

IMPROVED SAFETY FOR MANGANESE ALLOY SMELTING

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ABSTRACT

During the past years work has been done to improve safety significantly at the manganese smelters operated by Eramet Norway AS. Dedicated work within HSE has identified the electrode assembly area to be an area of special concern. In addition, eruptions of smelters caused by water leaks have increased the focus on water leak detection.

To improve the safety of the employees working with assembly of the electrodes both the procedures and physical barriers of the work area has been improved. Only trained personnel has now access to the critical areas in the vicinity of the electrodes. The personal safety equipment has also been improved, and the physical barriers to prevent a short circuit have been further improved. Other critical areas where the electrodes are exposed have also been closed off. The measures have raised the safety to what is practically possible while maintaining the furnace in operation.

History has taught us that water leakages inside the furnace cause a great security risk. Over the years several approaches to water leak detection have been considered, and an overview of tested and evaluated methods is given in this paper. The conclusion of the work is that the best available technology for water leakage detection is measurement of the flow in and out of each cooling circuit. In addition the use of a closed system gives better cooling of the furnace hood and reduces maintenance. The addition of water to the cooling system is monitored to find small leaks. A tool was developed to identify which water course is leaking. The detectable leak size is now down to around 45 liters/hour. An assessment has been made on what size of leak that is critical inside the submerged arc furnace, and the detection limit is now in line with the critical leak size.

KEY WORDS: *Manganese, safety, HSE, electrode, water leak detection, SAF, equipment.*

1. INTRODUCTION

Over the years employees and management in Eramet Norway AS has had a dedicated focus on HSE. The HSE covers topics from rather simple actions like usage of personal safety equipment, to more complex matters like water leakage detection systems. This work has been driven by a wish to reduce personal injury to a minimum. As a result of the dedicated work, the frequency of injuries where the worker has had to stay away from work is now approximately $3 \cdot 10^{-6}$ injuries per hours worked for each of the three manganese alloy plants in Eramet Norway AS. For 2009 and 2011 the number was 0 for the Kvinesdal plant, and in 2010 it was 0 for the plants in Sauda and Porsgrunn. The focus of this article will be two of the areas of special attention in the recent years; electrode safety and water leakage detection and the implemented improvements at the Kvinesdal plant.

1.2. Safety in the vicinity of the electrodes

Part of daily operations in a ferroalloy plant using Sødeberg electrodes requires operators and equipment to be in contact with the electrodes while in operation. This includes operations like

measuring the solid and liquid levels inside the electrode, welding steel casings and charging electrode paste to the electrodes. In addition there are other areas of the furnace building where the electrodes are accessible and there is a very short distance between the electrodes and for example the silo tubes. The potential between the electrodes is typically in the range 200-250 V, while between an electrode and ground it is typically in the range 100-150 V with a theoretical short circuit current of about 5-600 kA. When a current passes through the forearm the muscles will contract and the ability to let go of an object that a person has grasped will not be possible when the current is higher than around 16 mA. A current passing through the chest for a longer time that exceeds about 20 mA can be fatal [1]. The resistance of a human body can, under ideal conditions, be as high as 100 k Ω . However, broken or wet skin may drop this resistance down to 1 k Ω . Thus, under unfavorable conditions the critical potential that could cause a fatal situation can be: Voltage = Ohms·Current = 1 k Ω · 20 mA = 20 V, which is much lower than the potential between the electrodes. In addition, use of equipment in the close vicinity of the electrodes adds a risk for short circuiting either between two electrodes or between one phase and ground. This could cause damage to personnel and electrode equipment. Experience has unfortunately shown that even experienced operators make mistakes. Welding equipment for welding the electrode casings have been wired incorrectly, by either connecting it to ground or to one of the other electrodes. Chain from the lifting equipment has connected an electrode with ground by being in contact with one of the electrodes and the steel floor. There have also been instances where equipment, like a steel rod or an aluminum ladder, has been brought into the area around the electrodes, connecting an electrode with either ground or another electrode. Eramet Norway AS has been lucky that there have been no serious damage to personnel due to these type of accidents.

1.2. Water leakage

It is well known within the industry working with molten metals, that the combination of water and high temperature metal can be lethal. This has been seen in several explosions/eruptions (e.g. [2, 3]) that have occurred at ferroalloy plants around the world, causing damage to equipment and in some cases fatal injuries. The challenge is that the water cannot be removed from the vicinity of the furnace due to the need of cooling of different parts of the furnace, particularly the furnace roof. It is thus necessary to be able to detect any major water leakage at an early stage so that it can be eliminated quickly, particularly when the furnace is off load, i.e. with no power.

When a water leakage occurs and water is sprayed onto the top of the hot charge materials inside the furnace, the water will be evaporated and the charge will be cooled. During furnace operation rather large water leaks will increase risk of bridge formation or agglomeration of the charge, but due to the constant supply of energy to the furnace the charge is thought to be able to evaporate large amounts of water. Bridges will, on the other hand, cause a reduced permeability of the charge, which again will lead to a poor drying of wet charge. In addition the prereluction of the charge in the FeMn and SiMn processes, which reduces the amount of available oxygen, will be reduced. This increases the explosive or eruptive power of the charge materials.

Many complex phenomena take place in the furnace burden, and it is therefore quite difficult to assess the amount of water leakage that is acceptable. In order to make a first assessment of this amount, a simplified calculation was made based on a similar work performed by the Silicon industry: Tveit et al. [3] calculated that the charge of a submerged arc Si furnace, which has a top temperature of 1500°C in the calculation, can evaporate in the order of 5 m³ water after it has been switched off. The condition is a charge height of 3 m and that the water leakage is distributed over 2 m² and the charge is cooled from 1500°C to 400°C. Additional water added to the furnace may become harmful if it is suddenly mixed with hot charge materials.

A similar calculation can be made for a HC FeMn furnace. Obviously, the amount of water that the charge is able to evaporate will be very dependent on the temperature profile of the charge. In addition the heat capacity of the charge will change depending on the blend used as well. A simplified approximation will thus be made. It is assumed that the charge height is 3 m, the temperature range is linear from 200 to 1100°C. As mentioned previously, a bridge would reduce the permeability of the charge above it, and thus most likely reducing the temperatures these and gases these raw materials are exposed to considerably. For simplicity, a charge containing 85 % Braunitz and 15 % coke with a void fraction of 50 % is considered. The average heat capacity, $C_{p,ave}$ of the charge is estimated to be 0.86 kJ/kg·K (estimated from [4, 5]), and the average density, ρ , of the charge mix is estimated to be 1800 kg/m³. If it is assumed that the charge evaporates water effectively down to a temperature of 400°C, as Tveit et al. [3] did, Equation (1) gives the amount of energy available for water evaporation, E :

$$E = C_{p,ave} \cdot \rho \cdot \pi r^2 \cdot h \cdot \Delta T \quad (1)$$

where r is the radius of the area of the water leak at the top of the charge and ΔT is the temperature difference between the charge before and after evaporating water. Since this is a linear case, $\Delta T = (\text{maximum temperature} - 400^\circ\text{C}) = 700^\circ$. Since the charge top temperature is assumed to be 200°C, and thus at a lower temperature than the temperature that evaporates water efficiently the water will not start effective evaporation until reaching some distance (0.66 m) down in the charge. h is thus 2.33 m.

r is quite difficult to estimate, since a leak can be a nice wide spread covering a large area on top of the charge (ideal situation) or a thin jet hitting just a small spot (worst case). As the water trickles down in the charge, it is, however, reasonably correct to assume that the water does not spread out significantly in a cone shape, but keeps within a column.

The energy to evaporate and heat 1 Nm³ H₂O(l), 25°C to 100°C is, according to HSC Chemistry 7.11, 2.58·10⁹ J. The critical amount of water a charge with the given properties and $r = 0.15$ m in a stopped furnace can evaporate is then approximately 70 l. This means that beyond 70 l, the water can start to accumulate. This means that if it takes approximately 1 hour to inspect for undetected water leaks under the furnace hood after stopping the furnace, a 70 l/h water leak is what a water leakage system should be able to detect. By comparison the amount of water in a typical water cooling circuit at one of the operating manganese alloy furnaces is between 5 and 6 m³/h. As mentioned, there is a large uncertainty in this estimate, since the temperature profile will vary greatly in the furnace. Near the electrode much higher temperatures would be expected compared to close to the lining. The estimate of 70 l could with this in mind be viewed as a quite optimistic estimate.

To get a better feel of the forces involved in an explosion caused by water, the TNT equivalent can be calculated. This was done by Lee and Kozak [6], who assumed that a 1 cm layer of raw materials covering an area with a diameter of 1.66 m would react in a crucible at 1500°C, i.e. an equivalent to raw materials being exposed to metal. H₂ and CO gases would be formed by a reaction between evaporated water and carbon present in the furnace.

A 10 % H₂O in the mix would give a shock wave equivalent to a 2.3 kg TNT explosion. To put this into perspective, 1 kg of TNT shatters all windows at 30 m distance. 80 kg TNT shatters windows in a radius of 250 m, destroys normal roofs at 40 m and walls at 23 m [3]. In addition, decomposition of Mn sources with higher oxides releasing available oxygen will add significantly to the force of an eruption.

2. SAFETY IMPROVEMENTS

2.1. Safety in vicinity of the electrodes

The safety has been improved both by improving the physical barriers and by changing routines. There is now a mandatory course with a yearly update for all personnel who will be working in the vicinity of the electrodes. This includes both work instructions, understanding of the potential hazards and first aid. There is a demand that minimum two persons have to be present when work is done around the electrodes.

Except for the 4th floor, where the casing is being welded and the electrode paste is being loaded into the electrode, there is no access for non-electricians to the electrodes when the furnace power is on. Physical barriers are now in place in these areas.

At the 4th floor there are now physical barriers to restrict access to the critical areas. To prevent electrical contact between the electrodes and from an electrode to ground, isolating plates have been mounted on the floor and between the electrodes, as shown in figure 1. The picture also shows the isolating walls separating the silo tubes from the electrode area.

A clear description of the area and work procedures for that area is posted. Pictures are used to describe the procedures in a clear manner, as shown in figure 2. Standard protective wear for people in contact with electrodes now include dry clothing, dry shoes and special isolating rubber gloves to increase the physical barriers. Wooden ladders are used when needed. There is also a focus to keep a tidy work environment.



Figure 1: A locked gate restricts the access to the electrodes, and isolating plates have been mounted between the electrodes to prevent contact between them

2.2. Water leakage detection

Traditionally water leaks have been detected during furnace operation by using e.g. H_2 measurements, unsteady furnace operation or the raw material feed rate. H_2 is formed by reaction between $H_2O(g)$ and $CO(g)$ [7]. However, time and again rather large leaks have been discovered when no such signals have been observed by the operators. This can be due to the leak being away from the electrode, not being exposed to high temperatures. In addition, large amounts of water enter the furnace through the raw materials, either as snow and ice during the winter months or through wet raw materials due to rainy summers in Norway, may disturb the signal. The problem of using H_2 raw material feed and other secondary parameters was also identified by Dennis and Ganguly [8].



Figure 2: Procedures are posted and illustrated clearly by pictures

A crane is needed for handling both the electrode casings and the electrode paste. A double isolation is now in place between the lifting gear and ground. There is an isolation surveillance system in place, where a red light gives a warning of failing isolation. The procedures then demand that the isolation has to be checked and repaired before further work is done.

Based on the theoretical calculations and assessment of the size of a leak that the operators would consider to be critical, the goal of the water leak project was set to detection of water leaks over 60 l/h or 1 l/m. In the years 2009–2011 the Norwegian Labour Inspection Authority came with a set of regulations regarding water leakage detection in the ferroalloy industry in Norway. This was a direct consequence of the eruption at Elkem Thamshavn in 2006 [3]. The regulations are a result of a dialogue with the industry. The general requirements for a satisfying system were that a significant leak has to be identified. The water leakage detection system should identify where the leak is, and give an alarm to the operators with necessary information. In addition the valves for controlling the water flow should be placed in a safe area so that they can be operated without exposing operators to danger.

One of the methods for detection of water leakages in the furnace is an IR camera. This is used today for inspection under the furnace hood and helps to overcome fumes and dust that often cause a problem for getting a clear view. An example is shown in figure 3 where a water leakage hitting an electrode can be seen as the dark area. However, success with the hand held IR camera requires a trained user and that the water leakage hits a visible hot area in the furnace, such as an electrode. As a result, there are different opinions on whether or not this is a useful tool for identifying leaks. An idea for an online surveillance system was to mount IR cameras on hatches around the furnace vicinity, as shown in figure 4.

Part of the problem encountered was that the view was clogged by dust. A possible solution for this would be purging the area in front of the lens by nitrogen. In addition by drawing a simple coverage map of the areas that would be covered by mounting cameras revealed that a lot of cameras would be needed to cover the charge top, and the area between the electrodes would be a challenge to cover in a satisfying way. During an evaluation of water leakage systems in 2009 it was decided not to go further with this system due to the poor coverage and questionable ability to detect small water leaks. Hand held IR cameras are used today for inspection.

The water leak detection system described by Dennis and Ganguly [8], where the water vapour concentration in the off gas is measured, was assessed. A deviation from a baseline will indicate that a new water source, such as a water leak, is introduced.

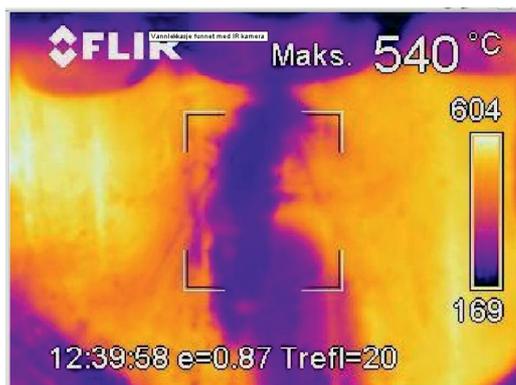


Figure 3: Water leakage under the furnace roof detected by an IR camera (picture taken by Haraldsen, Eramet Norway AS)



Figure 4: IR camera mounted on one of the hatches of the furnace roof. (Picture by Iversen 2007)

The system is reported as reliable and with low maintenance cost after a trial period of 12 months. The system was not chosen mainly due to the fact that it only considers finding out whether or not there is a leak, not where in the system there is a leak. In addition, a small leak was defined as below 20 l/m, i.e. roughly 20 times higher than the defined goal of 1 l/m. A question was also raised concerning so called false alarms, i.e. an alarm when there is no leak, connected to varying amounts of snow and ice in the system during the winter. These potential problems could probably have been solved if the system was more in line with our needs.

Another principle that was considered was dissolving helium (He) in the water and using a very sensitive detection device to measure if there is any He in the off gas. The advantage is that any He in the system will be from a leak, since no raw materials, including water, contains He. He is used today for discovering leaks in e.g. steam turbines, condenser tubes, heat exchangers, public water supply etc. There is (or was) such a system implemented in a blast furnace, which is where the idea came from. However, the authors have not been successful in getting a good description of such a system. The problem also in this case is that the system will only be able to reveal that there is a leak, but will not be able to locate the leak. The system is also very sensitive to the amount of off gas produced by the furnace. If 0.1 ppm He is the detection limit, the off gas amount is 10 kNm³/h and the solubility of He in water is $1.39 \cdot 10^{-3}$ g/kg water at 35°C [9] the smallest leak that can be detected will be about 115 liters per hour, which is higher than our goal. In addition, the lack of response from the suppliers of He detectors when they are informed of the dust concentration in the off gas, indicates that there may be problems regarding approaching the accuracy needed for detection.

Further, it was identified, based on the experience shared by Elkem, both through publication [3] and personal communication with Halvard Tveit, Elkem, that water course monitoring could be a solution. Since installation cost is much lower for ultrasonic flow meters compared to mass flow meters, it was decided to test ultrasonic flow measurement. This was also the system chosen by Elkem. The test gave reasonably good results, and it was decided to go forward with an installation on a furnace. A closed cooling system was chosen to lower the amount of particles in the water flow and thus increase the accuracy of the system. Experience show that closed cooling systems will cool the equipment more efficiently over time due to less growing in the system and lower the maintenance const.

Another benefit of a closed cooling water system is that the total addition of make-up water to the system can be monitored; giving a system that allows for detection of very small water leakages. Simply adding such a measurement to an existing closed cooling water system would enable

identification of the presence of very small leaks in the system. Based on this, the furnace can be shut down and the leak can be investigated.

After installation of the system on all water courses of a furnace, it was seen that a rather high limit on the difference between water in and out (hereafter called the difference) of a water course was needed to avoid excessive false alarms. False alarms were identified as one of the worst enemies of a water leakage detection system, as it would undermine the reliability of the system. According to the producer the measurement equipment should have much less uncertainty, typically below 0.5 %, but particles or air bubbles in the water, error in the temperature measurement, turbulence etc. would contribute to increasing the measurement error. An analysis of the data showed that the average variation in the difference deviated from 0, and was corrected accordingly to tune the system. The alarm limits could then be set at 400 l/h without false alarms. This system is operating without any delay, and will give an alarm if there is a large leak.

Further, to meet the goal of detecting 60 l/h, the signal noise was dampened by using a moving average over several minutes. As expected, a longer moving average gives a better result. A two minute moving average has been chosen for the first implementation of this system. The standard deviation is then calculated for large set of data for the difference of each water course. An alarm is set for 4.5 times the standard deviation, since we know that all normal variation will be within this limit. This is shown as the red line in figure 5. The limit will be individual for each water course since the variation in difference is different for the different water courses. Further, since the water cooling system is closed, there is an alarm if more than 500 l of water is added to the water cooling system per 24 hours. This amounts to 20.8 l/h. To be able to locate which water course the leak is at, the data system is set up so that the dampened adjusted difference in flow is shown as a column for each water course. An adjustable alarm limit, where the column turns yellow if above the limit, has been added. This alarm limit is also based upon the standard deviation, and the limit is set for example as 200%·standard deviation. When the furnace operator identifies that there is a small leak somewhere in the system, the alarm limit can be constantly adjusted down, until one of the water courses more or less continuously turns yellow, as shown in figure 5. Tests done have shown that leaks down to approximately 45 l/h can easily be found by this system.

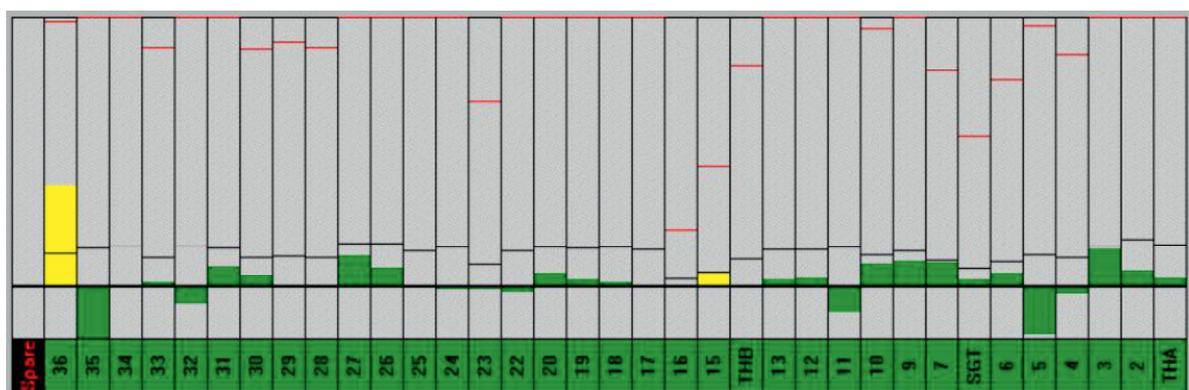


Figure 5: Illustrative diagram showing the operator window for finding small leaks. The water courses are numbered. Each column shows the adjusted dampened difference between water in and out of a course. The red limit is 4.5·standard deviation and the black line is the adjustable limit

The goal is reach a system that will give automatic alarm at leaks down to 60 l/h. To reach this, methods from statistical process control will be introduced. The situation that needs to be identified is what can be called a level change. Testing is currently done where e.g. six subsequent

measurements above the limit will trigger the alarm instead of just one. Preliminary tests on historical data are very promising.

As a result of being able to locate the approximate leak size and which water course that is leaking the routines have been changed accordingly. When the leak is above 70 l/h, the furnace will be stopped. The water for the particular course will then be shut off, which is now done in a safe area away from the furnace. After one hour, the electrodes will be moved up and down 10 cm to release any bridges. After another 30 minutes operators are allowed into the exposed area and will inspect the furnace to locate and repair the leak. The thought is that the 1.5 hours will allow the water from the leak to evaporate, thus reducing the risk of wet material being exposed to a hot zone in the furnace.

2.3. Physical barriers

As part of the strategy of Eramet, actions are taken to avoid the causes for explosions through for example water leakage detection systems and limits on the fines content in the charge blends. At the same time it is acknowledged that there is always a small risk remaining. This has been further reduced by installing blast walls around our furnaces, protecting workers and preventing them from entering dangerous areas. In addition, during rebuilding of the cooling water systems, the cooling water controls have been moved outside of exposed areas.

3. SUMMARY

Eramet Norway AS has significantly increased the safety by dedicated HSE work in the last years. The main focus of this article has been the work on safety related to the electrodes and water leaks.

Procedures and physical barriers related to work in the vicinity of the electrodes has been reviewed. A mandatory course with a yearly update is now in place for the personnel. Isolating material has also been introduced to prevent short circuiting and demands for personal safety equipment has been upgraded.

Water leaks are known to be potentially fatal and can led to damage to the furnace equipment. Water flow measurements have been installed so that leaks down to 45 l/h can be detected and located before operators enter the exposed area around the furnace roof for inspection and repair. Procedures related to water leaks have been reviewed accordingly.

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