

SIESO Medal

Popcorn polymer – the forgotten threat that keeps coming back

Asma Al Badri, Asma Al-Farsi & Danah Allihyani, University of Sheffield, UK

Summary

On Wednesday 27 November 2019, a catastrophic explosion and series of fires took place at the TPC Group plant in Port Neches, Texas. The incident led to widespread damage, the evacuation of over 60,000 residents, and significant regulatory and legal consequences. The physical failure was caused by the uncontrolled formation of popcorn polymer within the butadiene unit, which ruptured a pipe and released butadiene gas. The main systemic failures that led to this massive event included the lack of identification and control of hazards in non-operating piping sections ("dead legs"), poor prevention and control of polymer formation, the absence of remotely controlled emergency isolation valves, and the failure to implement previous safety recommendations. Collectively, these lapses point to a fundamentally flawed Process Safety Management (PSM) system, which failed to identify and control known hazards, reflecting a deficient safety culture within the facility.

Keywords: Popcorn polymer, dead leg

Introduction

A horrific incident at TPC Group's operating facility, caused by popcorn polymer, resulted in \$450 million in on-site damage and the indefinite shutdown of the butadiene unit. It left several workers and members of the public injured and led to the evacuation of thousands of people within a 6.4 km radius of the facility, as well as \$153 million in off-site property damage to nearby houses and businesses. The release occurred due to the development and expansion of a popcorn polymer in a dead leg within the butadiene process unit. This caused a pipe to rupture, releasing highly flammable butadiene, which quickly ignited, triggering multiple explosions. The explosions caused at least four columns to collapse, including a distillation column that was launched within the facility, resembling a missile in flight. Throughout 2019, the TPC butadiene unit faced a significant number of popcorn polymer formations and equipment plugging.



Figure 1 – Popcorn polymer in manhole (Credit: International Institute of Synthetic Rubber Producers Inc.)

Context and incident

The catastrophic incident resulted from popcorn polymer that had accumulated inside a dead leg in the piping system for at least 114 days without detection or intervention by the facility team. Popcorn polymer is an accidental byproduct from a chemical process that involves high purity butadiene (which is the main product of the facility) reacting with oxygen forming porous resin. It is a hazardous phenomenon because of its ability to grow rapidly and may generate high pressure that can rupture the equipment. A dead leg is created when the primary pump is taken out of service and replaced with a backup pump to continue the operation, leaving a section of piping open to the process without any material flowing through. The potential hazard associated with the dead leg was not identified nor controlled. Notably, the pump repair had originally been classified as "urgent" but was subsequently downgraded to "routine" on the basis that a spare pump was available – a decision that effectively obscured the process safety risk created by the resulting dead leg.

This pattern reflects a broader process safety management weakness identified by the CSB – the facility's maintenance

* 1,3-Butadiene (C_4H_6) is a conjugated diene and an important industrial chemical. It is a colourless, highly flammable gas produced primarily from petroleum-derived feedstocks. Its structure consists of alternating single and double carbon-carbon bonds, which gives it useful chemical properties for industrial applications.

Butadiene is used mainly as a monomer in the production of synthetic rubbers and plastics through polymerisation. Materials derived from butadiene are used in a wide range of products, including vehicle tyres, automotive components, and impact-resistant plastics used in consumer electronics. As a result, butadiene is an important raw material in the manufacture of many durable commercial and industrial products.

system prioritised operational continuity over process safety risk, with the pump's offline status treated as production concern rather than a hazard trigger. As the CSB concluded, TPC PNO did not have an effective safety management system capable of recognising when a deviation from normal operating conditions, such as an extended equipment outage, created a safety critical situation. The failure to act on precautionary measures such as prioritising the pump repair, purging the piping, or adding popcorn polymer inhibitor to the dead leg is therefore more accurately understood as a management and system-level failure rather than the shortcoming of any individual worker. In late 2016, the Process Hazard Analysis (PHA) team recommended implementing a monthly flushing requirement for lines associated with out-of-service equipment; however, this critical safety measure was never implemented. Although the butadiene unit was experiencing exceedingly high levels of hazardous popcorn polymer formation prior to the incident, the facility management had failed to take the necessary action of shutting-down and cleaning the pipes.

Process fluid continued to escape from the ruptured equipment, contributing to further explosions and fires that burned uncontrolled for more than a month.

The failure to isolate the flammable inventory remotely redefined what might have been a contained incident into a catastrophic event which affected both the facility and surrounding community.

Investigation and analysis

The investigation of the incident began by examining physical evidence, such as the ruptured pipe, reviewing TPC safety documents, and interviewing the plant's employees. Metallurgical testing confirmed that the pipe failed by a longitudinal rupture due to internal pressure exceeding its structural limit. A critical review of the Process Hazard Analysis (PHA) revealed number of shortcomings. The PHA team failed to identify the potential consequences of popcorn polymer accumulation and the resulting piping failure. Furthermore, the team did not identify the potential consequences of the spare

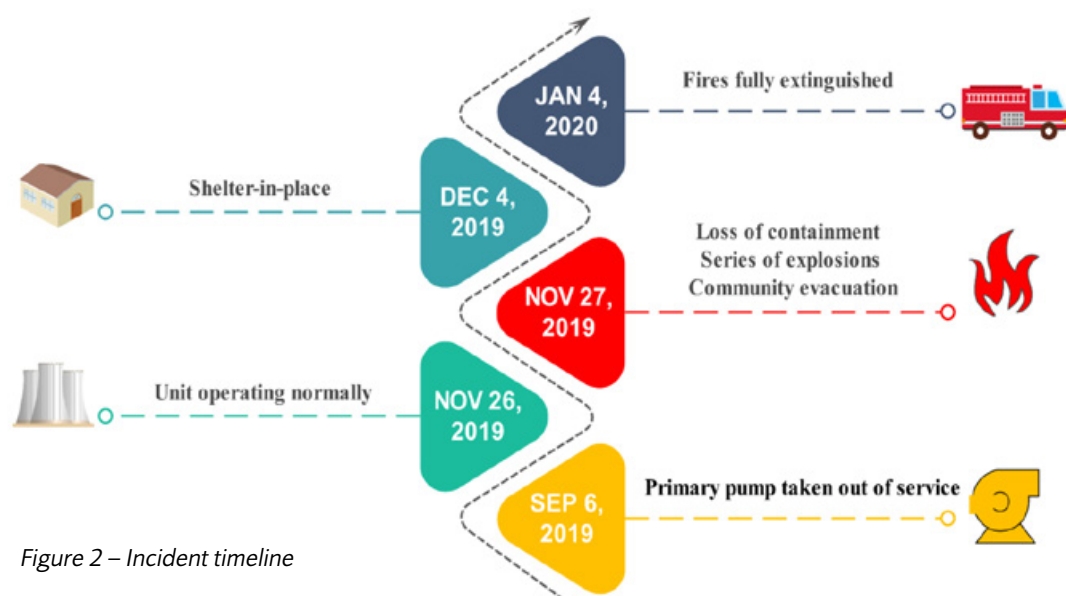


Figure 2 – Incident timeline

Through a chain of chemical reactions, the popcorn polymer developed rapidly inside the dead leg, continuously expanding and building pressure against the confined piping walls. As the accumulated pressure surpassed the pipe's structural capacity, it caused the section to rupture catastrophically.

When the piping ruptured, highly flammable butadiene was released and quickly ignited, creating an initial explosion. The explosion produced a pressure wave that was powerful enough to destroy portions of the facility and injure three TPC workers, and damage nearby homes and buildings up to 30 miles away from the facility.

Once the incident began, it became too dangerous for employees to access and operate the manual emergency shutoff valves installed at the facility. In the absence of remotely operated emergency isolation valves, personnel were unable to neither stop nor limit the initial release from the ruptured piping or shut down other facility sections from a safe location.

pump being out of service, including the possibility of dead-leg formation. The 2016 PHA recommended implementing a flushing program for out-of-service equipment in the butadiene unit. This measure would likely have prevented the polymer buildup; however, the recommendation was never implemented. Moreover, the review found that insufficient consideration had been given to installing remotely operated emergency isolation valves, which could have helped contain the incident and limit the release of fuel following the initial rupture.

Environmental impact

Fires lasted for more than a month, causing severe environmental damage. The impacts were devastating from intense air pollution and contamination of nearby water resources to soil depletion caused by residue and ash, as well as increased greenhouse gas emissions that led to ecological stress.

Process safety management system gaps

Inadequate understanding of hazards and risk

Dead legs pose a serious hazard as they can become sites for popcorn polymer formation, leading to clogs or even equipment ruptures. TPC failed to establish procedures to identify, control, and eliminate dead legs, and did not adequately assess nor understand the potential consequences associated with popcorn polymer formation.

TPC lacked proper internal procedures to guide employees on the required actions in the event of high level of popcorn polymer formation, and decisions were left to the discretion of site workers due to the absence of clear instructions.

Failure in managing risk

- **Management of Change:** The catastrophic event was largely driven by several simultaneous and poorly managed process changes introduced by TPC in early 2019. Two critical alterations were made simultaneously – the bypass of the water wash tower (which removes oxygenated impurities that catalyse popcorn polymer formation), and a significant reduction in the dose of the DEHA chemical inhibitor (used to suppress polymer growth). These changes effectively eliminated two critical safety barriers against uncontrolled polymerisation. Both were implemented without adequate management of change reviews or a thorough safety assessment of their combined impact.

Consequently, the butadiene unit experienced a rapid and hazardous increase in polymer formation in the subsequent months, which propagated downstream. Importantly, the inhibitor dose reduction was assessed solely from a product quality perspective, without adequately considering the minimum concentration required to maintain process stability and prevent polymerisation.

- **Asset integrity and reliability:** Maintaining asset integrity in the butadiene industry requires continuous monitoring and maintenance to ensure that equipment remains free of internal blockages and degradation, such as popcorn polymer formation. In this incident, a non-operated pump and connected piping created a dead leg that was unmonitored for months. This highlights that robust inspection, flushing, and reliability programs are essential components of asset integrity management.
- **Emergency management:** The manually operated valves installed at the facility proved unreliable during the catastrophic event, as they could not be safely accessed in the event of a release or fire. This highlighted the importance of installing remotely operated emergency isolation valves to enable safe and immediate shutdown of releases.

Failure in learning from experiences

Based on previous incidents, CSB issued recommendations regarding popcorn polymer incidents in 2009. It demanded the pipes linked to the inactive equipment in high-purity butadiene service to be flushed every month. This recommendation was not put into practice, which might have helped to reduce the formation of popcorn polymer inside the dead leg formed by the inactive primary pump. Moreover, learning from similar

events across the industry could have prevented this catastrophic outcome. For instance, a popcorn polymer-related incident occurred in Baytown, Texas, in July 2019, just months before the Port Neches explosion. Such repeated events highlight that lessons from our own and others' experiences must be actively shared and applied, rather than waiting for similar incidents to recur.

Conclusion

To conclude, the fires and explosions at the TPC Group operations facility on 27 November 2019, were a devastating incident that lasted for more than a month. Although the facility had already observed increasing growth of popcorn polymer within the plant, no preventive actions were implemented, ultimately contributing to the escalation of the situation. However, this incident raised awareness across multiple sectors, including health and safety and polymer research, particularly regarding butadiene. Ultimately, it served as a valuable learning experience for professionals in the field.

The incident highlighted critical weaknesses in several elements of the process safety management system: hazard identification, risk evaluation, asset integrity, emergency management, and learning from experience.

In the end, the TPC explosion is a strong reminder that maintaining safe operations requires proactive hazard identification and management, as well as the integration of process safety culture at all levels of the organisation. The lessons from this catastrophic incident should form the basis for strengthening the future safety system, ensuring compliance with industry standards, and preventing the recurrence of similar events.

For a detailed visual account of the incident sequence and key findings, the CSB documentary video provides a useful companion to this account (CSB, 2023).

References

1. U.S. Chemical Safety and Hazard Investigation Board. (2020, October 29). *Factual update: Fires and explosions at TPC Group Port Neches Operations facility, Port Neches, Texas* (No. 2020-02-I-TX). <https://www.csb.gov>
2. U.S. CSB (2023) *The danger of popcorn polymer: Incident at the TPC Group Chemical Plant*. <https://www.youtube.com/watch?v=6-3BFxpBcjC>
3. U.S. Chemical Safety and Hazard Investigation Board. (2022, December 14). *Final investigation report: Fires and explosions at TPC Group Port Neches Operations facility, Port Neches, Texas* (No. 2020-02-I-TX). <https://www.csb.gov>
4. Agency for Toxic Substances and Disease Registry (ATSDR). (2020). *Draft toxicological profile for 1,3-Butadiene*. U.S. Department of Health and Human Services, Public Health Service
5. National Center for Biotechnology Information (NCBI). (2016). *1,3-Butadiene*. In *Chemical Agents and Related Occupations*. NCBI Bookshelf.
6. International Institute of Synthetic Rubber Producers Inc., *Butadiene Popcorn Polymer Resource Book*, 2006
7. Bureau for Analysis of Industrial Risks and Pollution (BARPI) (2016). *Hazards identification and assessment – using lessons learned from accidents*. *Loss Prevention Bulletin*. [online] Available at: <https://www.icheme.org/media/2090/1pb250pg25.pdf>