coalescence corresponded with a dramatic peak in the rate of burning of the cribs.

In an accidental fire in two stacks of timber each 45.7 m × 12.1 m, separated by a 6.09 m gangway, Baldwin, Thomas, and Wraight (1964), found that flames merged for part of the time.

All through the 1960s, the behavior of fire merging received much attention. Most of the researchers tried to develop empirical models for describing fire merging behavior, by adding the fire spacing and the number of fire points into general single pool fire models. Among these attempts was the model proposed by Thomas, Simms, and Wraight (1964) for describing the steady spread of fire in cribs of wood in still air. The authors found it to be in reasonable agreement with the results that of laboratory experiments. The same authors (Thomas, Baldwin, & Heselden, 1965, pp. 983–996) later performed experiments with two pools employing, separately, timber and town gas and obtained a dimensionless equation relating the merged flame height to fire spacing. Other noteworthy studies included the ones by Baldwin (1968), Countryman (1969), Evans and Tracey (1966) and Thomas, Baldwin, Theobald, and Britain (1968).

Arguably the earliest experiments on MPFs generated by pools of liquid fuels were performed by Huffman, Welker, and Sliepcevich (1969) who reported that interaction of number of fires burning in close proximity has substantial effect on the burning rate of the fuel, the size of the flame, and the rate of heat transfer from the flame to the surroundings. They observed that individual pool fires start to burn more intensely with higher flames as the distance between them is decreased. Several authors have subsequently reported different forms of interactive effects that distinguish liquid pool MPFs in contrast to stand-alone pool fires (Chigier & Apak, 1975; Delichatsios, 2007; Fukuda, Kudo, & Ito, 2005; Kamikawa et al., 2005; Steward & Tennankore, 1981; Sugawa & Takahashi, 1993; Weng, Kamikawa, Fukuda, Hasemi, & Kagiya, 2004). This paper traces the history of major accidents involving MPFs, and catalogs the few controlled experiments that have been carried out to understand the manner in which MPFs evolve. The attempts to model MPFs, assess their impacts, and find ways to control them, are also reviewed.

2. Case histories of MPFs

Given the general paucity of scientific literature on MPFs, it may appear that accidents involving MPFs are few and far between. But an analysis of the past accidents reveals that such is not the case. Between 1950 and present hundreds of major MPF accidents have been reported worldwide (Hailwood, Gawlowski, Schalau, & Schönbucher, 2009; Tauseef, Abbasi, et al., 2011).

A few instances which illustrate the variety of situations under which MPF have occurred; the size and intensity of the MPFs, and the damage they can cause are presented below. These and some other representative MPF events that have occurred over the last 37 years are cataloged in Table 1.

2.1. Beek, The Netherlands

On November 7, 1975, there was escape of vapor and formation of a vapor cloud, during the start up of a Naphtha Cracker unit in a