Explosion inside an isomerisation unit

March 23, 2005

Texas City

United States

Explosion
Refinery
Isomerisation
Gasoline
Facility start-up
Maintenance
Victims
Property damage
Organisation / management

THE FACILITIES INVOLVED

Site description:

This refinery, America's third largest, was transforming 470,000 barrels of crude oil a day, a volume that represented 3% of the country's entire output. Renowned for its sophisticated layout, this facility contained some 30 refining units, encompassing a very broad array of activities. The site, originally built in 1934, covered a land area of 480 ha.

The refinery was being supplied for 30% of its input materials by pipeline, while ship transport accounted for the other 70%. Finished products were transported out of the plant by means of 3 pipelines (for 75%) and the remainder was loaded onto ships.

At the time of the accident, the facility employed a workforce of approx. 1,800, and another 800 subcontractors were engaged onsite. The organisation and management of both the site and the parent oil group had undergone major modifications over the previous years.

The involved unit:

The isomerisation unit, introduced at the site in the middle of the 1980's, served to transform light naphtha compounds made of C5 and C6 fractions with a low octane index (on the order of 67-70) into gasoline with a high octane index (83-85). This reaction is primarily intended to transform *n*-paraffins into iso-paraffins: the operation performed is slightly exothermic.

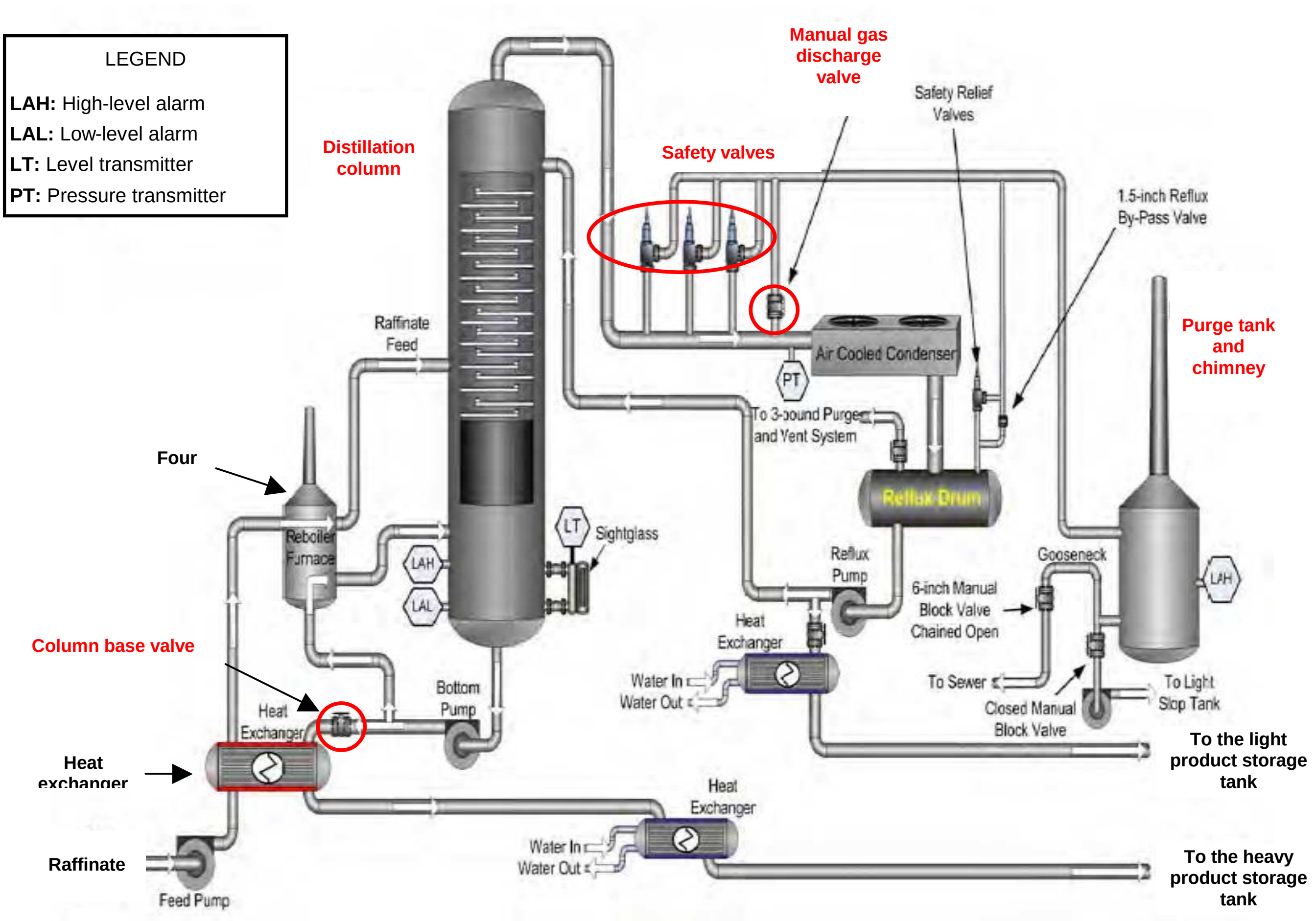
In geographic terms, the unit was located on the western part of the site, some 150 to 200 m from the property line of the refinery, itself located within the Texas City industrial complex.

The unit involved in this accident was composed of 4 sections:

- a gasoline "splitter" (or separator) introduced after the gasoline stabilisation phase to separate the heavier fractions (used for mixes or in petrochemical applications) from the lighter fractions, routed towards the hydrotreatment section and then isomerisation;
- hydrotreatment, where impurities such as sulphur and nitrogen compounds are removed from the chemical load, so as to avoid "contaminating" the catalysts used subsequently during the process, at the isomerisation stage;
- isomerisation reactor: this section hosted the stage of gasoline conversion into a product of a high octane index through contact with a catalyst, i.e. platinum in the case of this specific unit;
- a separator for gases recovered during the process, for the eventual purpose of mixing with the isomerate.

Some equipment used in the unit had been undergoing maintenance every year or every other year. The catalyst was scheduled to be changed every 10 years, with the most recent catalyst replacement at the Texas City facility having been performed in February 2005. This type of operation would entail a two-week assignment for a workforce of 20.

The accident occurred at the level of the unit's gasoline separator part (see diagram on the following page). The separator comprised, among other things, a simple fractionating column 54 metres high, containing 70 distillation trays, encompassing a volume of 580 m^3 and capable of supplying up to 7,155 m^3 of light crude product per day. This installation also featured a blow-down tank associated with a chimney stack directly open to the atmosphere. Introduced at the refinery during the 1950's, this equipment was designed to receive mixes in the liquid state and/or hydrocarbon vapour stemming from both the backup purge systems and drain valves; it was also equipped with a high-level alarm.



<u>The isomerisation unit's separation column</u> (Source: CSB)

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

On the day of the accident, several units at the site were shut down. The isomerisation unit was being restarted after 2 weeks of down time for maintenance: the assigned personnel were working on bringing the splitter back on-line, with the other components of the unit at various stages of the restart process.

Within the immediate vicinity of the isomerisation unit, three other units were also in a shutdown phase or had just been placed back into service. As a result of these downtime periods, the subcontractors' onsite quarters were set up close to the isomerisation unit.

At 2:15 am, technicians began inputting the load, which consisted of highly-flammable hydrocarbons, into the raffinate separation column. The liquid level at the base of the column during normal operations is approx. 2 m. The level indicator installed with a control room relay had been designed to measure levels of up to 3 m maximum. Beyond this height, the control room technician would not able to work with the product height actually in the column.

At 3:09 am, the first alarm indicated a high level, although the second backup alarm did not get triggered.

At 3:30 am, the load input procedure was halted and the indicator displayed a level of 3 m, even though the actual level at this time was in fact 4 m.

At 5:00 am, the night-time technician, who was supervising the isomerisation unit's restart operations in a secondary control room, left his station a full hour prior to the scheduled end of his shift after quickly informing the main control room technician of the state of progress in the restart routine.

At 6:00 am, the day shift technician assumed his main control room post and held a quick debriefing with the night-time technician, who then left the post at 6:23 am; no specific instruction relative to the isomerisation unit start-up and no indication of the height of product inside the separation tower was recorded in the log book.

At 7:15 am, the supervisor took up his post in the main control room, one hour late due to personal reasons.

Around 9:50 am, technicians initiated circulation of the load and proceeded to add liquid into the column, which was already filled with an excess amount of product, while the column output control valve was set in the closed position (as per the applied start-up procedure). Consequently, the entire load was re-circulated and the level in the column continued to rise.

Around 10:00 am, technicians turned on the furnace burners to reheat the load, as specified in the procedure, even though the height of liquid in the column was 20 times greater than the normal level (i.e. approx. 42 m); at the time, the control room indicator was displaying a level of less than 3 m.

At 10:45 am, the supervisor left his post to attend to a family emergency, thus leaving the control room technician on his own responsible for managing three refinery units, including the isomerisation unit. Since 1999, for economic reasons, the refinery had cut the second supervisory post from the payroll.

At 12:40 pm, a high pressure alarm was activated and two burners were turned off in order to bring the temperature down. The pressure control valve was no longer operating properly; failing to understand why the alarm sounded, a technician opened a manual valve to proceed with a discharge of gas towards the blow-down tank connected to atmosphere.

Then around 1:00 pm, technicians opened the valve at the column base to evacuate liquids in the direction of the storage tanks. However, since these very hot liquids were crossing by an exchanger and in turn heating the column intake, the column reached a temperature of above 150℃. This valve located at the column base should have been opened several hours earlier, in order to discharge the liquid gradually as raffinate was added, but such a step did not take place due to the erratic transmission of information among the various technicians.

Around 1:05 pm, the liquid contained in the column reached its boiling temperature, and its expansion further increased the level inside the column.

At 1:10 pm, the liquid overflowed the column and accumulated in the vertical ducts, exerting strong pressure at the level of the 3 exhaust valves located 50 metres below.

At 1:14 pm, these 3 valves were opened to allow the isomerate to flow towards the blow-down tank positioned at the other end of the isomerisation unit; without an operable high-level alarm, the tank completely filled and the product was sprayed via the chimney for about 1 min. A flammable cloud formed and spread over a large part of the unit.

At 1:20 pm, the running engine of a utility truck parked approx. 8 m from the blow-down tank ignited the cloud, thus sparking an initial explosion of the "Unconfined Vapour Cloud Explosion" type, followed by a fire. Witnesses reported seeing flames rise as high as 20 m. A black cloud of smoke, visible several kilometres away, formed above the site. The blast from the explosion was also felt over a several-kilometre radius.

Fire-fighting crews needed 3 hours to finally control the ensuing blaze.

Consequences of the accident:

The toll from this accident was very heavy, accounting for 15 deaths among the subcontracting personnel and 180 injured: 70 company employees and 110 subcontractors from 13 firms. A total of 66 individuals were seriously hurt, 20 of whom required lengthy hospitalisations (12 for stays of more than 3 days). The other injury victims who underwent hospital examinations were allowed to return home the next day.

According to various witness accounts, the victims were not working directly inside the refinery's isomerisation unit but were actually attending a scheduling meeting on the shutdown of the high-performance cracking machine within one of the prefabricated premises installed for subcontractors. These premises, located about 100 m from the isomerisation unit, were heavily damaged by the explosion and subsequent fire, as was the building housing the catalysts.

A representative of the local medical authorities indicated that the injuries observed were basically traumas due to the explosion and flying debris.

Moreover, the authorities requested 43,000 local residents to remain indoors for an hour; dwellings up to 1.2 km beyond the site sustained damage and deterioration.

174 m³ of high-gravity, gasoline-based chemical fractions spilled from the separation column: 166 m³ flowed into the plant's sewer system via gooseneck-shaped discharge pipes; the valve was left open, and 8 m³ overflowed from the blow-down tank stack.

From an equipment standpoint, damage was considerable not only in the isomerisation unit, but also at the level of the storage zone, 80 m away, where over 50 tanks were damaged. Except for isomerisation, the refinery's other units continued to operate normally.

The European scale of industrial accidents:

By applying the rating rules of the 18 parameters on the scale officially adopted in February 1994 by the Member States' Competent Authority Committee, which oversees application of the "*SEVESO*" directive on handling hazardous substances and in light of available information, this accident can be characterised by the following 4 indices:

The parameters composing these indices and their corresponding rating protocol are available on the following Website: http://www.aria.developpement-durable.gouv.fr

The "Quantity of hazardous materials released" parameter was rated at a "3" since the explosion effects, i.e. broken window panes up to 1.2 km away, corresponded to a quantity of explosive substance equivalent to one tonne of TNT (parameter Q2). The 174 m³ of discharged raffinate corresponded to a level 2 (parameter Q1: 0.56% of the 25,000-tonne upper tier of the *Seveso II* Directive).

The "5" value assigned to the "Human and social consequences" parameter reflects the 15 fatalities and 180 injury victims (66 in serious condition) among employees and subcontractors (parameters H3, H4 and H5).

Given that the environmental consequences of the accident were not formally evaluated, the corresponding index could not be rated.

The "Economic consequences" index was scored at a "6": the financial losses associated with this accident wound up exceeding $1.5 billion, with the operator required to pay out $1.6 billion to accident victims along with a $21 million fine.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The "Chemical Safety Board" (CSB), an independent American federal agency, conducted an onsite investigation to determine the causes of this event and issued a set of recommendations for reducing the probability of occurrence of such accidents. The Board's final report, released on March 23, 2005, provided a very thorough account of the fundamental causes of this accident; the report's primary elements will be presented below.

This tragic accident was the direct consequence of a good number of deficiencies, namely:

1. To initiate operations on the isomerisation unit, the column base valve had to remain open so as to channel the heavy phase to the storage tanks. Since this step had not been performed due to the conflicting guidelines addressed to technicians, the column filled for more than 3 hours and then spill over, causing safety valves to open and then the blow-down tank to fill and overflow. This sequence of events was made possible by a combination of several operational malfunctions:

    - The level indicator with control room relay had been designed to measure no higher than a 3-m level. Beyond this height, the control room technician had no benchmark to assess product height in the column.
    - The column level indicator indicated that the column was emptying even though it was in fact being filled. The backup high-level alarm did not sound and the column was not fitted with an automatic security system.
    - The control console did not provide information easily interpreted by the console technician, thus complicating notification that a hazardous threshold had been breached.
    - The lack of monitoring and trained personnel at the time of unit start-up, which happens to be a highly intricate phase, was not compliant with the set of safety-based recommendations. No control room technician was assigned to assist the technician who had already begun his shift despite specific recommendations issued upon initiating isomerisation unit operations.
    - Technicians and supervisors failed to sufficiently communicate on the ongoing unit start-up operations during shift changes, since the industrial group responsible for operating the site had no requirements in place regarding such communication among staff technicians.

- Isomerisation unit technicians had been assigned to 12-hour shifts for over 29 consecutive days running.
- The technician training programme was inadequate: the head office training division staff was cut from 28 to 8; and the unavailability of simulators prevented technicians from gaining experience in managing abnormal situations (less frequent and high-risk operations, like unit start-up and loss of unit control).
- Start-up procedures that had not been updated and did not consider the kinds of recurrent problems encountered during start-up, thus leading technicians to freely make modifications, to a point of noncompliance.
- On March 22, the refinery production planning department requested placing the column back into service even though it was already known to experience malfunctions (i.e. column level indicator, blow-down tank level gauge, pressure control valve), and moreover both the repair work on a corroded line and tower instrumentation verification according to the intended procedure had not yet been completed.

2. The dimensions of the blow-down tank were too small to contain the product once the safety valves had been opened. A feasibility study on installing a safety system had been initiated yet never completed.
3. The purge tanks fitted with an atmospheric chimney were not replaced on any of the group's sites, despite their obsolescence, though a series of accidents had already demonstrated that these facilities were indeed hazardous. As of 1992, the occupational health and safety administration (OSHA) had been recommending connecting these tanks to flares. The standards adopted by the refinery's industrial group also called for their replacement once major modifications started taking place on the unit. In 2002, refinery engineers proposed connecting the blow-down tank of the isomerisation unit to a flare; however, a less expensive solution was ultimately selected.
4. The prefabricated premises occupied by subcontracting crews were installed too close to a unit that used hazardous substances. All accident victims happened to be located in or near these premises.
5. During the years preceding the accident, flammable liquid had on eight occasions escaped from the unit's blow-down tank chimney, and nearly all unit start-up procedures had led to high liquid levels inside the column. The parent industrial group had not investigated any of these incidents.
6. Refinery managers failed to ensure that only those personnel specifically assigned to the unit were actually in the vicinity at the time of start-up.

A number of much more serious organisational breakdowns, responsible for major lapses in refinery safety and deteriorated operating conditions, could also be highlighted:

- Cost cutting, scarce capital investment, and production pressures exerted by the oil group's managing directors all served to compromise plant safety.
- Neither process safety nor risk management were included in the set of refinery management priorities or objectives. None of the Group's Board members were assigned to monitor performance of the site's safety awareness or the implementation of prevention programmes intended for major accidents.
- The confidence derived from the low workplace accident rate was not commensurate with either a realistic assessment of safety system performance or the absence of a *bona fide* safety approach.
- The inadequacies and poor anticipation built into the maintenance programme led to compound deficiencies on the equipment.
- Refinery management did not promote acquiring and maintaining a culture turned towards communication, information and knowledge sharing among the site's various hierarchical levels; moreover, feedback on incidents and near-accidents was not being taken into account. Key safety-related lessons, disseminated only after an accident occurred at a Group refinery in Scotland, had not been applied at the Texas City site.
- Over time, the working environment at the plant had deteriorated, as characterised by a resistance to change as well as a lack of employee confidence and motivation.
- Technicians were inclined to systematically indicate on all control documents and checklists that the required operating and safety conditions had been satisfied even if such was not the case.
- The objectives, reward system and campaigns relative to safety were oriented around improving individual performance in terms of workplace accidents and technician behaviour rather than around process safety and management systems.
- The little attention paid to improving the plant's risk management system led employees to accept working under increasingly hazardous conditions.
- The loss of interest in safety on the part of executive staff was responsible for not remedying a deficient warning system and a poor organisation of control protocols.
- A wide array of audits, studies and investigations had previously identified severe safety problems at the refinery, yet Group executive responses were, at all levels, both insufficient and belated.

- The organisational changes introduced at the industrial facility, along with the procedures in place defining professional exchanges among personnel, associated with communication lapses, caused confusion and errors in assigning roles, responsibilities and priorities to each post. The refinery operator had underestimated the impact of excessive modifications regarding safety steps.

ACTIONS TAKEN

The operator was in constant communication with the media, providing updates on the status of accident casualties, and moreover set up a counselling unit for victims' families and loved ones plus a logistics support unit. The operator continued to oversee the verification measures necessary both inside and outside the facility in order to evaluate and mitigate the impacts due to this accident.

On March 27, the U.S. Environmental Protection Agency issued a statement concluding that the local population was no longer exposed to any risk.

Subsequently, other measures were adopted at both the refinery and Group levels, including:

- Management shakeup
- Organisational streamlining
- Improved channels of communication
- Clarification of each post's roles and responsibilities
- Operational steps conducted in strict accordance with written procedure
- Creation of a team assigned to implement the new set of rules
- $1 billion to be invested over the period 2006-2011 on plant modernisation, featuring:
    - introduction of a new process control system
    - transition to a more efficient safety management system
    - higher-quality technician training programmes
    - removal of chimney stacks on the purge tanks
    - renovation of the plant's primary units.

Three organisations, i.e. the Chemical Safety Board (CSB), the Occupational Health Safety Administration (OSHA) and Paper Allied Chemical Employees (the PACE union), investigated the accident. It should be pointed out that technicians and emergency service crews had altered the position of valves and isomerisation unit equipment for safety purposes. These manipulations prevented investigators from knowing the exact status of installations just before the accident.

As part of the recommendations issued by CSB, the oil group operating the site assigned an independent commission to evaluate and propose a set of recommendations for improving not only safety oversight but also safety awareness at this site and the Group's four other refineries. This commission published its final report in January 2007, emphasising the following:

- Upgraded process safety management
- Introduction of a comprehensive and integrated safety management system capable of identifying, mitigating and controlling (both systematically and continuously) the risks inherent in refining activities at these sites
- Implementation of an operational procedure to ensure that all personnel, from plant management to technicians and including subcontractors, possess the requisite level of knowledge and expertise in the area of process safety
- Involvement of all stakeholders in pursuit of developing a shared corporate culture that promotes safety as part of positive and secure processes
- Expression of expectations and reinforcement of responsibilities in the area of process safety at all levels within production management teams
- Scheduled audits of the process safety management system.

LESSONS LEARNT

This event has served to highlight a number of pivotal aspects to be improved regarding plant management and organisation that are indeed applicable across many industrial sectors:

- ✓ A stable and comprehensible site management strategy with clearly defined and well-balanced responsibilities
- ✓ Coordinated communication flows and permanent dialogue between executive and technical personnel, between crew foremen and workers, with an emphasis on avoiding conflicting procedures and incorporating the various remarks, difficulties and proposals for improvement input by all staff members
- ✓ Involvement and recognition of all process actors
- ✓ A sustained and widely promoted corporate culture built around safety
- ✓ A clear set of up-to-date procedures and guidelines, with verification of their effective application
- ✓ Requirement that certain plant operations only be conducted in the presence of a certified inspector
- ✓ Safeguard of information relayed during shift change in order to ensure continuity of all ongoing operations
- ✓ Technician training on the emergency measures to be implemented in the event of a loss of unit control or other incident
- ✓ Access to the zone around hazardous units authorised only to those personnel necessary for unit operations, maintenance and monitoring
- ✓ Preventive equipment maintenance to eliminate the possibility of repeat deficiencies
- ✓ Analysis of incident causes and inclusion of feedback from events occurring not only at the same site but on other similar facilities as well
- ✓ Importance of measures dedicated to process control, safety and alarm systems, all of which must be considered, to the same extent as the production units themselves, as vital components that need to be efficient, regularly tested and well maintained.

This dramatic accident has very painfully illustrated the decisive role and responsibility of the executive team and staff management, both at the given industrial site and at Group head offices, in ensuring an effective safety oversight system for industrial installations. In Texas City, priority had been placed on productivity, while diverting attention away from the other values bonding the production team, such as the focus on safety, organisational comprehension and overlap of skill levels with corporate hierarchy. Moreover, the barriers that help limit the probability of accident occurrence fell one after the other, leading to a highly compromised operating environment. Heightened vigilance, especially in difficult economic times or during a major organisational reshuffling, proves essential to maintaining a satisfactory level of safety.

Information sources:

- CSB Investigation Report: "Refinery explosion and fire in Texas City", released on March 23, 2005.
- CSB video: "Anatomy of a disaster", www.csb.gov
- Refinery operator's investigation report: "Fatal accident investigation report, Isomerization unit explosion - Final report", released on December 9, 2005.
- Interim investigation report by the refinery operator: "Fatal accident investigation report, Isomerization unit explosion", May 12, 2005.
- Chemical Safety Board Website: www.csb.gov
- The refinery operator's Website, press releases.
- Information published both in the press and on the Internet.

Selection of detailed accident records in the database involving refineries:

- ARIA 19423 - Explosion in a cracking unit at a refinery site in Gonfreville l'Orcher (76), on September 3, 2000
- ARIA 23524 - Ignited leak in a gasoline hydrotreatment unit at a refinery in Grandpuits Bailly Carrois (77), on November 17, 2002
- ARIA 27459 - Fire in a hydrodesulphurisation unit of a refinery in Feyzin (69), on June 26, 2004
- ARIA 30406 - Discharge of hydrocarbons through valves on the atmospheric distillation column of a refinery in La Mède (13), on August 7, 2005
- ARIA 33637 - Fatality by asphyxiation at a refinery in Delaware City (United States), on November 5, 2005

Many other detailed accident records are available for consultation on: www.aria.developpement-durable.gouv.fr