

EXPERIENCES OF MASSECUITE PIPELINE EXPLOSIONS CAUSED BY THE HIGH TEMPERATURE DECOMPOSITION OF MOLASSES

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Abstract

A recent experience of a destructive explosion of a massecuite pipeline has highlighted the importance of continuing to publicise the causes and consequences of this type of event in the interests of preventing further occurrences. Details of the recent explosion in Central America and a similar event at Darnall in the 1970s are described. The common factor in these explosions was the use of high pressure steam for steaming out cut-over/drain lines. The causes and mechanism of the reaction which precipitates this type of explosion are explained on the basis of published results of laboratory experiments which were instigated by a similar explosion in Australia. Recommendations for avoiding possible future explosions of this type are given.

Keywords: explosion, pipeline, massecuite, safety, factory process

Introduction

During the commissioning of a new continuous pan in Central America in 2005, there was an explosion in a cut-over/drain line attached to this new pan. Given that this was a new installation, it was not unreasonable that the factory staff felt that the continuous pan might have been in some way responsible for the explosion.

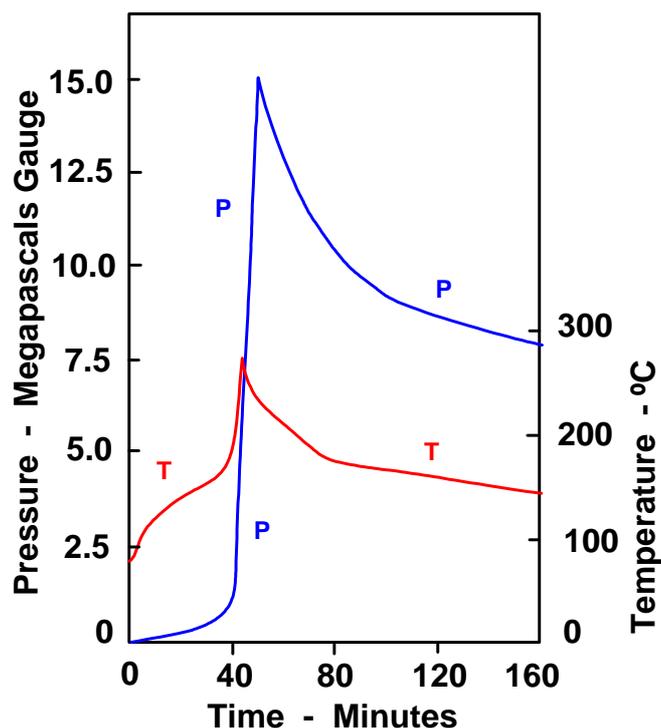
Fortunately there is no reason why a continuous pan should cause a massecuite line explosion and there is both past experience and research which can explain the cause of the explosion. Specifically, a similar explosion took place in Darnall in 1978, and an investigation into this event concluded that the cause was the use of high pressure steam for 'steaming out' the cut-over line. A review of the literature at that time found the publication by Foster (1974), which described detailed laboratory investigations into the explosive decomposition of sugar products when they held at elevated temperature for prolonged periods. This investigation was prompted by the failure of an A-massecuite cut-over pipe at an Australian sugar factory which caused considerable damage. The failure occurred whilst the pipe was being steamed out with 1000 kPa gauge steam (181°C). There is sufficient evidence that the recent explosion in Central America was also caused by the use of high pressure steam for steaming out the cut-over/drain lines attached to the continuous pan.

Although explosions of this type appear to be rare, it is clearly important to publicise the danger and possible loss of life which they pose, in the hope of preventing future occurrences.

Explosive decomposition of sugar streams

When considering the chemical decomposition of products in a raw sugar factory it is common to suspect that this is a consequence of the 'Maillard reaction'. The importance of understanding the Maillard reaction and its negative effects on processing was highlighted for local technologists in a paper by Newell (1979). The Maillard reaction is not a single reaction but a number of complex reaction pathways, which begin with the reaction between an amino acid and glucose. The speed of reaction is known to increase with temperature, and one of the reaction products is carbon dioxide, so it is possible that this reaction could lead to an explosion if an impure sugar stream were heated within a confined space.

Experiments by Foster (1974) have, however, shown that the explosive decomposition of sugar can occur even when there is no amino acid present (i.e. it will occur with pure sucrose) showing that this cannot be the Maillard reaction. Foster's experiments were conducted by placing a product sample into a tightly sealed container (a 600 ml steel 'bomb') and then monitoring the rise in temperature and pressure within the container when the whole container was placed in an oven at a constant temperature. The products tested were pure sugar massecuite, A and C massecuites and final molasses. The oven temperatures tested were 122, 148 and 170°C. Most of the tests showed that there was an 'incubation time', after which there was a rapid rise in pressure, accompanied by a rise in temperature which indicated an exothermic reaction. An example of a test result is shown in Figure 1.



**Figure 1. Pressure development in C-masseccuite (Foster, 1974).
Oven temperature = 148°C; Normal steam pressure = 349 kPa gauge**

The results of the range of conditions tested by Foster are summarised in Figure 2, which plots the time taken for the reaction to develop (the 'incubation time') as a function of the temperature (and thus the pressure of saturated steam to which it corresponds). The curves show that the time to reaction is shorter for impure products and, in all instances, decreases as the temperature (and thus corresponding steam pressure) increases. The term '% voids' refers

to the proportion of the sample container not occupied by the massecuite sample. The results for 'C'-massecuite thus indicate that, with a larger sample mass, the time to reaction is shorter.

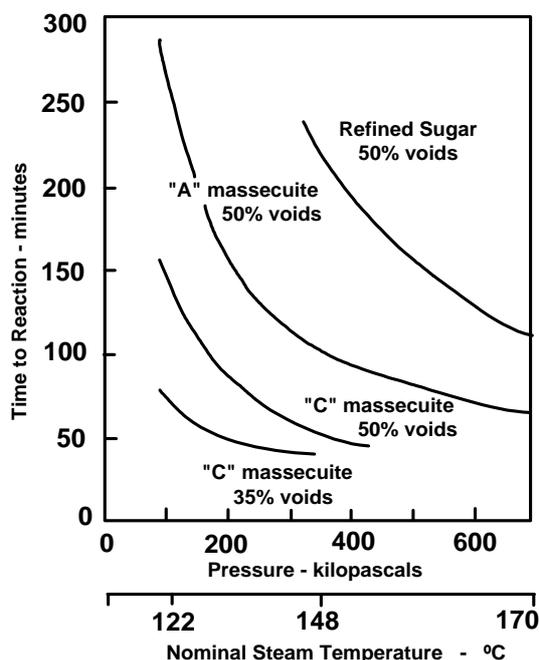


Figure 2. Summary of results in terms of time taken for the reaction to develop (Foster, 1974).

Foster's paper provides references which indicate that there are many possible complex degradation pathways for the thermal decomposition of sugar. Some of the possible products from these reactions are organic acids (levulinic acid in particular), aldehydes, ketones, hydroxymethyl furfural, hydrogen, carbon dioxide, carbon and water.

In the simplest overall sense, three possible pathways for the degradation of a carbohydrate can be considered. The first is the breakdown into carbon and water (i.e. complete dehydration), the second is the breakdown into carbon dioxide and methane, and the third is the breakdown into carbon dioxide, hydrogen and carbon.

Foster's tests indicated that the first pathway took place, but was unable to discern whether the second and third pathways had also been involved. There was carbonaceous residue left behind after the reaction (corresponding to the first and third pathways); however, the strongly exothermic nature of the reaction indicated the first pathway (since the second and third pathways both have low heats of reaction). Limited analyses of the gas evolved in the tests showed that the major constituent was carbon dioxide (approximately 90%), indicating the second and/or third pathways. No tests were done for the presence of hydrogen, so it was not possible to confirm the third pathway. Carbon monoxide was also present at between 1 and 6%. After scrubbing out the carbon dioxide, the remaining $\pm 8\%$ of the gas was found to be flammable, and gas chromatographic analysis indicated the presence of the following compounds: methane, ethane, propane and butane (and possibly isopentane and isobutane), indicating the presence of a range of side reactions.

Although it cannot be proven conclusively that the thermal decomposition described here was the cause of the explosions described below, it is clearly the most probable cause, particularly given the common factor of the use of high pressure steam for steaming out.

Explosion in Darnall 1978

An explosion in a cut-over line at Darnall took place at 09h45am on 16 June 1978. An investigation at that time was able to track the sequence of events just prior to the explosion. These events need to be understood in the context of the cut-over piping arrangement shown in Figure 3. The relevant section of the cut-over system is the line interconnecting Pans 1, 2 and 3 with the A-seed tank and the magma tank. This section could be (and was at the time) isolated from the rest of the cut-over piping, by closing the relevant valve.

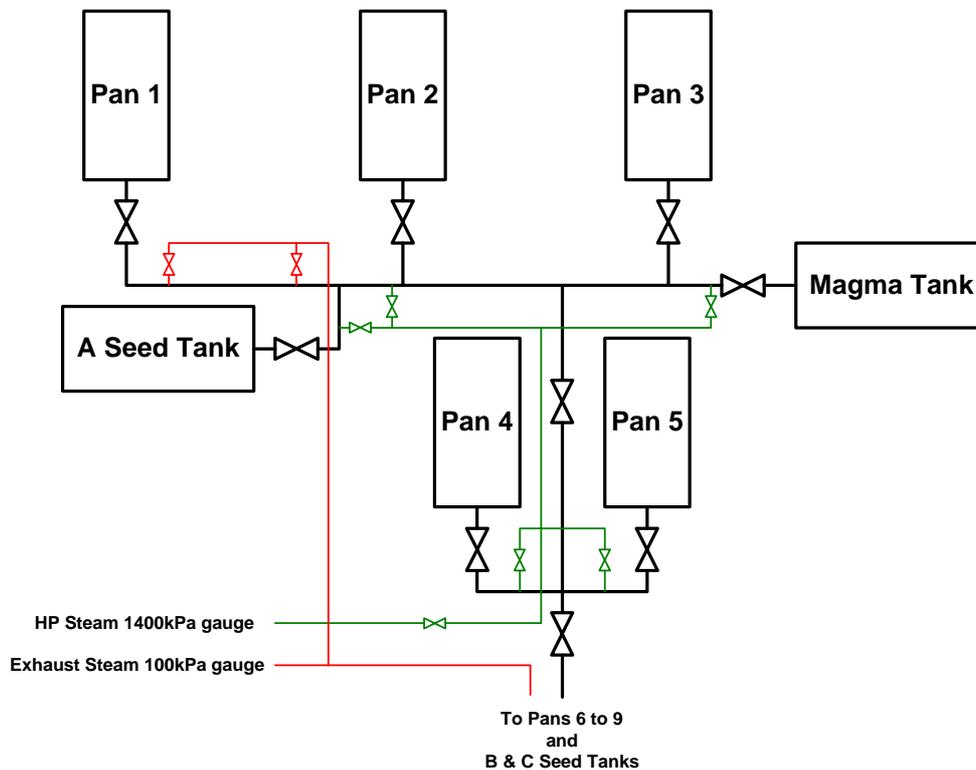


Figure 3. Darnall pan floor cut-over and steaming out system at the time of the explosion.

At 08h50 the total contents of Pan 2 (a seed created from a magma footing) was cut into Pan 1. This was done using the standard procedure at that time, as follows:

1. Raise vacuum in Pan 1.
2. Reduce vacuum in Pan 2 by adding Vapour 1 via the steaming-out line into the pan.
3. Open the cut-over valve on Pan 1.
4. Open the cut-over valve on Pan 2.
5. When the required quantity of footing has been transferred into Pan 1 (in this instance all of the seed in Pan 2), close the cut-over valve on Pan 2.
6. With the cut-over valve on Pan 1 still open, use exhaust steam to steam out the contents of the cut-over line into Pan 1 (assuming all steaming out points on the cut-over system are supplied with exhaust steam – see below).
7. Once this is complete, close the cut-over valve on Pan 1 and shut off the exhaust steam into the cut-over line.

At 09h10 the contents of the A-seed tank were cut into Pan 2, again using the standard procedure at that time, as follows:

1. Raise vacuum in Pan 2.
2. Ensure that seed tank is open to atmosphere.
3. Open the cut-over valve on Pan 2.
4. Open the cut-over valve on the seed tank.
5. Allow all the contents of the seed tank to be sucked into Pan 2 and then allow a little air to follow the last of the seed, so as to displace the massecuite in the line. As a result of this use of air, no steaming out is required.
6. Close the cut-over valves on both Pan 2 and the seed tank.

It was subsequent to this operation, at 09h45, that the explosion occurred.

At the time it was thought that all the steaming out points on the cut-over system were supplied with exhaust steam. Although high pressure steam (1400 kPa – 200 psig) had been used previously for steaming-out, a ‘slight’ explosion in 1974, which blew the top off a cut-over valve, resulted in the decision to change all the steaming-out points to use exhaust steam (100 kPa gauge). Examination of the damaged piping after the explosion showed that a number of the steaming-out points had inadvertently been left connected to high pressure steam, as shown in Figure 3. Almost certainly, one of these high pressure steam valves was left open after the initial cut of the contents of Pan 2 into Pan 1. This then, could have caused the explosive decomposition of massecuite which had been left in the cut-over line after cutting the contents of the seed tank into Pan 2. It was not possible to prove conclusively that a valve had been left open, as two 20 mm valves on the high pressure steam lines were never found. Fortunately no one was injured in the explosion, but to understand the force of the explosion and the dangers it posed, it is necessary to describe some of the details.

The explosion tore away a large section of the cut-over line below Pans 1 and 2. The pipe ripped off most of the body of the cut-over valve on Pan 1, leaving the valve tongue held on by vacuum, as shown in Figure 4.

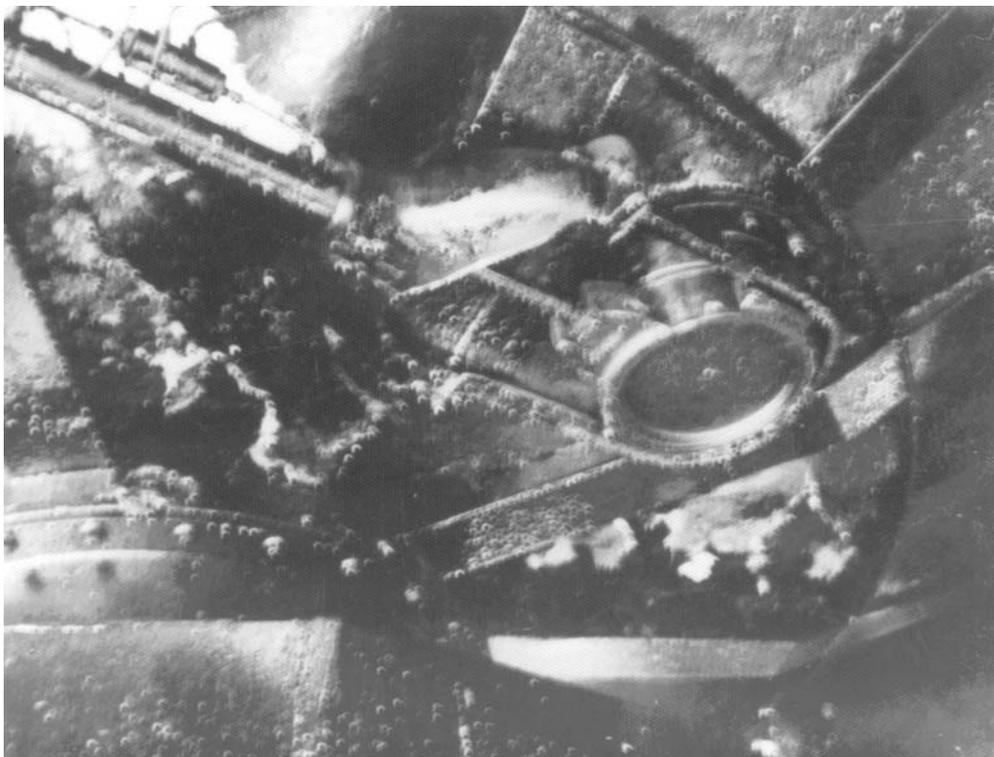


Figure 4. Tongue of valve held onto base of Pan 1 by vacuum.

The cut-over valve on Pan 2 was ripped off completely and the full contents emptied into a crystalliser below, which fortunately had sufficient space to accommodate the massecuite. The valve on the seed tank was badly damaged (see Figure 5), and it was fortunate that the tank was empty at the time.



Figure 5. Damaged valve on seed tank.

The section of cut-over pipe ripped away from the rest of the cut-over system, tearing away the saddle of a Tee-joint, as shown in Figure 6. As the 250 mm cut-over pipe tore away, it caused extensive damage to other piping (a 200 mm V1 line, a 150 mm water line) and to walkways.

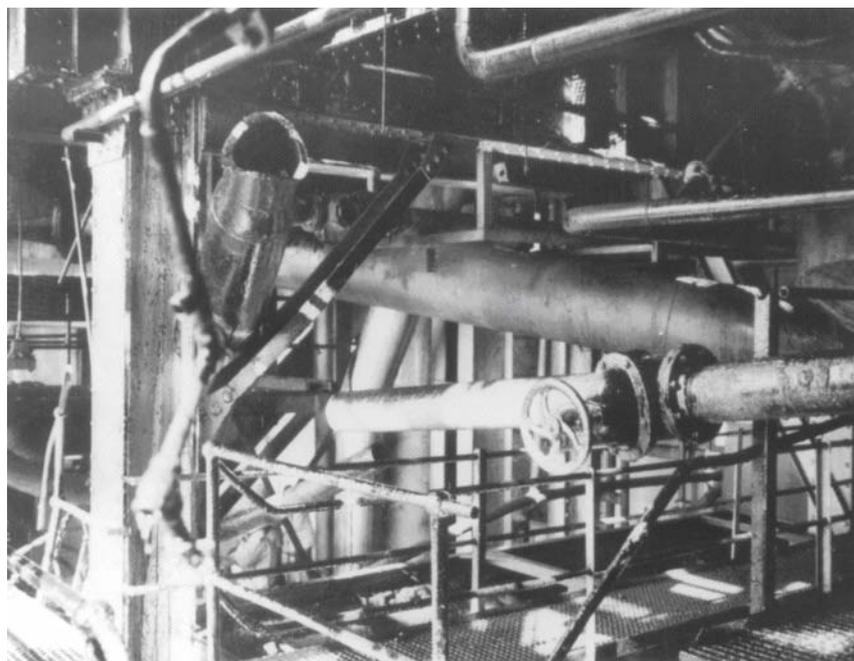


Figure 6. Cut-over pipe torn away at saddle.

Explosion in Central America 2005

An explosion occurred at 15h30 on 25 November 2005 in the cut-over/drain lines on a new C-continuous pan at a factory in Central America. The 130 m³ pan was of the Tongaat Hulett/Fletcher Smith design with 10 compartments. Because of the need to prevent mixing between the compartments, the pan has a number of drain/cut-over valves (some serving a pair of adjacent compartments and others serving single compartments). This also facilitates cutting different masseccuites into particular compartments. The valves and lines are used for filling the pan at start-up by cutting over from batch pans, and also for draining the pan when it is necessary to boil out the pan with water.

The explosion occurred during the early stages of commissioning. The pan had been filled earlier in the day by cutting seed masseccuite into the continuous pan from batch pans. On investigation, it transpired that the continuous pan steaming-out system was connected to a 200 psig supply (even though this had a normal operating pressure of around 150 psig). It appeared that a valve must have been left open, or had leaked, raising the temperature of the masseccuite left in the line when masseccuite had been cut-over into the continuous pan. Because of the extensive damage, it was not possible to confirm that this had taken place.

Fortunately no one was seriously injured in the explosion, although some operators suffered minor burns when they were covered in masseccuite. The explosion ripped the drain lines off compartments on the one side of the pan, with the result that half the masseccuite in the pan (75 m³ from compartments 6 to 10) drained onto the floor. The drain line smashed into the masseccuite outlet pipe from compartment 10, causing it to collapse and rupture. Because of the confined space, it was difficult to take photographs which would fully demonstrate the extent of the damage.

The force of the explosion shattered the windows of the control room about 30 m away and the residue of masseccuite coated adjacent equipment and tanks. The explosion also gave off acrid, choking fumes that caused discomfort 100 m away from the point of the explosion. The residual masseccuite from the explosion was 'charred', in line with the carbonaceous residue found by Foster in his experiments.

The explosion also flung metal onto a set of control panels and caused severe damage, virtually destroying three panels completely (see Figure 7). This affected the entire factory control system and meant a complete factory stop.



Figure 7. Damage to control panels.

Preventing possible future explosions of this type

The most important recommendation is never to use high pressure steam for steaming-out massecuite lines. The maximum pressure steam which should be used is exhaust steam (approximately 100 kPa gauge), although it is clearly safer to use Vapour one (approximately 60 kPa gauge).

Steaming out should be restricted to situations where the system is open to atmosphere. This can be achieved by providing a low level steamings tank (open to the atmosphere) where the dissolved products can gravitate and be collected before being pumped back into process.

As a further safety measure, bursting discs can be installed to provide the safe release of pressure in the event of an explosive decomposition reaction.

Conclusions

Dangerous explosions have occurred in cases where high pressure steam connections have been provided for steaming-out massecuite cut-over and drain lines. Systems should be checked to ensure that this could never happen in current factories, and that appropriate procedures are in place to further reduce the possibility of this type of explosion.

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