Explosion in a furnace in a metal alloy production plant

February the 21st, 2000

Feurs [Loire]

France

Metallurgy
Melting furnace
Loss of operational process control
Organization
Procedures
Victims

THE INSTALLATIONS IN QUESTION

The plant

The Feurs site employs 650 people and includes 3 units:

- ✓ a unit producing cast steel,
- ✓ a unit producing wear parts particularly for public works equipment,
- ✓ a unit created in late 1997 specialises in the conversion of industrial co-products and complex metallic composites (batteries, dusts and iron scales from foundries, catalysts derived from the petrochemical or chemical industry, milling sludge,..) through pyrolysis (drying, calcination, fusion), activty authorized by virtue of the prefectorial order of April 14th, 1997

In 2000, using a light-arc furnace, the plant processed:

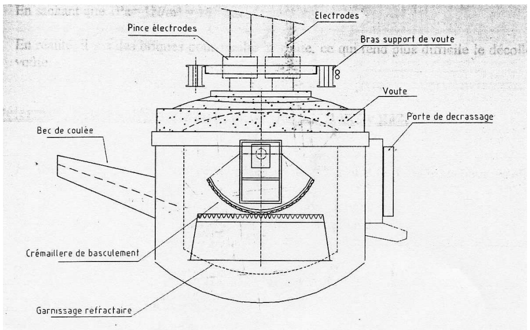
- ✓ 700 t of metal slag and dusts
- ✓ 800 t of nickel, cobalt, molybdenum and iron alloys
- ✓ 1300 t of batteries.

The unit

The furnace is hooded, and the fumes are drawn off (50,000 m^3/h) and filtered. The following parameters are recorded continuously: output, temperature, dusts, COT, CO, CO_2, O_2

The processing operation underway at the time of the accident was the fusion of a mineral and metal load in order to produce alloy ingots. The load was consisted of the following elements:

- ✓ 836 kg of sand, essentially comprised of alumina, silica and nickel oxide,
- ✓ 6690 kg of Fe - Mo - Co - Ni-alloy into 350kg-ingots,
- ✓ 540 kg ordinary structural steel,
- ✓ 240 kg lime.



The normal sequence of events for this processing operation is as follows:

- ✓ The prepared load is introduced into the furnace all at once;
- ✓ The electric arc, electrodes above the load, melts it,
- ✓ Gaseous oxygen is blown into the bath through a nozzle, for refining purposes,
- ✓ The electric arc is shut off, the refining operation continues,
- ✓ The furnace tips, the floating slag is removed, and the metal is then poured into ingots.

THE ACCIDENT, ITS BEHAVIOUR, EFFECTS AND CONSEQUENCES

The accident

The light-arc furnace started at 7.35 a.m. with the melting of metal scraps containing essentially iron, molybdenum and cobalt (3,210 kg) and scrap metal (1,080 kg).

The process took place without incident and at 12.40 the liquid metal was poured into ingots of approximately 800 kg.

The furnace was entirely emptied of its liquid metal. An inspection of the furnace was performed by the furnaceman. No anomaly was reported (no water leak, or refractory damage).

Loading of the furnace : chronology

1.20 / 1.25 pm : Introduction into the furnace of 836 kg of sand contained in a big-bag and consisting essentially of nickel oxide, silica and alumina. The sand is distributed in a homogenous manner at the bottom of the furnace to a height of approximately 20 to 25 cm.

1.35 pm: Introduction into the furnace of the metal alloy (6900 kg), "classic" metal scrap (540 kg) and lime (240 kg). using the loading basket.

1.45 pm: Closure of furnace arch and ignition of electric arcs.

Melting process

The main operation are the following ones :

- ✓ 0 to 1,000 kWh: electric arc only.
- ✓ 1,000 to 1,552 kWh (around 2.20 pm): electric arcs + introduction of gaseous oxygen into the metal bath
- ✓ At 1,552 kWh (around 2.40 pm): shut-down of the electric arc. The temperature of the metal in contact with the thermocouple is 1,530°C, and the blowing of gaseou s oxygen into the bath continues.
- ✓ At roughly 3.15 pm, the accident occurred. Approximately 10 minutes prior to the accident, the furnaceman reported that the metal in contact with the temperature reading thermocouple was 1,575°C.

Events at the time of the accident :

Metal and slag were ejected by the furnace's slag door. A few seconds or fractions of seconds after the metal and slag were ejected, the arch collapsed into the furnace; Incandescent particles were thrown with a muffled rumbling noise and an intense blast; an excessive amount of dust swept across the workshop. The event was not accompanied by an explosive blast noise.

Consequences

Six employees were taken to the hospital: 3 were released the same evening, 2 persons who were seriously burned were transported to a specialised hospital in Lyon, 1 person was slightly injured. These employees were injured by molten metal, incandescent dust and flames.

European scale of industrial accidents

By applying the rating rules of the 18 parameters of the scale made official in February 1994 by the Committee of Competent Authorities of the Member States which oversees the application of the 'SEVESO' directive, the accident can be characterised by the following 4 indices, based on the information available.

Dangerous materials released	☐	☐	☐	☐	☐	☐
Human and social consequences	■	■	☐	☐	☐	☐
Environmental consequences	☐	☐	☐	☐	☐	☐
Economic consequences	☐	☐	☐	☐	☐	☐

The parameters that comprise these indices and the corresponding rating method are available at the following address : http://www.aria.ecologie.gouv.fr

The level 2 given to the human and social consequences is due to the 7 employees injured, of which 2 were burned (parameter H4 and H5).

ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

The main factual data relative to the circumstances gathered follow :

- The level of the metal bath was abnormally high. The furnaceman had to raise the level of the dam and slightly incline the furnace spout.
- Solid products came to the surface of the metal bath when oxygen was being blown in.
- The furnaceman noted unmelted parts in the bottom of the furnace (by testing with a metal rod) a few minutes before the accident.
- There were no unmelted elements attached to the sides of the furnace.
- The average thickness of the arch bricks was measured at 180 mm. The new brick is 250 mm thick.
- A few bricks of the arch's outer row were found on the periphery of the arch's metal ring.
- A sample of metal ejected by the furnace door was analysed :

Element	C	Mn	Si	S	P	Ni	Mo	Co
%	0.35	0.05	0.83	0.061	0.252	2.38	16.43	6.22

× The analysis of the off-gas recorder on the stack outlet highlights the rapid increase of CO content at the time of the accident.

Time	3.00 pm	3.05 pm	3.10 pm	3.15 pm	3.20 pm	3.25 pm
CO concentration mg/m³	32.0	83.3	393.0	291.0	114.0	66.3

× No water leak was reported on the cooling systems and the refractory material of the hearth was in very good condition.

× While the load remaining in the furnace was melting after the accident, melting difficulties and rapid temperature increases to 1,700° C followed by abrupt drops to 1 ,550° C were noted. The temperature rise/drop pheno menon was noted 2 to 3 times. This phenomenon is interpreted by the dissolution of unmelted products in the bottom of the furnace and their rise to the top.

Based on testimony by the personnel, reconstitution of the previous casting operation through to just after the accident, and post-accident investigations, some hypothesis **relative to the phenomenon observed** were presented. After analysis, some of them were finally rejected (Water leak inside the furnace, presence of a hollow body, collapse of the arch, collapse of unmelted elements attached to the side of the furnace, water present in the slag tank).

However, the following **causes had been retained** :

× The nickeled sand in the bottom of the furnace did not melt completely; the intense mixing of the metal by the injection of gaseous oxygen helped the nickeled sand rise to the surface. The nickel oxide was deoxidised by passing through the metal; the oxygen thus released combined with the carbon present in the bath and produced large quantities of CO and CO_2 very rapidly. This hypothesis is substantiated by the recording of the gas analysers; a calculation shows that this reaction produces 73 m^3 of CO in a few seconds.

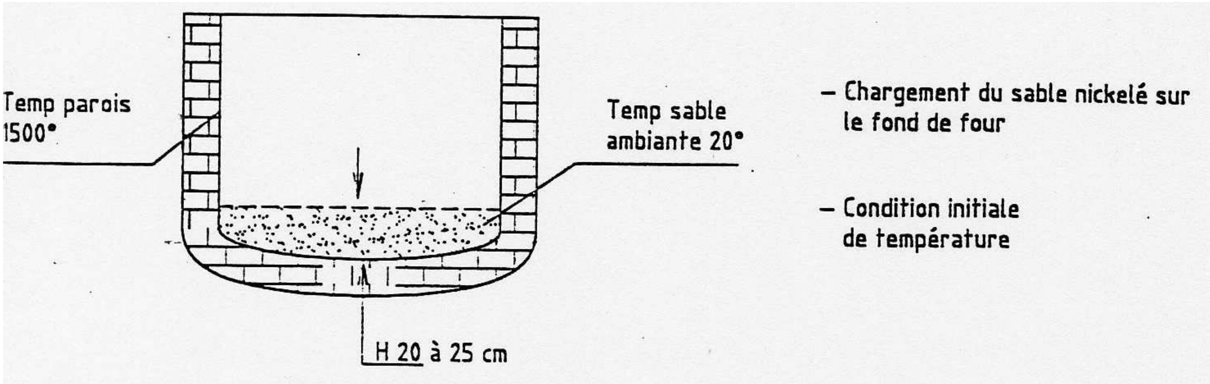
× The unmelted nickel sand in the bottom of the furnace contained a certain quantity of water and gas, held under pressure by a layer of pasty metal. The blast would have been due to the release of these gases; a calculation shows that this phenomenon generates 8 m^3 of steam.

× The analysis of the causes concludes that the loading method (nickeled sand in the bottom of the furnace) which was the origin of the accident.

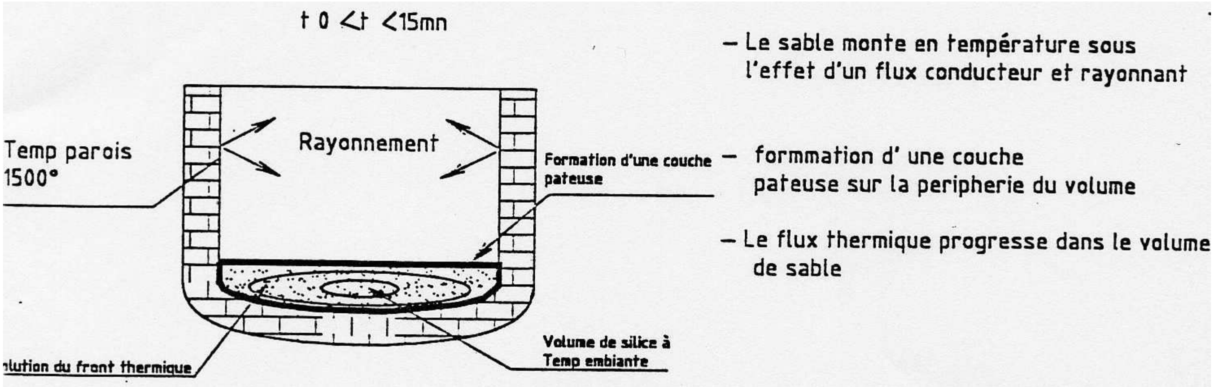
The presence of personnel not necessarily required around the furnace during the fusion operation was an aggravating factor in the number of people injured.

Possible development of the accident :

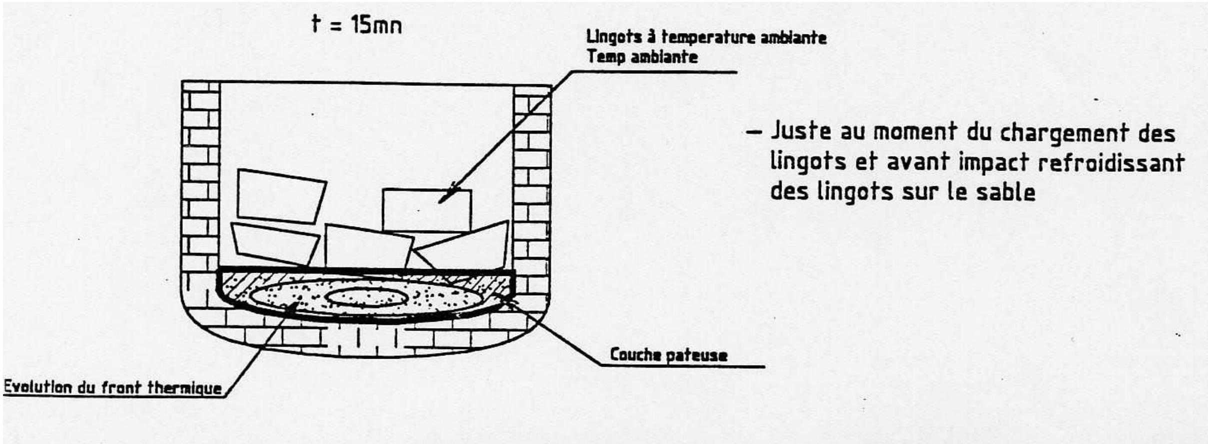
Start of the operations : t=0



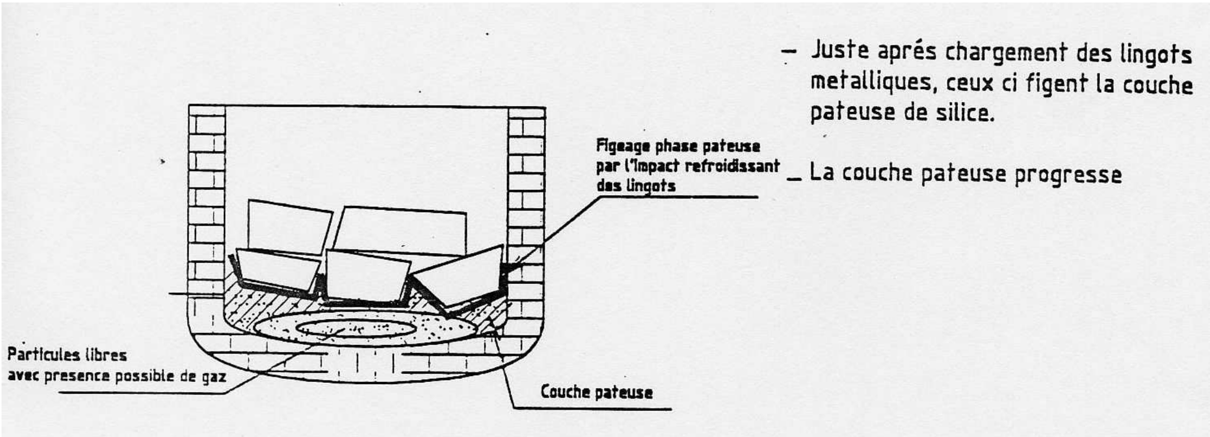
Intermediate period before the loading of the ingots t<15 min



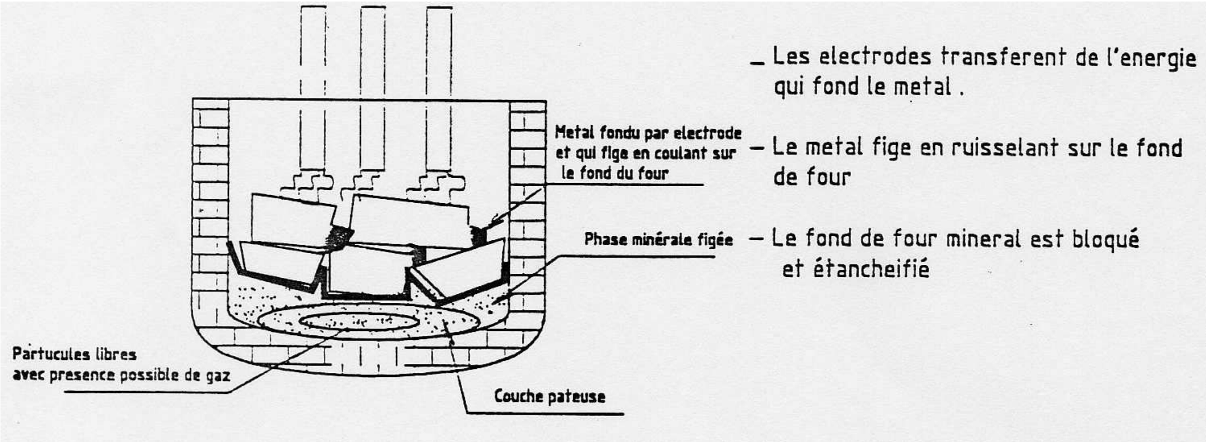
Loading of the ingots moment: t



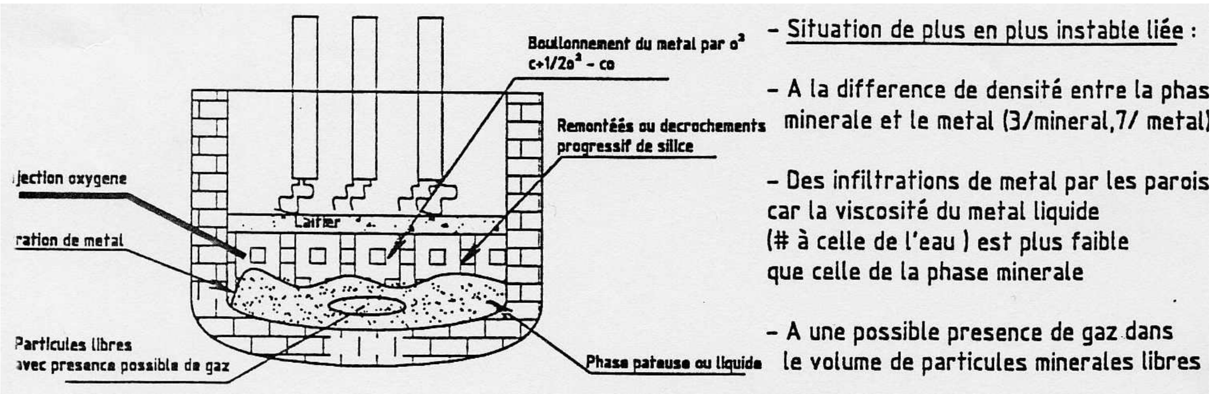
Thermal impact of the loading of the metal ingots



Fusion start of the metal ingots t=15min+x



Furnace situation, melted metal (t+15min +40min : injection d'oxygène et t+15min+45min : metal fusion)



ACTIONS TAKEN

At the time of the accident, the operators called the emergency rescue services, disconnected the electrical power and oxygen supply.

The furnace was rebuilt a week later; the metal remaining in the bottom was melted and poured.

An "emergency" prefectorial order was put into effect on February 28th, 2000, subjecting the recommissioning of furnace No. 2 to the understanding of the causes, consequences and the implementation of solutions to remedy the problems…

The letter by the DRIRE, dated March 10th, 2000 stipulates which responses were expected in terms of this prefectorial order, namely:

- ✓ the probable causes of the accident,
- ✓ accidentology of the activity sector and the reasons which lead to retaining the probable causes identified,
- ✓ the types of loads or pouring operations for which a restart is required, argued by the risk analysis and counterbalancing procedures.

For these three points, an evaluation by a specialised and organisation independent from the operator was requested. An institute spectialises in iron and steel metallurgy research was retained.

In response, the operator produced a file on March 24th, 2000; completed by the expert's report of March 27th, 2000.

The prefectorial order of April 7th, 2000 authorised furnace No. 2 to return to operation for the fusion of 3 product families, according to the procedures validated by the expert. The order also stipulated that a modelisation study be conducted concerning the phenomena which lead to the accident as well as an update of the danger study (last version: September 1996).

The modelisation study was conducted by a academic laboratory specialises in thermodynamic and metallurgical physical chemistry. Based on small-scale tests (200g of sand, 1kg of cast iron), the study confirmed the scenario of a sudden release of gas due to the deoxidation of the nickel oxide contained in the sand.

LESSONS LEARNT

The **main lessons** to learn from this accident may be summarised as follows :

- The unexpected and uncontrolled reaction in the furnace is the origin of the accident.
- The presence of people near the furnace at the time of the accident increased the human toll.
- Adequate operating procedures are sufficient to prevent the occurrence of this kind of accidents.

The operaotor took the following **measures** :

- Modification of the area surrounding the furnace: protective panels for observation purposes and certain operations, the creation of circulation zones, regulated access near the furnace…,
- Revision of all of the operating procedures, safety instructions (individual protective equipment ..),
- Recruitment of a safety engineer for the site.

The accident reminded the operator that basic precautions are required around a metallurgical furnace. In this instance, the routine, the poor understanding of the risks by the management and the operators allowed individuals to get into a dangerous situation.