Explosions involving water and molten metal


Source exploitant

⑤ Explosion in a cast iron foundry

ARIA 31881 - 15/05/2006 - 08 - VIVIER-AU-COURT

24.51 - Cast iron foundry

In a cast iron foundry that alternates the use of two cupola furnaces every other day, an explosion occurred at 6.30 pm during furnace unloading (carried out via hatches placed underneath the furnace) of meltdown products into a tub. Coke, cast iron and slag were all strewn throughout the building and 30 m² of roof were destroyed. Emergency services were notified and all company personnel had to be evacuated. Positioned 10 m from the cupola furnace and equipped with a powerful hose to spray these products with water should a fire break out, an employee suffered burns to the face and arms and required 4 days of hospitalisation; a second employee went into shock and received treatment from fire-fighters at the scene. According to the operator, a water / molten metal reaction would have caused the accident. The refractory cement enclosing the recovery tub had been set up the very same morning; moreover, the cement drying time was insufficient. The cost of material damage was estimated at 10,000 euros. A number of technical and organisational measures were adopted to limit the risk of a repeat accident: acquisition of 3 new tubs to ensure better alternation of equipment with adequate drying time for the refractory cement (36 hours); storage of tub contents in a zone protected from water; drying, by use of a gas burner, of the tub designated to receive the day's furnace drop; installation of a sound alarm intended to warn personnel during the time of manipulation; updating of the list of individual protective gear (sorted by either specialisation or workstation); layout of an identifiable protection zone; and assignment of a staff member to unload the furnace as well as rewrite the procedure.

Explosions involving water and molten metal

Explosions triggered by contact between water and molten metal are well-known accidents within the metallurgical industry and in some cases lead to significant human and material impacts. The ARIA database has inventoried some fifty events of this type involving molten metals, of both the ferrous and nonferrous variety.

Uncontrolled water / molten metal contact is capable of causing vapour explosions, a strictly physical phenomenon resulting from the vapourisation of water, with projections of liquid metal and a volumetric expansion that creates pressure waves; when exposed to the open air, the water / vapour transformation leads to volume increase by a factor of 1,700.

This contact may also give rise to oxidation-reduction reactions, which in turn generate hydrogen that subsequently burns as it is being produced (ARIA 4525) or that causes a very powerful explosion (ARIA 34800) with effects comparable to exploding several kilogrammes of TNT (resulting in an equivalence of 1 kg of TNT for just several tens of millilitres of water reacting with molten aluminium). In the presence of carbon (steels, cast iron), carbon monoxide emissions with explosive potential may also be released.

A number of phenomena, of both physical and chemical origin, arise at high temperature:

- ✓ Liquid H_2O → vapour H_2O (volumetric expansion due to the change in physical state)
- ✓ Reducing metal + H_2O → oxidised metal + H_2
  then $H_2 + ½ O_2$ → H_2O (explosion resulting from combustion with the oxygen contained in air)
- ✓ $C + H_2O$ → $CO + H_2$
  then $CO + ½ O_2$ → CO_2 (explosion resulting from combustion with the oxygen contained in air)

The circumstances of these explosions are apparent in all production phases: when melting inside a furnace (ARIA 23912, 27316), subsequent to metal casting in ingot moulds or ladles (ARIA 17205, 17548), upon discharging slag (ARIA 8640, 34527), and lastly during the transport of metal ladles (ARIA 23317). The prevention of these kinds of events requires an exhaustive risk analysis of each operating phase.

Organisational and human deficiencies contribute considerably to the occurrence or exacerbation of such events. Dropping a liquid steel ladle following inappropriate handling or stowage and inadequate controls (ARIA 28574), feeding the furnace with a wet load (ARIA 34239, 34513), massive casting of molten copper within a quenching tank (ARIA 3924) all serve to illustrate this recurring hazard. A set of adapted operating procedures and recommendations, in conjunction with the steps of dissemination and compliance among technical staff and contractors, and personnel training in risk management constitute the basic rules applied to limit the occurrence of these anomalies. Observed equipment deficiencies include worn refractory material (ARIA 8044) and/or cooling system leaks on installations (ARIA 4876), and leaky roofs (ARIA 22976); these provide examples, should it be necessary, of the need for a preventive maintenance programme to be properly coordinated (ARIA 26928, 33059) and the benefit of monitoring processes that introduce appropriate measures should anomalies be detected (ARIA 33059).

Exceptional causes, "external" to the facility, might also be the source of these water / metal contacts, as illustrated by the vapour explosion that occurred in Japan following the overturning of a metal railcar by a 15,000 m³ wave of water, which itself was caused by the sudden bursting of a gas-holder (ARIA 104).

In some cases, the human toll is of alarming proportions; 5 employees killed and 5 others injured in a steel foundry (ARIA 29633), 5 dead and 4 seriously hurt at a ferromanganese production plant (ARIA 34276), 1 death and 1 injury in a steel mill (ARIA 3512) are indicative of the severity of this risk. In addition to human casualties from accidents, the physical damage as well as operating losses can be sizeable (ARIA 28574), and the ensuing facility renovation works can disrupt operations and force layoffs for a number of weeks (ARIA 5663).
The introduction of containment cells for operator's protection (ARIA 17552, 29851), mandatory wearing of suitable protective gear by staff (ARIA 17548) and strict limitations on the number of individuals circulating within high-risk zones (ARIA 34513) offer a sample of measures taken to mitigate the consequences of accidents for personnel.

A violent phenomenon with potentially dramatic impacts, a "water / metal explosion" deserves special attention from facility operators. Compliance with the rules of good engineering practice for furnace operations and maintenance, coupled with effective management of all molten metal / cooling water interfaces and proper handling of infiltration/inflow (leaks, spills, etc.) are prerequisites for limiting the occurrence of such accidents. Achieving implementation of the corresponding set of preventive measures among all parties potentially involved in unit operations actually defines the level of risk prevention.

The accidents whose references are not underlined may be consulted at:
www.aria.developpement-durable.gouv.fr

ARIA 104 - 15/01/1989 - JAPAN - SAKAI / OSAKA-FU

24.1 - Steelmaking

As a result of a defective weld performed 15 years prior, cracking led to the sudden bursting of the water tank on a 35,000 m³ gas-holder and the discharge of 15,000 m³ of water and 25,000 m³ of gas containing a 70% concentration of CO. The CO cloud immediately ignited. The sheet of water overturned a railcar full of molten metal ("torpedo car" design) awaiting processing onsite and generated a vapour explosion. The metal projections then caused the fire to spread to 3 other buildings also part of the facility. The blaze was controlled in 3 hours thanks to a fleet of 17 fire-fighting vehicles. One injury was reported.

ARIA 3924 - 09/09/1992 - 33 - MERIGNAC

24.54 - Foundry for other nonferrous metals

Technician mishandling caused an explosion, resulting from the instantaneous vapourisation of quenching water subsequent to a massive casting of molten copper. Both the quenching tank and roof were destroyed. One facility employee was hurt and the furnace had to be turned off.

ARIA 4525 - 10/06/1993 - 38 - JARRIE

24.45 - Metallurgy of other nonferrous metals

During unloading of a furnace used for activating the reaction of zirconium tetrachloride (ZrCl4) on magnesium (Mg), an explosion occurred within a plant material handling zone that manufactures zirconium sponges.

Plant staff present at the time suffered hearing loss without perforation of the eardrum; the resulting material damage was phenomenal: 3,000 m² of plant siding and roofing, made of asbestos cement, were pulverised from the detonation blast; ditch cover gratings were projected 3 to 5 m into the air; the building door was torn off; hinges broken, etc. These damage observations suggest that the explosion represented the equivalent of 1 kg of TNT. The associated costs were estimated at 4.5 million francs.

The hypothesis of liquid magnesium flowing in a ditch that also contained equipment washing water was put forward. The explosion could have resulted from several simultaneous phenomena, including the formation of hydrogen by means of water decomposition, water vapourisation, and grinding of magnesium and its reaction with oxygen from air. An expert appraisal concluded however that only the thermal explosion (water vapourisation) could explain the level of damage recorded: the reactions of magnesium oxidation with water or air were contained; and the magnesium spill in the ditch served to generate hydrogen in a quantity proportional to the spill, with this fuel burning at a rate corresponding to its release at the ditch (given the presence of fire and sparking prior to the explosion).

The measures adopted to reduce the probability of recurrence of such an accident were as follows: creation of a metal retention structure for storing reaction cells after unloading while waiting for them to cool, temperature control by means of a temperature colour indicator before any handling, elimination of all washing channels and ditches in the plant that may contain water.

ARIA 4876 - 02/12/1993 - 78 - PORCHEVILLE

24.32 - Cold rolling of metal strips

At a steel mill, an explosion occurred inside an electric furnace following a water leak in a cooling circuit. The blast from the explosion tore off metal siding and broke a number of windows. Nine slight injuries were recorded along with some furnace equipment damage; 50 fire-fighters were called to the scene.

ARIA 8044 - 17/10/1995 - 55 - STENAY

24.52 - Steel foundry

A 1-tonne capacity electric induction furnace exploded inside a steel foundry without causing any casualties. The production loss was estimated at 400,000 francs per week of plant downtime. Water spraying onto the molten metal subsequent to heavy wear of the refractory material (despite having been inspected just a few hours prior), combined with the perforation of copper cooling tubes due to melting, were responsible for this accident. An independent body was contracted to investigate.

ARIA 17552 - 11/04/2000 - 78 - BONNIERES-SUR-SEINE

24.10 - Steelmaking

In an electric steel mill, once the furnace (capacity: 70 tonnes per casting) had been emptied into a ladle, an employee was called in to plug the drain hole, which represented the only operation still not automated. As the employee entered the "Dog House" (name given to the concrete enclosure surrounding the furnace), an explosion of vapourised water in contact with the molten steel occurred, killing him on the spot. The furnace was damaged: the cover became misaligned, and the vaulted chamber was projected several metres. A material defect (water leak on the cooling circuit) was the suspected origin. The premature entrance of the employee into the protective enclosure, even though the furnace had not returned to the normal position, would have been the fateful cause of the employee's death. A judicial investigation was conducted.

ARIA 26928 - 14/04/2004 - 87 - LE PALAIS-SUR-VIENNE

24.10 - Steelmaking

Around 7:30 pm, 5 or 6 vapour explosions in less than 60 seconds damaged the furnace (operating at 1,550℃) of a plant engaged in reprocessing industrial waste by means of pyrometallurgy techniques. The accident was caused by sudden contact between cooling water and molten metal and slag after perforation of the furnace sidewall due to refractory material wear; some 2 to 3 tonnes of molten metal and 35 tonnes of slag spread within the building. Three employees had to be hospitalised for hearing tests; one of them positioned 20 m from the point of explosion was diagnosed with a lesion on an eardrum, yet the condition was not found to be irreversible. Material damage was also observed: the 17-mm thick window pane on the facility's control room located 11 m from the explosion was destroyed, walls shaken without any collapse, broken glass and small-scale damage within a 40-m radius, melting of a portion of the collectors, damaged pipes, etc. The inoperable installations were secured. The inspectorate for hazardous facilities performed an investigation, and the expert appraisal evaluated the source term of the explosion to be 200 g of TNT, which corresponds to the abrupt pressure expansion from 55 to 1 bar of slightly more than 1 l of water at its maximum superheat temperature (270℃). Following piercing of the furnace (an opening 66 cm long by 15 cm high above the casting zone), the first explosion would have been generated from contact between a small quantity of water and molten material near the casting zone. The second blast erupted once this material arrived into the cooling water collector pipe from the furnace

casing (producing a thin liquid film inside the collector). The third explosion, which occurred 10 seconds after the first and according to witnesses was the most violent of the three, resulted from trapped water that had accumulated locally due to molten material flowing into pipe discharge zones. The other explosions were of much smaller magnitude and attributed to random water / melted material contact. The refractory materials refurbished in January 2004 were inspected; early abrasion subsequent to micro-fracturing following an assembly defect was cited for having prevented the creation of a sufficient dilatation space. Several measurements were taken: backup temperature measurements and their interpretation in the aim of preventing furnace perforation, confinement of potential water accumulation zones to avoid contact with molten material, issuance of guidelines laying out the set of operator actions and means for ensuring operator protection during accidental situations.

ARIA 28574 - 18/11/2004 - 57 - GANDRANGE

24.10 - Steelmaking

A 160-tonne ladle of liquid steel pivoted and then became unhinged around 3:00 am inside a steel mill; the accident occurred during ladle lifting by the rail-mounted bridge crane that connects the refining station with the continuous casting shop. The explosion was triggered when the molten metal made contact with the wet concrete shop floor outside the recovery ditch; fire-fighters extinguished the molten steel. An employee burned by the steel heat rays radiating at 1,500℃ had to be hospitalised, and 6 ot her employees are slightly injuried by explosion. Both the building siding and sheet metal protections on the adjacent workshop were blown out. The inappropriate positioning of one of the two hooks on the metal ladle and inadequate control (as specified in a recommendation) by the staff member assigned responsibility for verifying load fastening were the causes of this accident. The material damage was assessed at 500,000 euros, while production losses amounted to 700,000 euros.

ARIA 29851 - 16/05/2005 - 59 - GRANDE-SYNTHE

24.10 - Steelmaking

In a "*Seveso*"-classified hazardous installation, two explosions and the release of reddish smoke took place around 11:00 am during the casting of molten iron using a 450-tonne drum ladle wagon in a ditch at ground level. The technician stopped the spill. This casting step had been approved following detection of a flaw right at the wagon spout, which blocked normal transfer of the cast iron into straight ladles. Notified by numerous phone calls, fire-fighters advised onsite personnel on how to seek containment. No one was injured given that the casting control station was protected (bunker style) and a safety perimeter had been permanently marked off around the ditches. Water / molten metal contact was responsible for the accident; the excessively quick casting operation confined humidity from the tailings that composed the ditch bottom and caused the vapour to explode. The casting of residual 250-tonne loads, performed without incident around 12:30 pm, would nonetheless produce another reddish plume.

ARIA 33059 - 08/06/2007 - 78 - PORCHEVILLE

24.10 - Steelmaking

In an electric steel mill at 7:10 pm, the supervising operator of a melting furnace (70-tonne capacity) noticed blue flames from the surveillance camera images, interpreted as a sign of the presence of water in the furnace. He closed the safety hatch in front of the glass pane separating the control booth from the furnace enclosure and proceeded by requesting the evacuation of all personnel in the area. A powerful explosion occurred a few moments later upon contact between water and molten metal.

During the afternoon, a water leak had been observed on two cooling return tubes from the furnace crown; one was changed and in order to remedy the second, it was decided to activate the emergency return circuit. Since the water valve on this backup circuit had not been opened, a cooling system malfunction occurred and caused perforation of a tube and, along with it, water inflow into the furnace. Two employees sustained slight concussions and were taken to hospital; they were both released during the evening. The material damage was significant: collapse of doors on the "dog house" (furnace enclosure), broken crown suspension tie rods, projection inside the building of a portion of the smoke recovery device. The cost of this material damage was estimated at 1.64 million euros, with operational losses totalling 630,000 euros.

During its investigation work, the hazardous installations inspectorate recorded the following: an inadequate organisation of maintenance work specific to water supply pipes feeding the furnace crown (procedures, management of technical personnel, monitoring, etc.), onsite instrumentation unable to efficiently control either furnace crown cooling or water circuit function (no temperature or pressure variation measurement), and the lack of instrumentation on the backup cooling circuit. The operator commissioned an investigation by an independent body in order to elucidate the causes of this accident as well as determine both the technical and organisational measures to adopt for avoiding a repeat accident. The investigation also provided specifications for: backup circuit instrumentation, maintenance organisation overhaul, implementation of a hydrogen detector, and completion of a study on cooling circuit instrumentation to improve efficiency monitoring.

ARIA 34276 - 24/02/2008 - SOUTH AFRICA - CATO RIDGE

24.10 - Steelmaking

An explosion occurred on a Sunday morning in one of the blast furnaces of a ferromanganese production plant, destroying a wall of the facility control room; 5 employees died and 4 were seriously injured. According to the press, a water / molten metal contact could have caused the accident. Authorities then closed the plant to allow for the industrial inspection team to assess the level of installation safety.

ARIA 34513 - 25/04/2008 - 03 - COMMENTRY

24.10 - Steelmaking

An explosion took place around 3:00 am in a 28-tonne electric furnace inside a steel mill. The POI Internal Emergency Response Plan was activated, all fluid feeds were shut down and local fire-fighters were alerted. The molten metal was transferred from the furnace using a ladle. Local rescue crews were not called to the scene as the pressure surge from the blast was confined to the furnace (furnace crown brought down internally). No injuries were reported since personnel were not in the vicinity at the time of the explosion. No layoffs had to be scheduled either.

The leading potential cause of the accident was the same as that responsible for the explosion that occurred in this same facility on February 8, 2008 (see ARIA reference no. 34239), i.e. water / molten metal contact due to the presence of water in significant quantity being introduced via a "big bag" of in-house recycled dust as part of the steelmaking process. These bags were being stored outdoors. It would appear that the loading operator did not comply with the set of internal rules established following the previous accident, which forbade the use of dust bags that would have been exposed for more than one day to the open air. Management reinforced these procedures and tightened controls on all charging of materials in the furnace.