Incident

A sticky problem – new light shone on Boston's great molasses spillage

Tony Fishwick

Summary

In the afternoon of 15 January 1919, a massive leak of molten molasses burst out of a storage tank near the city's docks. As it literally poured and rolled through the streets, it demolished houses and buildings, engulfed people, horses and other animals and caused widespread destruction. A total of 21 people were killed and about 150 injured. At the time, no fully plausible cause for why the wave of molasses caused so much death and damage was established. Recently, however, a new study has been carried out and findings have been presented which explain what happened and the logic behind it[1,2,3] This article summarises the incident and these new findings, and makes brief reference to other disasters involving foodstuff or drinks, to demonstrate the fallacy that a product is always safe simply because it is safe to consume it. Any liquid, powder or other free-flowing substance can be hazardous when stored or used in large quantities. The results of the study could have applicability to the causes and effects of other, similar, fluid spillages.

Keywords: Spill, leak

Introduction

An excellent and detailed description of the incident, the manner of failure of the tank and the design and safety factors relevant to the accident, can be found in a previous LPB article[4] so these features are summarised only briefly here and the reader directed to this reference for more information. This article discusses the new evidence presented to explain the terrible consequences of the accident, then briefly presents some case studies of other incidents involving foodstuffs. These occurred from the early 19th century right up to modern times, demonstrating that this is by no means a phenomenon solely of the past.

Description of the accident and its consequences

A storage tank, owned and operated by United States Industrial Alcohol (USIA), containing about 2.3 million US gallons of molten molasses burst and disintegrated into seven pieces. The resulting flood killed 21 people, injured about 150 more, swept away timber houses, carried away motor trucks and drowned or seriously injured dozens of horses. The wave of molasses was about 10 metres high and moved at a speed of around 35 mph (56 km per hour). The force of gravity, acting on the viscous fluid, provided sufficient driving force to account for the speed of the wave. One house became trapped under an elevated railway. A piece of the tank, weighing 2.5 tonnes, was carried 55 m into a playground and a fire station 50 m away suffered severe structural damage. A fireman inside it was one of the dead, trapped underneath a billiard table and a piano. Photographs taken at the time (Figures 1, 2 and 3) give a stark impression of the devastation left behind[5]. In Figure 1, the top of the tank can be seen just in front of the white building on the harbour. Figure 3 is a close-up of the tank top. When the worst of the flow was over, the rescuers became coated in the sticky fluid which then spread over the city and beyond. Passengers in public transport up to 70 km away became stuck to their seats. Fire hoses using the public water supply proved ineffective in swilling away the masses but sea water from the docks worked somewhat more efficiently.

The tank at the time of the accident was almost full to capacity. It was made of structural steel plates riveted together. The bottom of the tank was flat and rested on a foundation of cement and sand mixture laid dry. The roof was conical. It had been designed with a specified safety factor of 3.0 and before being brought into use, was hydraulically tested by running 150 mm depth of water into it. The tank had been known to leak at its seams and to need caulking. After its collapse into seven pieces, it was noted that the bottom had bulged and that there was a depression in the cement/sand base mixture. The principal tear ran from a point in the tank bottom, about 3.5 m from the side, right up the side and through the manhole cover. At every level in the tank, the thickness of the plates was less than that specified in order to get a permit for construction and the *actual* safety factor of the tank was less than the *specified* safety factor. At its weakest point, it was 1.5 compared to 3.0.

The trial lasted 300 days and the outcome took six years to publish. It was decided in favour of the plaintiffs and the court awarded them damages of $300,000. Legal costs raised this figure to over $600,000, a total of about $8.3 million in current value. The defence proposal that the incident had been caused by an anarchist planting a bomb inside the tank was totally rejected. More plausibly, the tank probably failed due to a combination of inadequate pre-operation testing, and reactions taking place inside it. It was never filled to capacity before being brought into use for molasses and it leaked from the start of its use. The rivet holes were not reinforced, making them more likely to fail under stress and the steel plates were less robust than modern ones because the steel did not contain manganese. Furthermore, fermentation inside the tank possibly resulted in a build-up of pressure.

These and other factors relevant to the causes of the

0260-9576/18/$17.63 + 0.00

accident are discussed in Stephen Puleo's excellent book on the subject,[5] which examines in great detail the causes of the tank rupture, the operator's failure to heed the many warnings from workers, and the proceedings, and outcome, of the subsequent legal action. Amongst many relevant pieces of information, the following stand out and are worthy of specific mention:

- Incredibly, the tank truly was "hydraulically" tested to a depth of only some 6 inches (about 150 mm) of water. The USIA manager responsible for supervising the construction of the tank was under pressure to meet a very tight deadline so, knowing that it would have taken many days, or even weeks, to fill the tank, authorised testing to this wholly inadequate level. This covered just up to the first joint at the base of the tank. Not surprisingly, no leaks occurred, so the manager declared the entire tank fit to use.
- The very tight deadline arose because the molasses (blackstrap molasses) was vital to the USA war effort. It was distilled into industrial alcohol that would be used as a major ingredient in the production of munitions, especially dynamite, smokeless powder and other high explosives.
- When the tank was eventually brought into use and filled with molasses, numerous reports of leakages from its joints were made. Sometimes these were so copious that children used to hold cups and other vessels against the tank to fill them with molasses which they would then take home and spread on their bread. The company took scant notice of these complaints, even threatening one particularly diligent plaintiff with dismissal.
- At one stage, the company had the tank painted a rusty-brown colour, to make the molasses leaking down the outside harder to see.
- Shortly before the disaster in December 1918, the company did have the tank joints thoroughly caulked to stop the leaks existing at that time. However, this was totally inadequate to withstand the pressure eventually exerted by the quantity of molasses loaded into it before the accident.
- The number of rivets used to hold the tank plates together was insufficient for the pressure exerted by a full tank of molasses.
- The pressure exerted on the tank's walls just before the accident was estimated to be 31,000 psi. A safe pressure would have been about 16,000 psi. The "factor of safety" – the maximum pressure the tank walls could stand without buckling – was of the order of 1.5, whereas standard practice would have specified about 3.0.
- The thickness of every tank plate was less than called for in the specification. For example, the thickness of the top plate should have been 8mm. In fact, it was only 7mm.

Clearly, the tank failed primarily because of poor design and construction and inadequate testing prior to operation, compounded by shortcomings in operational control.

However, the question of why the molasses caused such widespread devastation was never satisfactorily explained at

Figure 1 – The devastating aftermath of the Boston Molasses Release: Wreckage of the collapsed tank in the Background, Right, in front of the white building

knowledge and competence

engineering and design

0260-9576/18/$17.63 + 0.00

IChemE

the time or for many decades after, other than the fact that the force of gravity would be sufficient to drive the viscous fluid to the speed that it attained. This question has recently been rigorously investigated and referenced in the scientific press[6,7] with the result that a very convincing explanation of the phenomenon is now available. This study, and its outcome, are now summarised.

Why the molasses spread so widely

There is an old adage "slow as molasses in January" which needs no explanation. So, given the cold temperature in Boston at the time of the spillage, the burning question was "why did the molasses spread so far and so quickly?" The findings of the new research provide the answer.

The team carrying out the work firstly carried out rheological studies on blackstrap molasses, similar to the molasses in the spillage, then modelled the resulting data. Rheology is, of course, the science of flow and deformation of matter – clearly relevant to this accident. They studied the flow properties of molasses to explore its viscosity and how that is affected by changes in temperature. Experiments on cold, spreading molasses were carried out. Then, they compared the model's predictions with historical accounts of the actual flood and found very reasonable agreement. Thus, they were able to move forward with some confidence.

Molasses is a non-Newtonian fluid so the relationship between its viscosity is not constant, but varies with its rate of deformation. Specifically, it is shear-thinning which means that deforming it at a faster rate (flowing faster) reduces its viscosity thereby allowing it to flow even faster. However, at the temperatures existing at the Boston Flood (about -16ºC), this would have been an extremely small factor and is dominated by the effect of the temperature itself. Experiments showed that cooling molasses from 10 to 0ºC increases its viscosity by a factor of three and further cooling causes even more extreme changes in viscosity.

Figure 2 – Damage to an overhead railway

At the time of the tank rupture, the molasses in the tank was probably about 5ºC warmer than the surrounding air. Once the molasses spilled over the waterfront, it would have

Figure 3 – The molasses tank top

0260-9576/18/$17.63 + 0.00

cooled rapidly, especially as ambient temperatures dropped still further after sunset. This would have resulted in a dramatic increase in the viscosity of the molasses. Gravity currents would have then come into play, whereby a dense fluid tends to spread horizontally into a less dense one (in this case, molasses into air). The density of the molasses would account for the initial speed of the tidal wave which, literally, bowled people over and made it virtually impossible for them to escape.

The model further suggested that the wave would have gone through three main stages:

(i) a slumping regime, when the molasses would have lurched from the ruptured tank in a large, looming mass;
(ii) next, inertia would play a major role, determining by effect of the large volume concerned, how rapidly the wave front swept forward, as described above and as it actually did;
(iii) finally, a viscous regime ensued, dictating how slowly, but inexorably, the molasses spread out and how difficult it was to escape or be rescued.

The researchers concluded that it was their view that the results of the study could provide valuable insight into other structural failures and their consequences. Investigations of breaching or over-topping of levees and bunds, and major industrial spillages from vessels, would all benefit from application of similar fluid dynamics, structural mechanics and engineering principles.

Other major mishaps involving edible or potable fluids

Case Study 1 – Molasses spillage into Honolulu harbour

In September 2013, a major spillage of molasses into Honolulu Harbour occurred. About 230,000 gallons escaped from a cracked pipeline which was being used to transfer the molasses from an onshore storage tank to a ship in the harbour. The molasses sank to the bottom of the harbour and killed some 23,000 fish (see Figure 4). It also adversely affected the coral reefs and boosted the algae population which, in turn, robbed the water of oxygen. There was no way that the spillage could be recovered from the bottom of the bay and its lack of strong ocean currents meant that it would not be churned out to sea quickly.

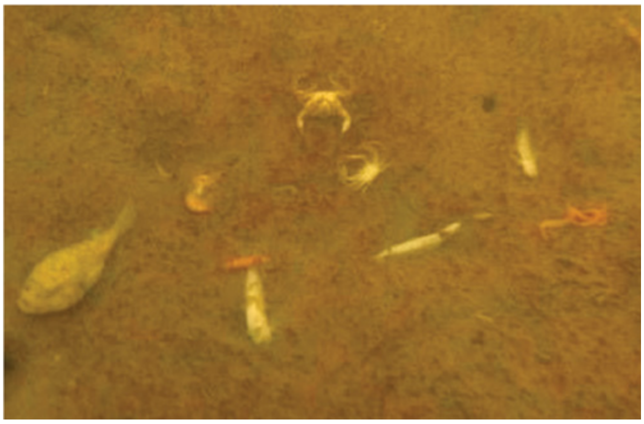

Figure 4 – Dead wildlife on the seabed

Neither the responsible company, nor the government had a contingency plan for responding to a large molasses spill but, within days of the spillage, the Hawaii Department of Transportation issued an order that required all businesses which pump their products through port pipelines to provide the state with documentation covering pipeline inspections and spill response plans. Since post-spillage clean-up was almost impossible, these plans would focus on prevention and early detection methods. The Hawaii Department of Transportation had found the same pipe to be leaking in 2012 and reported it to the company.

The company incurred major legal and other costs as a result of the investigation into the spillage. Firstly, in October 2014, they pleaded guilty to two federal misdemeanour charges by the US Attorney's Office and had to pay $400,000 in fines and $600,000 in restitution. Then, in July 2015, they agreed to pay Hawaii State $15.4 million in reimbursement costs for cleaning up the harbour, regrowing a new coral nursery and removing a molasses tank facility. Some of this money also went towards supporting an international environmental conference. Finally, in January 2017, they reached a settlement with the U S Environmental Protection Agency regarding Clean Water Act violations and paid a civil penalty of $725,000. They have ceased to ship molasses from Honolulu Harbour, thus terminating a business that had gone on for about 30 years.[8,9]

Case Study 2 – The London beer flood

The London beer flood occurred on 17 October 1814 at the Meux and Company's Horse Shoe Brewery in the parish of St Giles, London. A huge vat, containing over 135,000 imperial gallons (610,000 litres) of porter beer, ruptured, causing other vats to succumb in a domino effect. As a result, over 323,000 imperial gallons (1,470,000 litres) gushed out onto the streets in a wave at least 15 metres high that destroyed two homes, crumbled the wall of the nearby Tavistock Arms pub, and killed a total of eight people. The brewery stood at the corner of Great Russell Street and Tottenham Court Road in what was then a densely populated tenement slum area which afforded little opportunity to escape from the flood as it proceeded.[10]

In 1810, the brewery had installed a 22 foot (6.7m) high wooden fermentation tank that was held together by a series of massive iron rings and, at around 4.30 pm on the day of the accident, a storehouse clerk inspected the tank and noticed that one of these 700 lb (318 kg) iron rings had slipped off the tank. This was not unusual, as it occurred two or three times each year. The clerk's boss said that no harm would ensue, despite the tank being full, with pressure from the fermentation process building up inside it. He instructed the clerk to arrange for the matter to be rectified at a later date.

Soon after, at around 5.30 pm, the clerk heard a massive explosion from inside the storeroom. The tank had ruptured, releasing the hot fermenting beer with such force that the tank ruptured and the back wall of the brewery collapsed. The blast caused a domino effect, knocking a valve off an adjoining cask and breaking open several more vats, the contents of which were added to the flood, which then burst onto the street.

A torrent of porter beer rushed through the narrow lanes sweeping away everything in its path and swamping everyone with liquid. The streets had no drainage, so the basements of the tenements were inundated and collapsed. Residents

0260-9576/18/$17.63 + 0.00
IChemE

climbed on tables and other furniture to try to save themselves from drowning or being swept away but, for some, this was to no avail. A lady and her four-year-old daughter had just sat down to tea when the flood hit and killed them; at a wake, being held for a two-year-old boy, his mother and four other mourners perished; a teenage pub servant, washing pots at an outdoor water pump behind one of the walls of the pub, was killed instantly. Amazingly, all the brewery employees survived.

The brewery was eventually taken to court over the accident, but the disaster was ruled to be an "Act of God." Not only did the brewery not have to pay any compensation, but they were also able to reclaim the excise duty that they had already paid on the spilled beer. This, plus compensation for the barrels of lost beer, saved the company from bankruptcy. This seems incredible by modern standards of investigation of a fatal accident, but this was the early 19th century. However, one good outcome was that wooden fermentation tanks were gradually phased out and replaced by lined concrete vats.[11]

Author's comments and lessons that can be learned

At first sight, little seems to be similar in these three accidents except that two of them involve molasses. They occurred over a time span of about 200 years with around a century separating each one from the next. The social, cultural and legislative changes and developments, and the advances in attitudes to safety and protection of workforces and the public, that evolved over that period of time, whilst not incomprehensible, were certainly vast. Nevertheless, there are some common themes from which lessons can perhaps be learned today. Thus:

- In the Honolulu and London cases, there were prior warnings which, had they been fully acted on, might have prevented the accidents — the previously cracked pipeline at Honolulu and the slipped retaining ring in the London brewery. The lesson here, though sometimes difficult to apply, is very clear — always try to follow up on non-standard observations to a satisfactory conclusion. In doing this, it can help if the question "what is the worst that could happen?" is asked. In the London brewery case, a degree of complacency seemed to have crept in — the retaining rings were always slipping so "never mind" instead of "we ought to do something about it."
- In all three cases, there was a lack of an effective contingency plan. In the London and Boston cases, this is not surprising considering how long ago they happened. In the case of the Honolulu Harbour spillage, occurring in the 21st century, it was criminally reprehensible, as the legal judgements showed. Having an effective and well-rehearsed response to accidents — an emergency plan — is a necessary and effective means of limiting damage to individuals, plant, property and the environment.
- All three accidents involved edible/potable substances stored in large quantities prior to being transferred on to distributors or customers. There is sometimes a tendency to view operations involving foodstuffs or drinks as being safer than those in which toxic, corrosive, or other hazardous materials are handled, simply because they are encountered in everyday life. There is no evidence that this attitude existed in any of these three cases, but it does exist, and it is profoundly mistaken. It is vital to apply the same rigorous standards of safety and risk management to these materials as to other, more obviously noxious, substances. The outcome may be different in terms, for example, of the chemical properties, but where physical effects are concerned, it is often the same.

References

1. *Kennedy J Sharp N and Rubinstein S, American Association for the Advancement of Science – Division of Fluid Dynamics, 69th Meeting, November 2016.*
2. *Kennedy, J and Sharp, N, American Physical Society Division of Fluid Dynamics, Portland, Oregon, November 21, 2016.*
3. *Mother Nature Network, http://www.mnn.com/family/protection-safety/stories/the-1919-boston-molasses-flood*
4. *Marshall, V C, Loss Prevention Bulletin, August 1988 (082) 27.*
5. *Dark Tide; The Great Boston Molasses Flood of 1919, Stephen Puleo, Beacon Press, Boston, Mass, ISBN 0-8070-5021-0.*
6. *New Scientist, Issue 3102, December 2016.*
7. *American Physical Society News, Vol 26, No 1, January 2017*
8. *Mother Nature Network, http://www.mnn.com/earth-matters/wilderness-resources/blogs/why-is-molasses-spill-so-terrible*
9. *U S Environmental Protection Agency News Release, January 19, 2017*
10. *Wikipedia https://en.wikipedia.org/wiki/London_Beer_Flood*
11. *The History Press http://www.thehistorypress.co.uk/articles/the-london-beer-flood*

0260-9576/18/$17.63 + 0.00