SIESO Medal paper

Flixborough – looking forward

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Summary

On Saturday 01 June 1974 at 4:35 pm, the biggest explosion to occur in Britain during peacetime took place at the Nypro Chemicals' site at Flixborough. The consequences of the explosion were so severe that 28 workers were killed and 36 onsite and 53 offsite severe injuries occurred. While Flixborough was not the first major accident to occur during the 60s and 70s, an industry step change in the consideration of process safety followed, such that the changes it introduced are still relevant today. Looking forward, the chemical industry is expected to undergo drastic changes and face new challenges, and it is important that process safety is kept at the forefront.

Keywords: Flixborough, explosion

Introduction

Nearly 50 years on, Flixborough is still recognised as a wake-up call for process safety in the chemical industry. Until the Buncefield depot explosion in 2005, the Flixborough disaster was Britain's biggest peacetime explosion. The release of 10 to 15 tons of cyclohexane from the plant resulted in a vapour cloud explosion equivalent to 15 to 45 tons of TNT[1]. The consequences of the explosion resulted in 28 fatalities and complete destruction of the plant[2]. The Flixborough disaster served as an initiator of an investigation that led to guidelines for process safety in the chemical industry[2]. As a result, the outcomes of the disaster have been far reaching and the design philosophy of chemical plants has changed considerably since[3]. As chemical processes become more complex and the industry faces emerging challenges, it is vital that the process world continues to keep process safety and lessons learned at the forefront[4].

Background

The explosion occurred on a warm summers Saturday afternoon at the Nypro Chemicals plant in North Lincolnshire. The site was surrounded by fields and situated on low lying land on the east bank of the River Trent, a tributary of the Humber[1]. The Flixborough plant was operated by Nypro Chemicals, owned jointly by Dutch State Mines and the National Coal Board (NCB) at the time of the disaster[1].

The Flixborough plant produced caprolactam, a precursor for the production of Nylon 610. The process involved the partial oxidation of cyclohexane to produce a mixture of cyclohexanone and cyclohexanol by air injection in the presence of a catalyst[5]. This reaction was slow, and it was desirable to keep the conversion low to avoid the production of unwanted by-products[5]. This meant that the plant inventory was large relative to the production rate. The reaction took place in a train of six stirred reactor vessels at a pressure of 125 psi and a temperature of 155°C connected by 700 mm diameter metal bellows[1]. The reactors were made of 13 mm steel and a 3 mm thick stainless-steel liner, and each was of 5 m height and 3.5 m in diameter, built with an interior overflow weir, baffle plates, and an agitator[6].

In the subsequent stages, the reaction product was distilled to separate the unrecycled cyclohexane (which was fed back to the reactors with a mixture of fresh cyclohexane) and cyclohexanone and cyclohexanol, which are then converted to caprolactam[7]. At the time many similar processes were operated, with slight variations, in many plants around the world[6].

How the disaster occurred

Two months prior to the explosion on 27 March 1974, a 2 m long vertical crack leaking cyclohexane was discovered on Reactor 51. Subsequently, the plant was shut down and the reactor removed for repair[8]. In order to permit continued operation of the plant, the site management team decided to remove Reactor 5 and install a 0.5 m diameter bypass pipe between the bellows to take its place. Due to elevation changes, it was necessary to incorporate a 'dogleg' shape into this bypass as shown in Figure 1.

This modification was fabricated onsite without any engineering drawings, calculations or testing[1]. The team

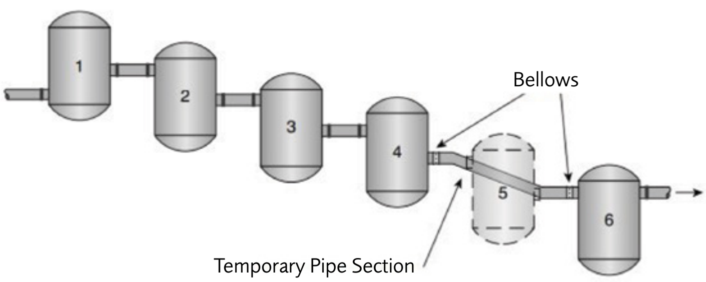

Figure 1 - Reactor vessels showing reactor bypass and bellow[9]

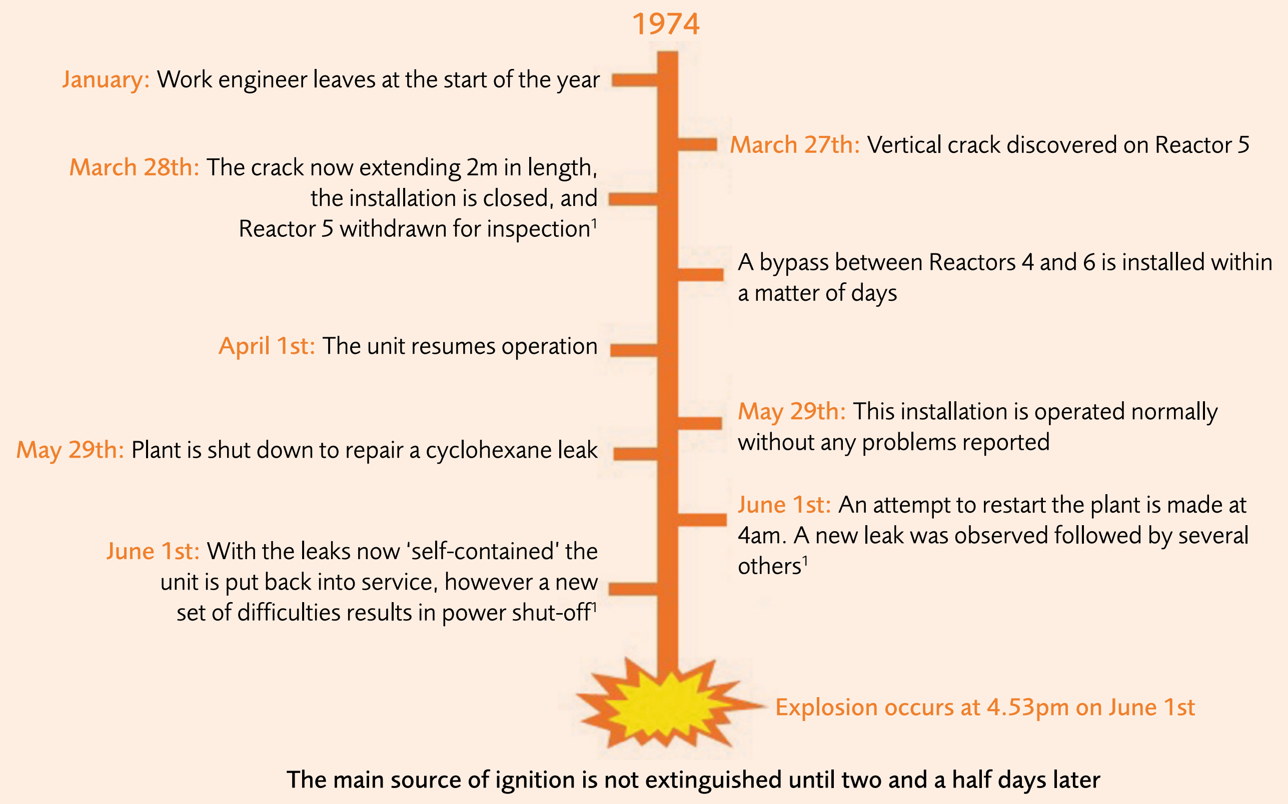

Figure 2 - Timeline of events of Flixborough

tasked with making and installing the temporary pipe were not professionally qualified to do so[5]. The pipe was constructed and supported by scaffolding; however, no account was taken for the turning moment that would act on the pipe due to fluid flow. Consequently, the scaffolding support was not adequate to resist the shear forces[1].

The temporary pipe performed satisfactorily for two months until, at the end of May, the plant was shut down to repair a leak. During the late afternoon on 01 June 1974, whilst the plant was being restarted, a slight rise in pressure occurred, well below the relief valve set point, causing the temporary pipe to twist[5]. The installed bypass ruptured, and tonnes of boiling cyclohexane were released. The cyclohexane formed a flammable vapour cloud and, at 4:53 pm, a massive vapour cloud explosion ignited. A brief outline of the timeline of events are presented in Figure 2.

Aftermath

In order to understand the causes of the disaster and the lessons learned an official Court of Inquiry was established. The investigation aimed to determine the causes of the disaster and find the lessons to be learned from them. The Court concluded the direct cause to be the release and explosion of cyclohexane caused by introducing a modification that destroyed the integrity of a well-constructed plant[6]. The plant modification occurred with only limited calculations on the integrity of the bypass line, and no analysis was conducted for the shape of the pipe and the bellows. At the time there were no specific UK regulations in place to control major industrial hazards. As a result of Flixborough, regulations regarding industrial processes were made considerably more rigorous[10].

Failings in technical measures and lessons learned

In the closing paragraphs of the report by the Court of Inquiry, various lessons are listed including issues that were referred to other bodies[11]. Reading through accident reports from recent incidents, the recommendations to prevent future accidents are often very similar to those contained in reports published several years previously. In the case of Flixborough, several major accidents could have been prevented if the lessons from this disaster had resulted in the adoption of the necessary measures discussed and recommended, such as the 2005 BP Texas City accident and the lessons in occupied buildings[11].

Management and control changes

The Court of Inquiry highlighted how deficiencies in management at the plant in Flixborough contributed to the incident[1]. After discovering the crack in Reactor 5, no action was taken at the plant to determine its cause. It was clear that the bypass between Reactors 4 and 6 was not considered a technical problem and no possible design alternatives were discussed[10]. Production was also favoured over safety in this critical moment as the main concern was to restart production with as little delay as possible due to market pressures from Nylon providers in Europe[10].

Nowadays no discussion on plant modifications occurs

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without mention of Flixborough as an example on the hazards of plant modifications[12]. No modification should be made until it has been authorised by a competent person and all the consequences of the change should be identified in detail[5]. Since Flixborough, there have been several tragic and catastrophic chemical plant accidents due to failures in managing changes in chemical plants, such as the tragedy at Pasadena, Texas in 1989[12].

Furthermore, the cause of the crack in Reactor 5 can also be linked back to a process modification. Prior to the crack there was a leak of cyclohexane from the stirrer gland and to condense the leaking vapour, water was poured on the top of the reactor[5]. Plant cooling water was used as this was conveniently available. However, the water contained nitrates which caused stress corrosion cracking of the mild steel pressure vessel. This was a common method of providing cooling, however, this was still a process change that should have undergone an appropriate modification procedure.

The article in issue 1 of the 1975 *Loss Prevention Bulletin (LPB)* Are your plant modifications safe? proposes a Management of Change procedure. The article explains that there should be a system in place for expenditure proposals to ensure that the right materials are selected, and to ensure that there are no unforeseen effects on any safety systems. Nowadays, the importance of a robust management of change procedure is well understood[13], and the application of such a procedure would have undoubtably prevented the disaster from happening.

Qualified staff

Prior to the incident, the works engineer had left at the start of the year, and by June 1974 the company had yet to find a replacement[1]. Instead, the services engineer had been given a coordination role managing day to day maintenance activities despite not receiving adequate training to equip him with assessing mechanical engineering issues[1]. To a suitably qualified engineer it would have been clear that the plant should be shut down until the other reactors were checked for defects. This was highlighted in the report that by the time of the accident 'there was no mechanical engineer on site of sufficient qualification, status, or authority to deal with complex or novel engineering problems and insist on necessary measures being taken.'[7]. This case emphasises the importance of a balanced team containing people of the necessary professional experience and expertise. On the other hand, it is equally important that engineers understand what they do not know. At the time of the incident, nitrate induced cracking was generally known to metallurgical specialists but was not very well known amongst engineers.

Occupied buildings

At the time of the disaster, large scale explosions were not considered in the design and location of occupied buildings. In Flixborough, the control room was located close to the plant for operational reasons[1]. Many features of the design of the control room offered little to no protection against relatively small overpressures and some features exacerbated the death toll — such as brick walls and its position on the ground floor underneath a concrete floor[1]. The Chemical Industries Association has since developed guidance on the location and design of occupied buildings which were published in the late 1970s and since Flixborough protection against overpressure was incorporated into new constructions[1].

Most of the fatalities were in the control room and the cause of which was the collapse of the building. Since Flixborough more attention has been paid to plant layout and location and the strengthening of control buildings, and many companies have built blast resistant control rooms. It is now clear that buildings within the blast zone must be blast resistant and only essential personnel are located within these, with others located away from units in appropriately designed buildings. It is now the industry standard that plants are laid out such that the impacts of an explosion are minimised. Despite this lesson, fatalities caused by an explosion in the case of the BP Texas city refinery highlights the importance that all buildings occupied for even limited time periods as well as temporary buildings need to be assessed for possible explosions, and their location and design needs to reflect this[1].

Inherently Safer Design (ISD)

As explained earlier, the plant site contained excessively large inventories of cyclohexane, naphtha, toluene, benzene, and gasoline[9]. These inventories likely contributed to the fire after the initial blast, which burned for ten days following the explosion. At the time, the high-inventory process used by Nypro was much the same as every other manufacture of nylon and considered the 'best current practice'[5].

Flixborough revealed issues in industry not previously considered, highlighting the idea of designing to minimise hazards rather than designing to control them. ISD should have been applied in order to mitigate the hazards at the source. It became clear that if the industry set out to reduce inventories in the early stages of the design the resulting plant is often cheaper e.g. less added-on protective equipment is needed, smaller cheaper equipment.

Since 1974 progress towards inherently safer plants, though significant, has been relatively slow. In part this has been due to recessions in the chemical industry but also due to the fact that ISD requires more time during the early stages of design for alternatives to be evaluated, which may not be desirable if the plant needs to meet a new market opportunity quickly[5].

Future outlook

Why is Flixborough still so relevant nearly 50 years on since the disaster? While Flixborough is very well reported and understood to experienced engineers, for students it serves as a fundamental basis for fostering an appreciation for safety. Using innovative methods such as virtual safety-based games, interactive models etc. can ensure this information is learned at an early stage in a student's professional career. Our triptych, shown in Figure 3, aims to provide an accessible and interactive method of sharing this information. As part of a multidisciplinary collaboration, utilising students in fields such as textiles and robotics it provides new and outside perspectives from different artistic fields on how lesson learning should and can be achieved.

Furthermore, Flixborough is also important as the chemical industry faces new challenges as it undergoes huge changes worldwide. Countries such as China, India, and Brazil have

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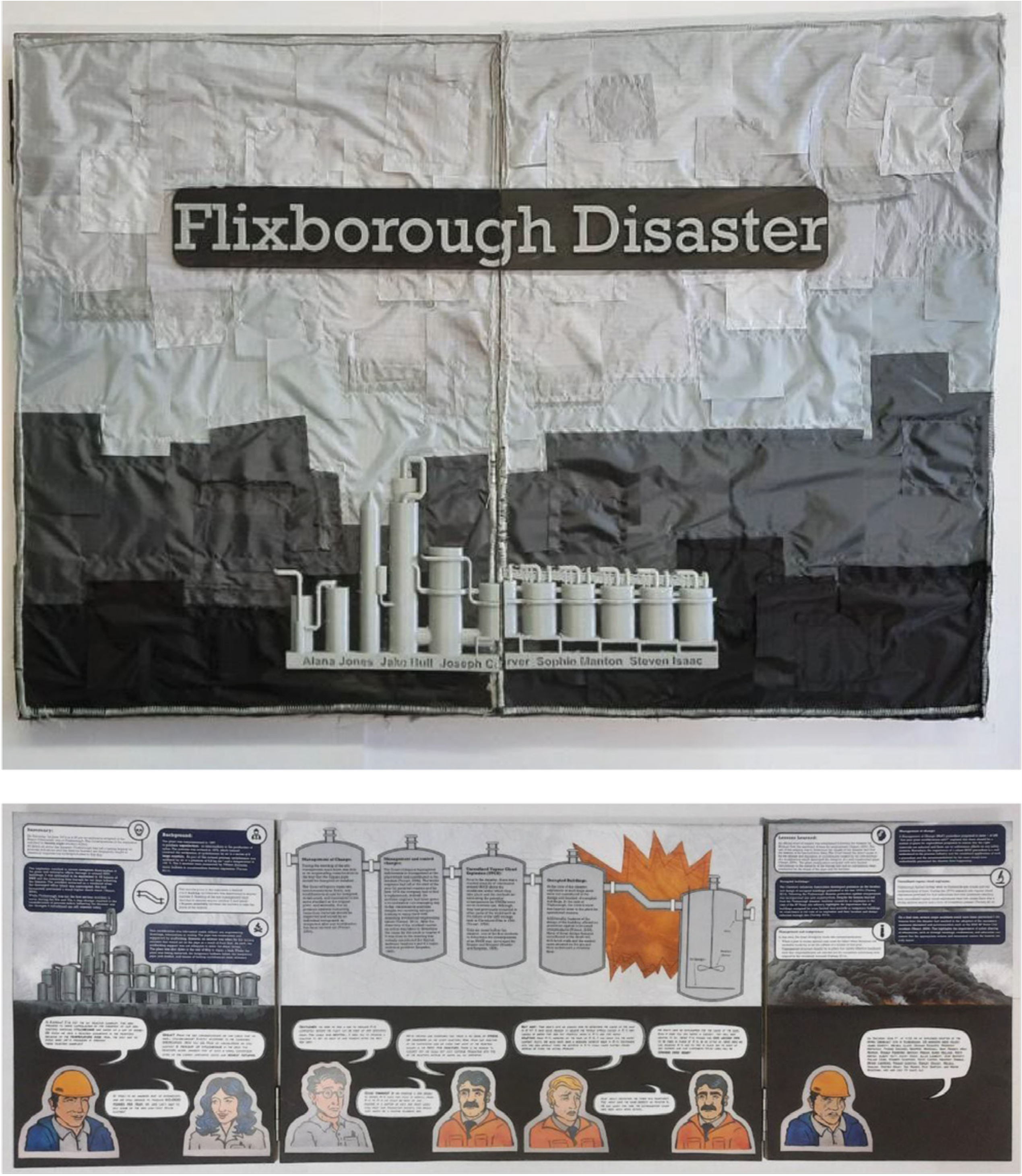

Figure 3 - Images of wooden triptych a) closed b) opened featuring artwork, 3D printing and textiles work

emerged as manufacturers of chemicals on a mammoth scale[14] with China alone between the years 2001 and 2014 increasing its percentage share from 8.1 to 30.4 of total worldwide chemical sales[14]. This presents a challenge for companies in the US and Europe to remain competitive among the growing international competition while ensuring they comply with regulations in safety and protecting the environment. On the other hand, the emerging countries face a number of challenges such as a lack of government supervision and weak safety management foundation of enterprises[15]. Flixborough showcased the role poor management and a lack of competency contributes to major disasters. It is therefore critical that there is awareness of events beyond national borders as the lessons of Flixborough become increasingly relevant[11].

Furthermore, as we strive to reduce our dependence on non-renewable resources to produce energy, chemical industries may be prevented from adopting effective safety management practices due to lack of time, lack of risk consciousness,

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and loss of process specific experience[14]. Similarities can be drawn between this and Flixborough. In the case of the latter, production was favoured over safety at critical moments in the face of market pressures. It is vital that this mistake is not repeated as oil and gas become scarcer and more expensive. Ensuring competency and proper training is also vital as the industry navigates these changes – another key lesson from Flixborough.

Conclusion

The Flixborough disaster helped to contribute and promote significant changes in the hazard processes. Key outcomes following the disaster include:

- Management of Change procedures that are now commonplace in the process industry.
- Guidance on the location and design of occupied buildings.
- Guidance on management structures and ensuring that qualified staff are employed.

As chemical process become more complex, and the chemical industry faces new challenges, industry needs to make sure that learning lessons is a fundamental aspect of process safety in the coming years.

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Editorial note

Ramin Abhari depicts the story of the Flixborough explosion in his graphic novel *Nylon Years*, which is available for free download from the LPB website.

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