RESEARCH ARTICLE

Spread rate of flammable liquids over flat and inclined porous surfaces

Very large quantities of flammable substances are produced, transported, and refilled across the world. Of these some, like gasoline and diesel, are liquids at normal temperature and pressure while some others – like liquid petroleum gas (LPG – are pressure liquefied gases. Ever so often accidental spills of these chemicals occur. While some spills are contained before they could do much damage, many others catch fire and often also lead to massive explosions. Indeed, accidental spills have been the initiators of the majority of industrial disasters the world has seen. Given the exceptional importance associated with the containing and controlling of accidental spills, it is essential to understand the factors which effect the spill dynamics so that ways to reduce the risk posed by such spills can be devised. But even as a great deal of work has been done on the dynamics of spills occurring on flat surfaces, little past effort is on record pertaining to the study of spills occurring on inclined surfaces. This is surprising because the spillways actually provided in the industries for large storage tanks invariably have downward slope to enable quick drainage of the flammable liquid away from the storage tank in the event of an accidental leak. The present work is an attempt to make some contribution towards the understanding of the dynamics of spillage of flammable liquids on inclined surfaces. When accidental spills occur in the open – during transportation by road, railroad, or pipeline – the receiving surfaces can be porous and the liquid can percolate down, making environmental contamination that much difficult to remediate. To incorporate this aspect in the present study we have chosen porous surfaces and studied the dynamics of the spill of three different flammable liquids on them at angles of inclination varying from zero to 20°.

By Tasneem Abbasi, Vipin Kumar, S.M. Tauseef, S.A. Abbasi

INTRODUCTION

Spills of hazardous chemicals from industrial plants, oil rigs, or during transportation happen rather frequently. In some cases, the spills occur in confined areas and it becomes possible to control their spread. However, often spills occur in unconfined spaces/settings and occur at a rate and in a manner that makes immediate control impossible. Such spills are known to have caught fire to generate pool fires or moving liquid fires. Or the spilled liquids have evaporated to form highly flammable vapor clouds which have then generated flash fires or vapor cloud explosions.[1–16] These happenings have, in turn, led to more fires and/or explosions, thus multiplying the harm caused by the initial accident several times over.[17–26] Spills causing such chain of accidents, or 'domino effect', has been a recurring phenomenon of great impact.[27,28] Illustrative examples presented in Table 1 reflect the kind of harm such accidents cause.

Tasneem Abbasi *is affiliated with Centre for Pollution Control & Environmental Engineering, Pondicherry University, Chinakalapet, Puducherry 605 014, India. (email: t.abbasi.cpe@pondiuni.edu.in).*

Vipin Kumar *is affiliated with Centre for Pollution Control & Environmental Engineering, Pondicherry University, Chinakalapet, Puducherry 605 014, India. (email: vipin021kumar@gmail.com).*

S.M. Tauseef *is affiliated with Environmental Research Institute, University of Petroleum and Energy Studies, Dehradun 248 007, India. (email: smtauseef@ddn.upes.ac.in).*

S.A. Abbasi *is affiliated with Centre for Pollution Control & Environmental Engineering, Pondicherry University, Chinakalapet, Puducherry 605 014, India (e-mail: prof.abbasi.cpe@pondiuni.edu.in).*

1871-5532
https://doi.org/10.1016/j.jchas.2018.02.004

The catastrophes at Buncefield in 2005 (above) and Jaipur in 2009 (below) were initiated by fuel spill (http://www.bbc.co.uk/news/uk-england-beds-bucks-herts- 34919922; https://www.ndtv.com/photos/news/fire-at-oil-depot-in-jaipur-780).

This propensity of accidental spills of flammable substances to precipitate major disasters has made it very important to study the factors which influence the rate and the manner with which different types of hazardous liquids spread over different types of surfaces. Only an understanding of this spill dynamics can lead to strategies with which the spills can be contained and controlled. As a consequence, studies on the formation of the liquid pools, spreading of the liquid pools, and subsequent evaporation/vaporization of the pools has received significant attention in the past.

Of the various properties of terrain over which the spill occurs, inclination of the terrain is believed to have predominant effect on the rate of spread. Although a number of studies have been done to understand the dynamics of hydrocarbon spilled over flat surfaces, little work has been reported on the effect of inclination of the surface on the dynamics of spilled hydrocarbons.

May and Perumal,[29] based on the review of some of the early experiments done on hydrocarbon spills by Burgess et al.,[49] Feldbaer et al.,[50] and Boyle and Kneebone,[30] have opined that a simple gravitational spread model, in which the radius of spread varies as the square root of time, can adequately predict the observed pool spread behavior over a flat surface. Raj,[31] based on the experimental data generated by Burgess et al.,[49] Boyle and Kneebone,[30] and Reid and Smith,[51] proposed a model which predicts the spill radius by considering the coupling between the hydrodynamics of the spilled liquid and the heat transfer to the spreading liquid over a perfectly flat and frictionless solid substrate. Webber[32] developed models to understand liquid pool dynamics in terms of spreading and evaporation rates.

Table 1. Representative Examples of Major Disasters Initiated by Accidental Spill of Flammable Liquids Across the World.

Accident identifier	Year	Number of deaths	Number of people injured	Estimated losses, in million US dollars
Feyzin	1966	18	80	15
Pernis	1968	2	85	141
Flixborough	1974	28	36	20
Newark	1983	1	23	10
Sao Paulo	1984	508	>1,000	Not available
Mexico city	1984	650	6,400	31
Naples	1985	5	170	51
Siberia	1989	462	>96	Not available
Denver	1990	–	–	31
Saint Herblain	1991	1	2	Not available
Vishakhapattnum	1999	80	>100	60
Tolouse	2001	29	2,500	1,000
B P Texas	2005	15	180	1,000
Buncefield	2005	–	43	13,000
Jaipur (IOC)	2009	12	200	32
Sharjah	2011	–	–	0.2

A number of numerical simulations have also been done to understand the dynamics of hydrocarbons spilled over flat surfaces. They involve solving equations describing the physics of the pool spread, ranging from simple treatments to relatively complex ones. The models addressing the physics of shallow pools assume symmetry while solving for the spread velocity and pool height with respect to pool radius and spread time.[33–39] Table 2 summarizes the past work done to understand the dynamics of hydrocarbons spilled over flat surfaces.

This study is perhaps the first attempt at assessing the dynamics of three common fuels spilling over porous inclined surfaces. Several experiments were done to quantify the effect of fuel surface tension, viscosity, and porosity, of the liquids, and the roughness and inclination of the receiving surface, on spill dynamics.

METHODOLOGY

Experiments were done to study the spill dynamics of three hydrocarbon fuels – ethanol, kerosene and gasoline – over sandy soil and beach sand, representing two porous substrates. The surfaces were inclined at angles of 0°, 5°, 10°, 15°, or 20° and the fuels were spilled using a peristaltic pump (RH-P 100 L-1–1,000) at the rates of 200 ml/min or 300/400 ml/min.

The surface over which spill tests were conducted was prepared by covering a plywood sheet of 1 m × 1 m area with a thin layer (2–3 mm) of soil or beach sand. Holes were drilled in the plywood sheet at the center and at a distance of 10 cm from one of the

Please cite this article in press as: Abbasi, T. et al., Spread rate of flammable liquids over flat and inclined porous surfaces. J. Chem. Health Safety (2018), https://doi.org/10.1016/j.jchas.2018.02.004