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Influence of the source size on domino effect risk caused by fragments

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ABSTRACT

We developed the movement equations for fragments with the size of the bursting vessel. The ground distributions of fragments, the probability of impact between the fragments and the target, the rupture probability of the impacted target, and the domino effect risk caused by fragments were investigated for different source types and sizes using Monte-Carlo simulations. The distribution of fragments from the lower half of the source vessels onto the ground was non-zero, that is, it is probable that the fragments would hit the target vessel close to the source. The relative difference of impact probability is larger than 10% when the target vessel is within eight times the source diameter for the three types of sources considered. The proportion of impacts of fragments from the lower part of the source to total impact decreased with distance, while that for fragments from the upper part increased. The proportion of upper and lower parts is equal for distance approximately five times the source diameter. The source size needs to be considered along with the distance from the source to the target when less than approximately 14 times the source diameter. Its effect on impact probability and domino effect risk was significant. The rupture probability of the target depended very little on the source size.

1. Introduction

In chemical industries, equipment explosion may generate fragments which can be projected over long distances, damaging other nearby equipment, and may cause severe consequences. This is known as the domino effect, a well-known cause of major accidents (Antonioni et al., 2009; Cozzani et al., 2006; Nguyen et al., 2009). Fragment projection in explosive accidents is an important origin for the domino effect on a chemical process vessel (Pietersen, 1988). Generally speaking, when an explosion occurs, the containers are ruptured by internal pressure and fragments from the ruptured vessel propagate randomly in any direction. The fragments may then fall to the ground or collide with other equipment nearby. When a fragment impacts on a given target vessel, the impacted vessel may be penetrated or perforated, causing a secondary explosion. These subsequent explosions themselves cause fragments, and multiple events may spread throughout the facility.

Each cycle of the domino effect includes three considerations: the source, fragment trajectories, and the target:

- the source: fragment generation from the original explosion;
- fragment trajectories: fragment projection;
- the target: fragment impact on a target vessel, which may penetrate or perforate it, creating secondary incident(s).

Significant prior research has been undertaken to investigate the three considerations, and the dominant effects may be summarized as follows in Tables 1–3:

It is shown in Tables 1–3 that the mechanism of fragment generation, projection, impact, and damage to equipment has been explored by many researchers. The dominant effects may be roughly summarized as follows (four stages):

- Probabilistic models have been developed for fragment generation, including the number of fragments, shape and size, mass, initial velocity at departure, initial (horizontal and vertical) departure angles, aerodynamic lift and drag coefficients, and the degree of filling of the source vessel).
- Trajectory equations of the fragments, probabilistic models of fragment impact, and a simplified plastic model for assessing the rupture probability with high reliability have been

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Table 1
Summarized flow of dominant effects of significant prior research on the source (fragment generation).

Year	Author	Reference	Dominant effects of significant prior research on the source (fragment generation)
1971	Westin	(Westin, 1971)	Ruptured tank cars involved in accidents were summarized.
1980	Tulacz & Smith	(Tulacz and Smith, 1980)	Missiles generated by pressure component failure and its application to gas-cooled nuclear plant design were assessed.
1985	Holden and Reeves	(Holden and Reeves, 1985)	Random variables (fragments number, shape, mass, initial velocity at departure, and initial departure angles, etc.) were discussed.
1986, 1988	Holden	(Holden, 1986, 1988)	Random variables (fragments number, shape, mass, initial velocity at departure, and initial departure angles, etc.) were researched.
1994	CCPS	(CCPS, 1994)	Guidelines for evaluating the characteristics of vapor cloud explosions, flash fires, and BLEVEs were developed.
1996	Lees	(Lees, 1996)	Hazard identification, assessment, and control for loss prevention in process industries were derived.
1998	Baum	(Baum, 1998)	Rocket missiles generated by failure of a high pressure liquid storage vessel was investigated.
2007	Abbasi & Abbasi	(Abbasi and Abbasi, 2007)	The mechanism of the boiling liquid expanding vapor explosion (BLEVE) was explored.
2009	Mébarki et al.	(Mébarki et al., 2009a, 2009b)	Probabilistic distributions of the source terms were developed.
2009	Gubinelli & Cozzani	(Gubinelli and Cozzani, 2009a, 2009b)	The reference fragmentation patterns of the vessels were identified, and the fragment number and drag factors were assessed.
2012	Abdolhamidzadeh et al.	(Abdolhamidzadeh et al., 2012)	The roots, triggers, and other aspects of a domino accident were investigated.
2012	Sun et al.	(Sun et al., 2012)	More specific and accurate probabilistic models of the number of fragments from a horizontal cylindrical vessel explosion were developed by collecting and analyzing data from past accidents leading to fragment projection, and a more reasonable probability density function for the number of fragments from a spherical vessel explosion was proposed.

Table 2
Summarized flow of dominant effects of significant prior research on fragment trajectories.

Year	Author	Reference	Dominant effects of significant prior research on fragment trajectories
1977	Baker et al.	(Baker et al., 1977)	The pressure wave and fragment effects of exploding propellant tanks and gas storage vessels was investigated.
1985	Holden and Reeves	(Holden and Reeves, 1985)	Fragment hazards from failures of pressurized liquefied gas vessels were investigated.
1986, 1988	Holden	(Holden, 1986, 1988)	Incident experience relevant to major hazard plant was reviewed for assessment of missile hazards.
1988	Baum	(Baum, 1988)	Preliminary design guidelines for fragment velocity and the extent of the hazard zone was developed.
1995	Baum	(Baum, 1995)	The velocity of a detached end-cap was explored.
1997	Van den Bosch and Weterings	(Van den Bosch and Weterings, 1997)	Methods for the calculation of physical effects were summarized.
1999	Baum	(Baum, 1999a, 1999b)	The velocity of end-cap and rocket missiles generated by failure of a gas pressurized vessel containing particulate material, and the velocity of end-cap and rocket missiles from failure of a horizontal pressure vessel containing a high temperature liquid were studied.
2001	Baum	(Baum, 2001)	The velocity of large missiles resulting from axial rupture of gas pressurized cylindrical vessels was considered.
2001	Hauptmanns	(Hauptmanns, 2001a, 2001b)	The flight of missiles from the explosion of cylindrical vessels was analyzed and the flight of missiles from tank explosions was treated.
2003	Stawczyk	(Stawczyk, 2003)	LPG tank explosion hazards was evaluated using an experimental approach.
2007	Abbasi & Abbasi	(Abbasi and Abbasi, 2007)	The consequence assessment of the boiling liquid expanding vapor explosion (BLEVE) was explored.
2008	Genova et al.	(Genova et al., 2008)	Blast-wave overpressure and fragment initial velocities for a BLEVE event were obtained using empirical correlations derived from a simplified model of released energy
2009	Mébarki et al.	(Mébarki et al., 2009a, 2009b)	The trajectory equations and ground distributions of the fragments were proposed and evaluated.
2009	Qian et al.	(Qian et al., 2009)	Fragment projectiles from a spherical tank BLEVE were analyzed using Monte-Carlo simulations.
2010	Liu et al.	(Liu et al., 2010)	The projectile fragments from a cylindrical tank BLEVE accident were analyzed using Monte-Carlo simulations.
2010	Qian et al.	(Qian et al., 2010)	The use of a barrier net between the accident source and target vessel to compensate for the lack of actual distance was investigated. This method of diverting fragments from a vessel explosion was proposed on the analysis of fragment trajectories using Monte-Carlo simulations.
2012	Sun et al.	(Sun et al., 2012)	The effects of algorithms for movement approach, fragment rotation, wind, and number of simulation runs on fragment trajectory (the ground distributions of fragments) were explored using Monte-Carlo simulations.