Enquiry into a Fire in the Bag Filter Attached to Two Ferromanganese Furnaces

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ABSTRACT

In July 1997, a new bag filter connected to two, up-rated, ferromanganese furnaces was commissioned. These furnaces were of the open top, submerged-arc type where the combustible off-gas is burnt in excess of air under an open hood above the furnace. In October 1997 a major fire occurred in this bag filter plant.

As part of the investigation into the fire and its cause or causes, some other ferromanganese producers were approached for information on fire history at their plants. Two of the ferromanganese producers had each experienced multiple bag filter fires, and there were several other lesser incidents reported such as a slimes dam smouldering when dried out, or containers of bag filter dust were found to be red hot.

A literature search did not reveal references to any particular fire hazard associated with the dust and fume arising from the combustion of gases collected from open top, submerged-arc furnaces producing high carbon ferromanganese. The investigation narrowed the causes down to scenarios based on spark carry over or spontaneous combustion of dust. Evidence gathered made it difficult to reject either scenario.

The paper gives a description of the plant and the evidence collected during the fire investigation. The conclusion is that due to the environmental and economic consequences of such fires, the circumstances surrounding them should receive wider scrutiny. Drawing the attention of a wider audience to the problem may lead to further work that can identify the cause of such fires with more certainty.

1 INTRODUCTION

In July 1997 Pyromet completed a turnkey project to replace and up-rate the No. 1 & 2 furnaces at the Cato Ridge works of Feralloys Ltd. in South Africa. Previously the furnaces were of the closed type and fitted with 9 MVA transformers. Gas cleaning was by venturi scrubbers. The new furnaces are of the open type due to the fines content of the ore, and fitted with 22 MVA transformers. Gas cleaning is by bag filter. Due to the large up-rating factor, space is at a premium and a bag filter using a needled felt fabric with a high filtration rate was chosen instead of glass-fibre as used elsewhere on the plant. The furnaces are used for the production of 78% high carbon ferromanganese.

The fire that will be described in this paper took place on the 21st of October 1997. The plant had only been in operation for three and a half months, including sequential ramp-up time for the two, newly up-rated furnaces.

2 PLANT DESCRIPTION

Figure 1 shows a plan view of the gas filtration plant layout. Gas leaves each furnace by two off-gas ducts from each furnace hood. The ducts run up to and through the roof of the building. Within the building there is a tee-section in the stack from which the furnace gas is drawn off to the gas cleaning plant. At the top of the stacks, emergency stack dampers are fitted to allow furnace gas to escape to atmosphere if the gas filtration plant ceases to operate while a furnace is on load.

Considering one furnace flow path only, gas flows along the ducts above the furnace building roof to a spark arrestor situated just before the trombone cooler. Gas leaving the spark arrestor passes into a large plenum that is connected to the inlet end of the trombone cooler tubes and a cooler bypass duct (shown crosshatched). The bypass duct was fitted with an automatically controlled temperature-regulating damper. The inlet chamber of the bag filter is fitted with an automatically operated dilution air damper that admits ambient air if the inlet gas temperature becomes too high.

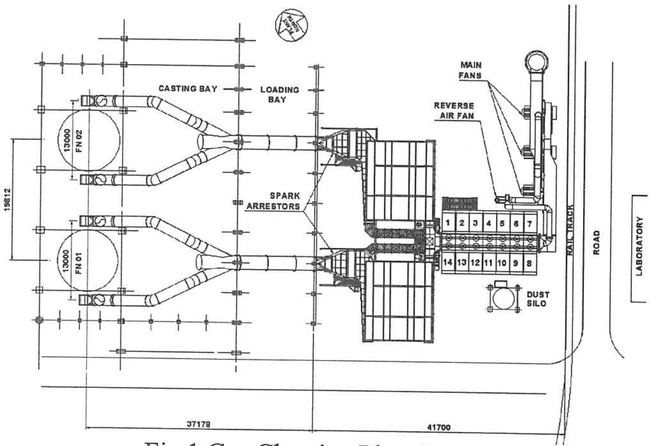

Fig.1 Gas Cleaning Plant Layout

Figure 2 shows the gas flow path through openings in the lower sidewalls of the inlet chamber that lead into each dust collection hopper below each bag compartment.

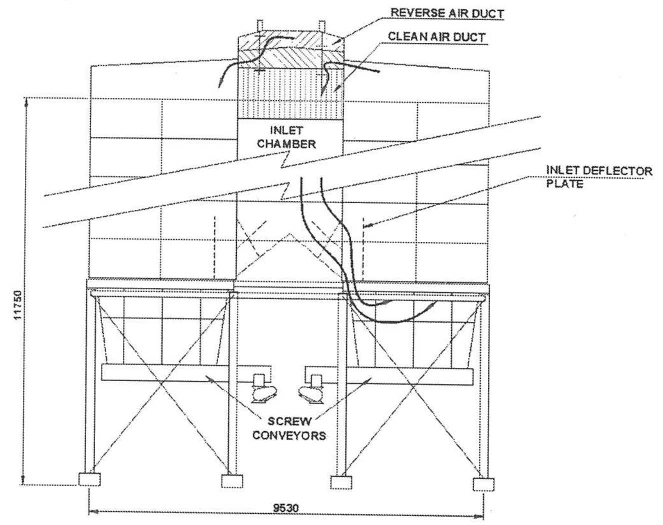

Fig. 2 Section Through Bag Filter

A fixed deflector plate at each dust hopper entrance reduces the gas inlet velocity and directs most of the gas flow downward. This promotes settlement of suspended solids in the dust hopper before the gas rises at low velocity into the bag compartment above. Gas passes through the bags, and solids remain on the outside of the bags until removed with a combination of reverse air and a shock wave from the pulsejet cleaning system. The dust cake blown off the outside of the bags falls into the dust hopper below.

Passages for the clean gas outlet and reverse air also make use of the central space between the two rows of bag compartments. The clean gas and reverse air passages are arranged so that a single pneumatic cylinder and rod, fitted with two poppet dampers, can alternately connect a bag compartment to the clean gas duct or the reverse air duct.

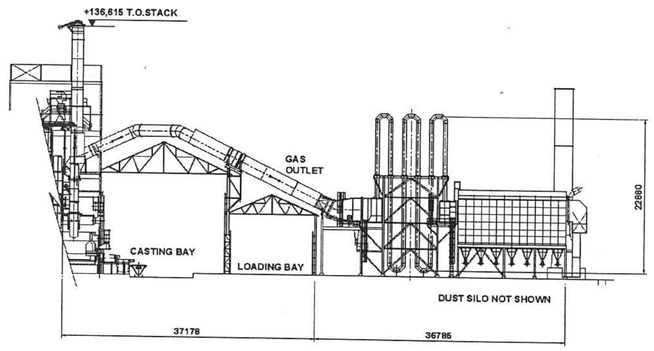

Fig. 3 Elevation on Gas Cleaning Plant

Figure 3 shows an elevation of the gas cleaning plant to clarify the vertical arrangement of the various components of the plant. Spark carry-over from the furnace is a possible cause of the fire, and it is necessary to have a clear idea of the plant layout in order to assess the probability of spark ignition as a cause of this fire.

Relevant design parameters for the plant are as follows: -

Furnace rating	22 MVA each
Furnace power	17 MW each
Design gas vol.	231 200 Nm^3/h
Max. gas temp.	500 °C
Normal gas temp.	200 to 400 °C
Spark Arrestor (x2)	
Type	Horiz. Multi-cyclone
No. of cyclones	90
Pressure drop	425 Pa
Trombone Cooler (x2)	
Outlet temperature	180 °C max
Volume	115 600 Nm^3/h
Average gas velocity	22 m/s
No. of tubes	13
Diameter of tubes	600 mm
Total length of cooler tubes	150 m
Bag Filter	
Type	Suction
Inlet gas volume	442 870 m^3/h
Max inlet temperature	180 °C
Inlet dust loading	5 g/Nm^3
Bag cleaning method	Pulse & rev. air

No. of compartments	14
Bags per compartment	140
Arrangement of bags	10 x 14
Nominal bag length	6.5 m
Bag area	3.27 m^2
Bag material	Nomex
Filtration velocity excl. reverse air	1.15 m/min
Filtration velocity incl. reverse air	1.31 m/min
Cage material	Mild steel
Bag pressure drop	1.6 kPa

3 INCIDENT DESCRIPTION

The following information is taken from more detailed records of the fire incident [1, 2]

- 03:15 – Operator from No. 6 furnace taking a sample to the laboratory noticed a hot spot on the side of the bag house and sparks being released from the clean gas stack.
- 03:20 – Operator notified supervision on furnace 1 and 2 by telephone about the situation at the bag house.
- 03:20 - (According to charts). The foreman, who had problems with materials handling, switched off the induced draught fans on the bag filter plant, and then checked the plant. He noticed that the screw feeders were not running, and an air injection hose on top of the bag house was leaking. He then proceeded to the control room to call out the standby fitter and electrician to respectively rectify these problems.
- 04:33 – Due to lack of raw material, the foreman switched out the No. 2 furnace.
- 05:15 – The fitter who went to repair the air hose noticed flames and smoke emerging from the covers of compartments 2 and 3.
- 05:49 – No. 1 furnace was switched out and the roof of the bag house was drenched with water from a fire hydrant.

4 INVESTIGATION

The bag filter outlet temperature trend, Figure 4, shows that the fire started at approximately 01:04 on 21/10/97. After remaining steady at just under 150 °C for the preceding several hours, the bag filter outlet temperature suddenly increased to 200 °C over a period of 15 minutes.

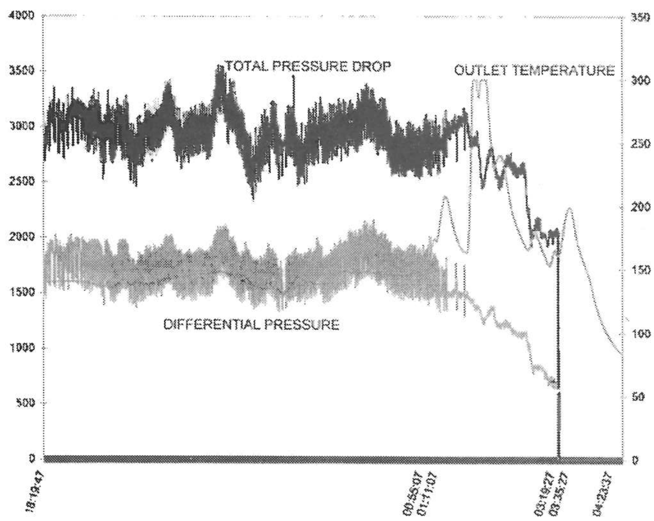

Fig. 4 Bag Filter Temperature & Pressure

It appears from the trend that the fire subsided and then re-ignited in more compartments. The outlet gas temperature rose very rapidly at approximately 01:45 and went off scale at 300 °C. The fire was probably spread to other compartments by burning bag fragments entrained in the reverse air cleaning system. The final temperature peak around 03:40 could indicate the cessation of flow through the bag filter when the fans shut down at 03:20. In the absence of a through draught, the burning of residual combustible material could explain the brief temperature surge before reversion to the overall cooling curve.

Figure 4 also shows the total system pressure and the differential pressure across the filter bags. Inspection of these trends also indicates that a disruption of the operating conditions occurred between 01:00 and 01:30. At 01:05 the differential pressure was well above 1.5 kPa, and the cleaning cycle was continuous. As bags were destroyed, the differential pressure across the bags decreased. At 1.5 kPa the cleaning cycle activity diminished for a while, probably due to the differential pressure fluctuating around the bag cleaning set-point pressure. After that, bag cleaning ceased completely as the differential pressure dropped below the cleaning cycle set point. Thereafter the bag-filter differential pressure decreased progressively as the bags were destroyed. At 03:20 the total and differential pressure trends suddenly decreased to zero, indicating that the main extraction fans shut down at this time.

Figure 5 shows the trombone cooler inlet and outlet temperatures. Although not helpful in pinpointing the outbreak of the fire, the trends show that some hours before the occurrence of the fire, the furnace off-gas temperatures dropped markedly below normal.

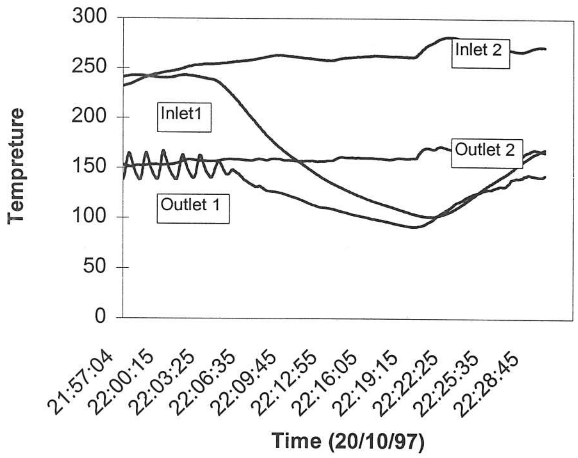

Fig. 5 Trombone Cooler Temperatures

This could be related to the fact that there were raw material supply difficulties to the furnaces before the fire. At approximately 22:00 on 20/10/97, No. 1 furnace gas temperature started to decrease, probably due to load reduction related to the feed shortage that eventually led to shutdown of No. 2 furnace at 04:33, and No. 1 furnace shortly after.

The SCADA trends shown here are consistent with the occurrence of the fire at around 01:00 and main fan shut down at 03:20. The trends show that the maximum intensity of the fire had already passed before it was reported. The fire was put out 4 hours and 45 minutes after it started.

The fire was concealed for most of the time, and this resulted in more damage than would have been the case if the situation had been recognised earlier as a fire-fighting emergency.

5 RELATED FIRE HISTORY

One of the first actions after the occurrence of the fire was to make enquiries within the industry about fire history on similar furnaces, with the following results.

Transalloys, South Africa, SiMn production.
1985, No. 5 furnace, with trombone cooler installed. Half of the bag house burnt out after an eruption in the furnace caused by a water leak.

Samancor, South Africa, FeSi production.
M9 furnace, suspect burning cotton waste and rags from machine swarf carried over to the bag house only 20 m from the furnace with no spark arrestor. No recurrence of fire since installing a coarse screen made of steel grate floor panels in the gas duct.

Samancor, South Africa, FeMn production.
Most FeMn production in closed top furnaces equipped with wet scrubbers. Fine solids pumped to slimes dams for disposal. Report received of parts of these slimes dams starting to smoulder when dried out. Solids heated sufficiently to show signs of sintering.

TEMCO, Tasmania, HC FeMn and SiMn production.
Two fires in a bag filter connected to three closed top furnaces. The bag filter was connected to tap hole fume hoods and the hood above each furnace roof where electrode leakage fume was captured. No recurrence of fire since disconnecting the bag house from the electrode leakage fume. Also, instances of bag filter dust in transport bags being found to be "red hot" after being left standing overnight.

TEMCO's investigations have concluded that the potential ignition sources were sparks and spontaneous combustion of the dust (due to the presence of sufficient fuel; organic and elemental carbons, and Mn). TEMCO have installed equipment to detect a smoulder fire before extensive damage is done. A nitrogen extinguishment system has also been added. Whilst not a preventative measure, this has been successful on two occasions. Investigators at TEMCO consider spark carry over as the most likely ignition source, and hence current work involves trialling a spark detection and extinguishment system – a preventative approach. This trial will be concluded in September 2000. If successful, TEMCO plans to recommission the plant with both the preventative and reactive measures above [5].

Feralloys, South Africa, HC FeMn production.
i) Fire in the exhaust filter of the pneumatic dust transport system associated with a bag filter. This incident is of interest because of the greater isolation of the exhaust filter from furnace sparks.

ii) March 1998, spontaneous heating of dust removed from two blocked dust hoppers on No. 5 furnace bag filter. No heat exposure or damage to the filter bags, which were all made of glass fibre. Described in more detail later in this paper.

Eramet Marietta, USA, MC FeMn production.
Fires in bag filters collecting dust from alloy crushing and screening operations.

Manganese Metal Company, South Africa, Mn metal production.
Dust explosions (very fine metallic Mn).

METAS Steelworks, Izmir, Turkey, steel production. One of the investigating team had personal experience of spontaneous combustion occurring in a shipment of sponge iron. The material was offloaded in the open and exposed to rain overnight. In the morning the pile of material was covered in blue flames and some molten iron ran out from the bottom of the heap.

This feedback from industry showed that bag filter fires are sometimes caused by sufficient carry over of hot gas and burning solids to a bag filter. This feedback also drew attention to the possibility of an additional fire risk due to exothermic chemical reactions in the dust arising from ferromanganese production.

6 TESTS

Three groups of tests were carried out in an effort to gather information to identify the cause of the fire. The first set of tests was carried out at the Council for Scientific & Industrial Research (CSIR) in Pretoria, South Africa. After the fire, dust samples were taken from various parts of the ducting and dust hoppers, and analysed for elemental content and crystalline type. Filter cloth from the bag house, as well as new filter cloth were tested for auto-ignition point and ability to sustain flaming combustion. The powder samples were analysed with the use of a scanning electron microscope (SEM) with energy dispersive x-ray (EDX) detection. They were also mounted onto glass slides and analysed by X-ray diffraction (XRD). The results showed that the dust in the bag filter was mostly in the form of Hausmanite (Mn_3O_4), and samples taken from the spark arrestor (closer to the furnace) consisted mainly of Manganosite (MnO). The XRD and EDX results also showed that finely divided carbon exists in the dust entering the bag house [3].

Table 1 shows the results of combustion tests on samples of bag material. The conclusion was that the time before ignition for the dirty bags was about half that for the clean bags, indicating that the dust on the bags contributes to the ignition process [3].

Table 1

Sample	Auto Ign. Temp.	Time to Ignition
Clean bag	540 °C	100 seconds
Dirty burnt bag	560 °C	52 seconds
Clean bag	530 °C	90 seconds
Dirty bag	530 °C	55 seconds

The second group of tests was carried out at Avmin Research Laboratories, Johannesburg, which is an R&D facility in the Feralloys holding company, Avmin. Chemical analyses of dust samples taken from various parts of the plant shortly after the fire are shown in table 2.

Table 2

No.	ID	C	Mn	Fe
1	F1, Trombone inlet	13.3	38.8	4.1
2	Compartment 4	1.73	46.6	1.8
3	Trombone S-10	8.23	43.7	1.9
4	F1 Trombone	5.51	48.9	2.4
6	F2, by-pass duct	7.68	44.5	2.9
7	F2, Trombone	11.0	39.9	3.0
8	F2, Spark Arrestor*	28.9	27.9	3.7

*Immediately upstream of the spark arrestor

When the spark arrestor sample was taken, light and dark layers in the dust were noticeable. It appears from the analysis of the dust that the dark colouration was due to the presence of carbon in large quantities. Also of interest is sample 2 taken from compartment 4. This sample contains much less carbon, the implication being that it was burned off in the fire, or could have been consumed in initial heating of the dust.

The dust samples submitted to Avmin Research Laboratories were also examined under an optical microscope. Figure 6 shows the dust from the No. 2 furnace spark arrestor under polarized light. White areas are graphite particles. The round particles are Mn rich metallics including some Si and Fe. Other particles are a mixture of unreduced and partially reduced ore. The large dark spots are holes caused by dust particles falling out during the sample polishing process.

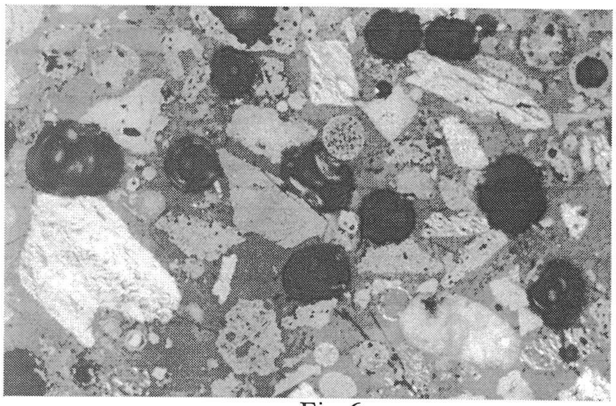

Fig 6

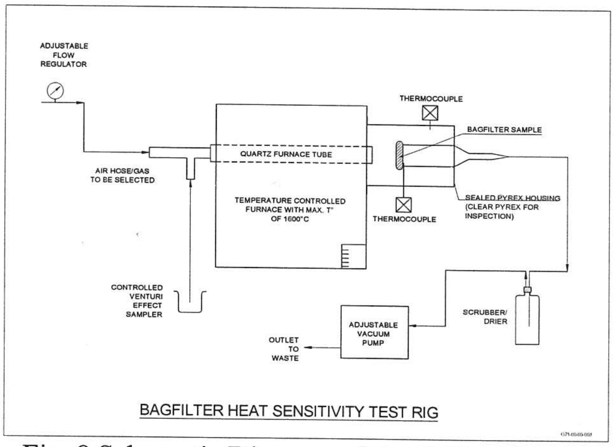

Fig. 8 Schematic Diagram of Spark Test Apparatus.

Figure 7 shows dust from compartment 10 (Mag. 65). Light grey areas are partly reduced oxides. Some unreduced ore particles can also be observed. The fineness of the dust in the light grey areas is noteworthy.

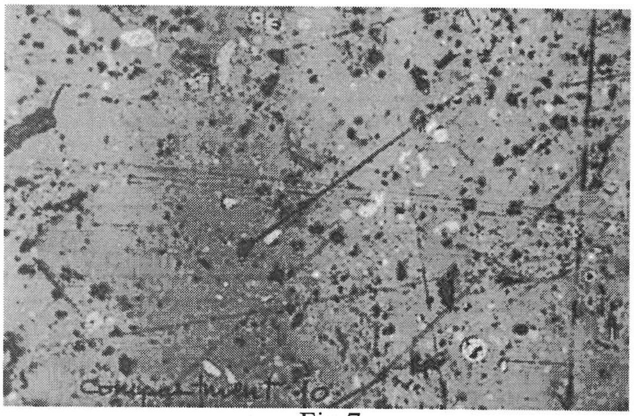

Fig 7

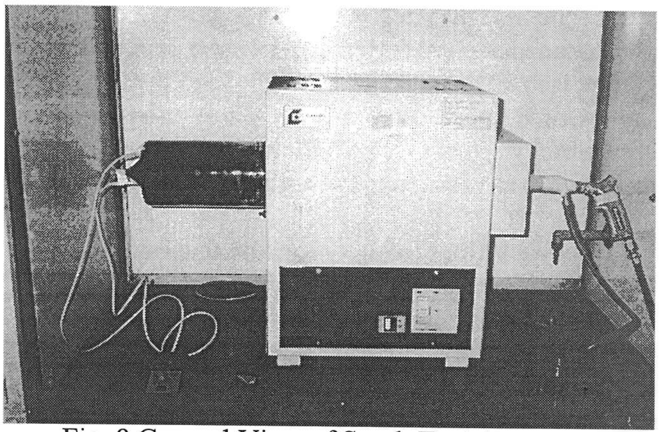

Fig. 9 General View of Spark Test Apparatus

The third group of tests was carried out in the Chemical Sciences section of the Eskom Technology Group. Eskom is the principal electricity supplier in South Africa. This facility has extensive expertise in combustion technology.

An experiment was set up to show how susceptible the filter bags were to spark ignition. Figure 8 shows schematically how the apparatus was set up to bombard a test piece of filter bag with glowing dust particles.

Using medical air and pure oxygen as transport media, bag compartment dust, spark arrestor dust (taken immediately upstream of the spark arrestor) and anthracite dust were used to bombard the bag filter material with sparks ignited by passage through the ignition tube maintained at 1400°C. Figure 10 shows the apparatus in operation.

The apparatus could be operated in open or closed mode. Closed mode is as shown in Figure 9, where a controlled atmosphere can be maintained around the bag filter material. Open operation is shown in figure 10 where the bag sample is in ambient air. Extreme operating conditions could be imposed in the closed mode, and more representative operating conditions could be imposed in the open mode. Gas temperature up to 650 °C could be obtained in closed mode. The bag material could only be ignited in closed mode, and only if pure oxygen was used as the spark transport medium. The sequence of events leading to ignition of the bag was as follows: -

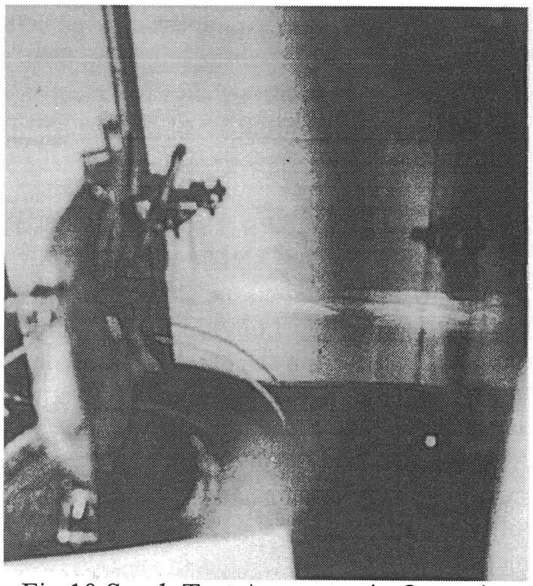

Fig 10 Spark Test Apparatus in Operation

The fabric had previously been subjected to silo dust, spark arrestor dust and anthracite dust, so it was to a certain degree coated with dust. Strong oxidising conditions were introduced causing superheated sparks to strike the fabric. Due to the high oxygen level, the mixture of dust types entrapped in the fabric was ignited.

In open mode, bombardment with sparks for up to an hour did not ignite the bag fabric although it was singed and discoloured, due in part to exposure to radiant heat from the spark igniter tube.

With the aid of a catchment area below the bag sample, it was shown that the only way to ignite the accumulated dust was to moisten it with hydraulic oil. No other plant parameter could bring about ignition of settled dust accumulated below the test piece.
These spark bombardment tests showed that the fabric used in the bag house is highly resistant to spark induced combustion. For sparks to have initiated the fire in the bag filter, it would seem that the presence of dust with abnormal properties would have been necessary.[4]

7 HAZARD ANALYSIS

To minimise the risk of a repetition of the fire, a team with relevant knowledge was assembled to carry out a formal cause analysis on the bag filter fire. The process was led by an independent specialist from the chemical industry, and made use of the Fault Tree technique. With this technique, the end event such as "Destruction of the filter bags" is developed into its immediate causes, and then each cause is subsequently developed into its immediate causes and so on, until root causes can be identified.

The fault tree led back to destruction of the bags by hot gas originating either from:-
i) an eruption in the furnace, or
ii) to combustion supported by combustible dust, an ignition source and oxygen in the normal gas flow.

The ignition source was attributed to either,
i) a slug of hot gas and dust being drawn through the system, the finer particles managing to slip through the spark arrester and reach the filter bags or,
ii) spontaneous combustion arising from accumulation of reactive components of dust in the bag filter.

With the information available at the time of the investigation, some participants did not support the spontaneous combustion concept.

8 SUBSEQUENT "HOT DUST" EPISODE

A spontaneous combustion incident was observed on 12 March 1998 at the Feralloys No. 5 ferromanganese, open furnace, bag filter. This was some 5 months after a fire severely damaged the bag filter serving furnaces 1 and 2.

The dust from furnace 5 accumulates in 10 hoppers situated below the bag filter compartments. The dust is conveyed from each hopper via a sealed mechanical conveying system to a large storage silo. Dust is removed from the silo from time to time and dumped on an outside stockpile.

A blockage developed on 11 March in the large storage silo, resulting in a build up of dust in the 10 hoppers. Hopper 1 choked up first and this hopper was isolated and emptied onto the floor of the bag filter building during the afternoon of 11 March 1998. By the following morning the complete bag filter was taken off-line to allow the emptying of the other nine compartments. Whilst emptying the compartments, the engineering foreman noticed that the dust that had been dumped the previous day was particularly hot, with the surface of the dust pile showing some "blistering". The moment the surface of the hot pile was disturbed, one was able to see that the dust was red hot.

Table 3 gives the analysis of the dust.

Table 3	
Component	% by mass
Mn	33.4
Fe	2.7
C	12.2
S	0.8
CaO	3.8
MgO	2.9
K_2O	9.0
Na_2O	2.0
Al_2O_3	2.3
BaO	0.3

Temperatures inside the heap were measured in the range between 390 °C and 500 °C. Figure 11 shows the approximate shape and size of the heap.

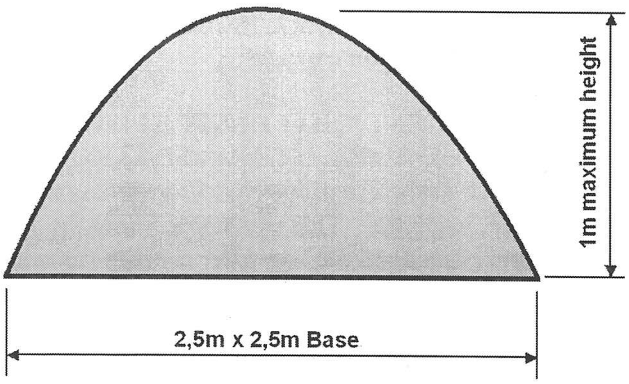

Fig.11 Size indication of hot dust heap

The dust from a further hopper was discharged onto the concrete floor and it was found to be at near ambient temperature (±30 °C). Within a few hours the pile had heated to between 35 and 55 °C, depending on where in the pile the measurement was taken. At this stage the temperature of the dust was checked by hand. After inserting the hand and forearm into the dust, it was confirmed that the dust was noticeably hotter to the touch at depth. This was a strong indication that spontaneous combustion had started.

Approximately 20 hours after the pile was formed, the temperature of the dust in the pile had risen to between 390 and 500 °C. It was clear that a spontaneous combustion process had occurred.

Operating staff were alerted to the fire risk presented by spontaneous combustion of the bag filter dust, and training was given on the importance of detecting and removing abnormal accumulation of dust in the furnace bag filters.

9 REVIEW OF THE SPARK CARRY-OVER SCENARIO

This hypothesis was based on the assumption that the fire was caused by the most obvious cause, namely sparks and/or hot gas from the combustion zone of the furnace reaching the bag filter, and setting fire to the filter bags. It was postulated that due to a mix collapse on the furnace, the generation of hot sparks could have been greatly increased, and some of these sparks could have got past the spark arrestors.

It would not be unusual for episodes similar to that shown in Figure 12 to occur with a frequency of once or twice per day.

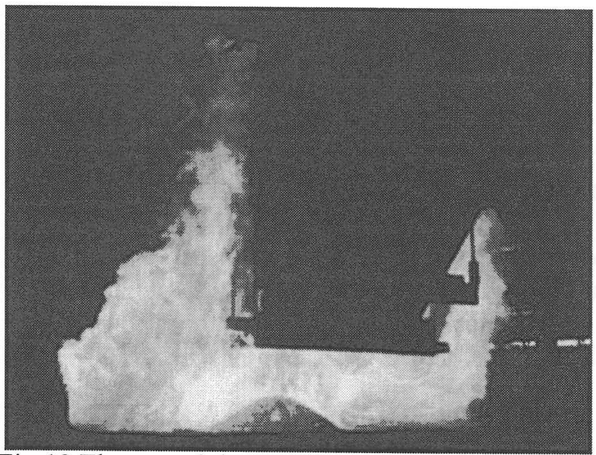

Fig 12 Flame and dust spillage during mix collapse

The temperature control bypass on the trombone cooler could reduce the flight time to the bag filter from 9 seconds to 2 seconds and increase the probability of glowing sparks reaching the filter bags.

Spark ignition probably played a significant part in the spread of the Cato Ridge fire from compartment to compartment, because burning bag fragments would have been extracted from the clean gas duct and passed to other compartments by the reverse-air cleaning system. The entrained bag fragments would have been conveyed without hindrance from a spark arrestor in the reverse-air ducting. It is unlikely that spontaneous combustion would have occurred in several compartments at about the same time.

The spark impingement tests showed that it is difficult to ignite the bag material with hot particles in the size range found in the spark arrestors. This size range was up to 500 microns.

Larger particles should have been more effectively removed from the gas stream by gravity and centrifugal action of the spark arrestors.

To reach the bags in sufficient quantities to cause ignition, sparks would have to:

- Traverse approximately 50 metres of duct ahead of the spark arrestors.
- Pass through the spark arrestors.
- Travel through the trombone cooler or the bypass duct.
- Enter the bag filter inlet chamber.
- Descend to the compartment entrance openings.
- Pass below the deflector plates in the compartment entrances and enter the dust hopper space.
- Rise with gas moving at only 2 m/s into the bag space.
- Settle on a bag and continue to burn with sufficient energy to cause ignition of bag material or the dust coating the bags.

The evidence gathered showed that it is possible for fire to spread from the furnace to the bag filter if there is a vigorous eruption in the furnace, and large quantities of hot gas and burning dust reach the filter bags. Under these circumstances the gas conditions are thought to be more representative of a fireball than of a shower of sparks.
There was no report of any unusual furnace eruption on the night of the fire.

A fire was reported some years ago in the exhaust filter of the pneumatic dust transport system of the bag filter attached to No. 5 furnace at the works of Feralloys Ltd. It is difficult to explain how sparks from the furnace could have reached this small filter attached to the dust silo of the main bag filter.

10 REVIEW OF THE SPONTANEOUS COMBUSTION SCENARIO

The reactivity of manganese ores used in the smelting of ferromanganese is well known. The tendency for higher manganese oxides in ores to decompose at elevated temperature to lower oxides and release oxygen has been attributed in the past as the cause of severe furnace explosions, some of them with fatal consequences.

When the bag filter was stripped, it could be seen that some of the dust hoppers were over full. In No.10 compartment the lower ends of the filter bags were buried in dust to a depth of approximately 0,5 m. Accumulation of dust, and the consequent retention of heat in the volume occupied by that dust could contribute to the occurrence of spontaneous combustion. When digging out the dust hoppers, two similar lumps of solidified metal were found. The larger of the metal lumps weighed 12 kg and its shape did not suggest solidification in a pool. The surface was totally irregular with lobes projecting in all directions, indicating that the metal had solidified beneath the surface of the dust in the hopper. Figure 13 is a photograph of the larger lump. The metal was quite ductile and found to consist almost entirely of iron. It is presumed that the metal came from the bag cages, although it is surprising that the burning of fabric for a relatively short time could melt the steel cages.

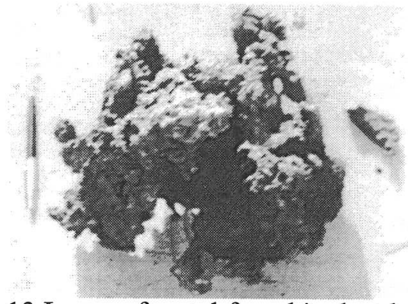

Fig. 13 Lump of metal found in dust hopper

Figure 14 shows a Gibbs free energy diagram for reactions of Mn_3O_4 with CO, H_2 and O_2. The Gibbs free energy is negative right down to room temperature, indicating that the reactions are feasible down to these temperatures. The following chemical equations show the reactions involved.

[1] $(Mn_3O_4+1/4O_2)$ (25°C) = $3/2Mn_2O_3$ (317°C)
[2] $(MnO+1/6O_2)$ (25°C) = $1/3Mn_3O_4$ (1181°C)
[3] (Mn_3O_4+CO) (25'°C) = $(3MnO+CO_2)$ (299°C)
[4] $(Mn_3O_4+H_2)$ (25°C) = $(3MnO+H_2O)$ (100°C)

The figures in square brackets refer to the delta G lines in figure 14. Figures in round brackets show theoretical temperatures for the reactions in order to give an idea of their exothermic properties. Similar equations can be written for the other manganese oxides which are MnO_2, Mn_2O_3 and MnO. Since the principal component of the bag filter dust was found to be Mn_3O_4, and space is limited, only Mn_3O_4 reactions are given here.

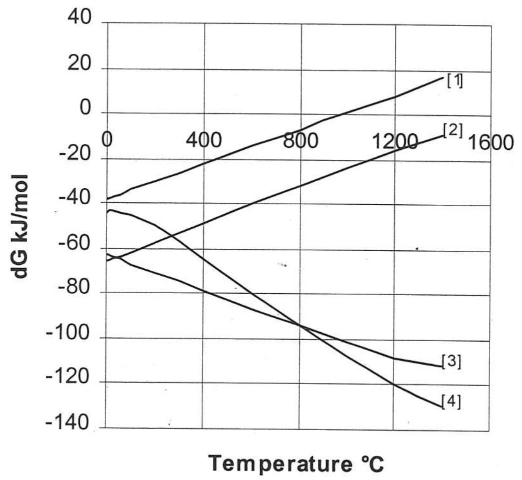

Fig.14 Gibbs free energy for Mn_3O_4 reactions

The reactions of the manganese oxides shown above are thermodynamically feasible at room temperature. Factors like activation energy, catalytic effects of trace substances and particle size will also influence the rate at which the reactions occur, and the rate at which heat is released. Reaction [2] is notable for the temperature rise and substantial negative delta G at low temperatures.

When considering the drying out of slimes dams it is unlikely that the spontaneous combustion effects would be related to CO or H_2. Reaction of atmospheric oxygen with manganese oxides, carbon, organics or manganese metallics is more probable, and the finer the particles, the more likely they are to react.

The energy released by manganese oxide reactions can cause significant warming, but the energy release is small in comparison with the energy released by the oxidation of finely divided carbon and metallics. It is suspected that very fine carbon and/or manganese dust particles reacting with oxygen may be the real fuel source in the spontaneous combustion of bag filter dust.

There were raw material feed difficulties and periods of low load on the No. 1 furnace during the evening preceding the fire. For one example see figure 5. Lack of feed for the furnace results in low burden level, and could lead to increased losses of carbon particles and manganese fume to the off-gas.

At 20:52 on 10/3/98 the log sheet for No. 5 furnace records a mix shortage. On the afternoon of 11/3/98 dust from blocked hoppers was dumped on the floor, and on the morning of the 12/3/98 the dust was found to be red hot.

At 07:45 on 20/10/97 the log sheets for No. 1 & 2 furnaces record a bag filter trip due to high differential pressure. High differential pressure prior to a hot dust incident has been recorded elsewhere [6]. High differential pressure is indicative of dust accumulation on the bags and reduced cooling gas flow.

Various mechanisms can be envisioned for the aeration of accumulations of dust in the bag filter. For example, slumping and subsequent settling of a heap of dust in a bin could temporarily aerate the pile, and then rapidly restore the heat insulation. Alternatively, leaks through seals on rotary valves, screw feeder shafts and the like, could introduce a small aerating stream into an accumulation of bag filter dust.

Fires have occurred on dust extraction filters serving crushing and screening plant for MC FeMn. The ignition source has been attributed to sparks from the crusher.[7] For ignition to occur from such an intermittent source of energy, the fine metallic dust on the filter bags must be extremely reactive.

Explosions due to the presence of very fine manganese dusts have been investigated but the results have not been published.

Electrostatic discharge has not been considered as the ignition source in this paper, because the authors have never witnessed any tendency to static charge build up in furnace bag filters over many years. This should not be taken as ruling out electrostatic discharge from future investigations.

It could be that all dust from a ferromanganese furnace is reactive, and the significant factor is the time taken for an effective heat insulating thickness of dust to be built up. If this is the case, a very small heap will never get very hot, because its dimensions are simply too small for effective heat insulation of any part of the heap. Dust added slowly to a large heap could lose heat rapidly from the thin layer of fresh material on the cone. By the time that the dust is buried to an effective heat insulating depth, the reaction could be completed. In a heap of intermediate size however, the reaction may not be completed by the time the dust is buried to an effective heat insulating depth. This could explain why spontaneous combustion is not an everyday occurrence in the disposal silo of a bag filter where large volumes of dust are routinely collected.

The problem with the spontaneous combustion or combustible dust theory is that the conditions for exothermic reactions in the dust to occur are not reproducible at present. More understanding of the problem is needed to be able to replicate the previously reported instances of "hot dust." The conditions conducive to these reactions occur infrequently, and when they do, the evidence is usually destroyed.

11 LITERATURE SURVEY

Despite extensive search efforts, the authors were unable to find published information on the incidents of spontaneous combustion identified informally through contacts in the industry. The authors would welcome feedback on the availability of published information concerning the ignition of dusts collected during the manufacture of ferromanganese alloys. Published sources found dealt mainly with spontaneous combustion of coal and situations occurring in wooden buildings fitted with insulation and badly designed or located electrical appliances.

12 PRECAUTIONS TO PREVENT RECURRENCE

The cooler by-pass was welded up and minimum gas temperature control was sacrificed. This increased the risk of acid dew point effects, but with the benefit of hindsight this was judged to be the lesser risk. After nearly three years since closing the by-pass, the filter bags are not showing symptoms of abnormal deterioration. The inherent pH of the bag filter dust, when mixed in water, is of the order of 10, therefore some alkalinity is believed to be present to lessen the effect of dew point acidity on the bags.

Level detectors were installed in the dust hoppers and spark arrestor discharge chutes. The dust in the hoppers is very fine and prone to stick on surfaces. More than one type of probe has been tried in the hoppers but false alarms are frequent. Nuclear bin level detectors may be the only way to obtain reliable warning of high dust level in the hoppers. Safety, maintenance and training concerns of the user have to be considered before installing a multiplicity of nuclear level detectors on the plant.

Monitoring equipment was relocated from an unmanned control room to a manned control room. In the unmanned control room the operating history was available for routine assessment of filter performance. After the fire it was deemed necessary to have on-line monitoring and reporting of deviations to operating staff for immediate response if necessary.

Thermocouples were installed in the outlet of each compartment, and set to trigger fire alarm and automatic shutdown procedure on the occurrence of defined plant signals such as compartment outlet temperature greater than inlet temperature.

Training was given to highlight the fire risk in the bag filter and to ensure prompt and adequate response to the first fire warning.

13 CONCLUSIONS

This investigation was not able to find with certainty whether the fire was due to spark/flame carry-over or spontaneous combustion of dust.

Experiment showed that bag filter material was not easily ignited by sparks alone. It would appear that spark ignition requires the presence of an easily ignited component in the dust.
A subsequent incident of spontaneous combustion in bag filter dust was observed and recorded. This lends more credence to earlier reports of spontaneous combustion that were not verified and recorded at the time of occurrence.

Experience has shown that there is an increased risk of fire in bag filters attached to ferromanganese furnaces when compared with say ferrochrome furnaces. The reasons for this are not clear.

When a bag filter is damaged by fire, high costs are usually incurred. Quite apart from this, unfavorable attention is drawn to an industry that is under increasing pressure to reduce its environmental impact.

This is a strong motivation to reduce the incidence of bag filter fires in the ferromanganese industry.

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