Severe corrosion in a waste incinerator plant due to flue gas and steam leakage

Ton de Weijer and Wally Huijbregts

Anti-corrosion methods and MaterialsVolume 50-2003-pg 334-340

The authors
Ton de Weijer is based at ARN BV, Weurt, The Netherlands.
Wally Huijbregts is based at Huijbregts Corrosion Consultancy, Renkum, The Netherlands.

Keywords
Incineration, Waste disposal, Corrosion environments

Abstract
In a new build waste incinerator, the waste (refuse derived fuel) was burned on a discontinuous moving grate. Frequent furnace overpressure peaks occurred because of this firing method and as a result, flue gas and fly-ash were pushed out of the boiler and into the building. During the plant start up period, a seal in a water-feed pipeline broke, and a large amount of condensed steam was discharged into the boiler house. Shortly thereafter, very severe corrosion was noticed on the galvanised gangways, steel building components, the boiler aluminium sheeting and on processing lines. A theoretical study of the condensation of the flue gas indicated that sulphuric acid would condense before it reached the external aluminium sheeting and that under normal conditions, dry hydrochloric acid fumes would be removed by the boiler house ventilators. However, the steam leakage had caused the hydrochloric acid to be dissolved in the condensed water and that had resulted in the severe corrosion damage, which had become evident subsequently.

The Emerald Research Register for this journal is available at
httpal+vww.emeraldinsight.com/researchregister
The current issue and full text archive of this journal is available at
httpa/www.emeraldinsight.com/0003-5599.htm

1. Introduction

Afvalverwerking Regio Nijmegen (ARN B.V) took a new incineration unit into experimental (start-up and commissioning) operation in November 1994. It is normal for this type installation to utilise refuse derived fuel (RDF). During the pre-treatment stage, all inert components such as sand, glass, stones and metals are removed from the waste and the remaining mixture of paper and plastics is burned in the boiler. During the first period of operation, there was some difficulty in achieving a steady firing rate on the unit. This resulted in peaks of combustion gas overpressure in the unit and, in consequence, flue gas was discharged from the boiler casing into the building. The precise cause of the overpressure phenomenon was not clear at that time because furnace overpressure had not been observed on any of the other three identical boilers that were already in service elsewhere in the Netherlands.
In an unrelated incident, a seal in a feedwater pipeline got burst in the early hours of the morning at the top of the building, about 30 tons of condensed steam escaped into the boiler house. Four hours later, the line was isolated after the plant was taken out of operation. A new seal was installed and was then returned to service in order to dry the building as soon as possible (i.e. within 23 h) after the incident occurred. However, during a boiler inspection conducted a month later, very severe corrosion was observed to gangways, boiler external cladding and on the steel walls of boilerhouse.

2. Fiscal considerations

A few days after seal leakage, it became clear that the atmosphere within the building had been very corrosive. The operators insurance company was informed and the building had to be cleaned as thoroughly and as soon as possible. There were problems in arranging for the cleaning to take place because of the following reasons.

- Construction of the plant had been contracted in separate bids to a number of companies (boiler, grate, flue gas cleaning system, turbine, etc.) and there was a tendency to blame each other for the overpressure condition
- The installation was still in the early stages of start up and commissioning operation, thus in part not yet accepted as being the property of ARN B.V, and it would have constituted too high a financial responsibility for the operator to take sole responsibility for ordering the cleaning operation.
- The insurance company did not wish to take responsibility for ordering cleaning activities without a guarantee of the long-term outcome, but cleaning companies would not agree to provide such a guarantee as they were not in control of the cause of the fault condition.

2.1 Actions

Cleaning eventually commenced on 6 May 1995, approximately 3 months after the incident. In the meantime, the cause of the overpressure condition had been identified. It was determined that it resulted from the discontinuous movement of the grate in combination with the burning RDF. Compressed packs of RDF heat up and do not burn homogeneously. When a pack became very hot and the grate then moved, the pack disintegrated and almost explosive combustion could occur. This explained the sudden peaks of overpressure and it also explained the fact that the other plants in Holland with the same technical components, but which were firing standard waste (not using the RDF packages) had experienced no overpressure peaks.

A complication in solving the problem was that the grate company had patented the discontinuous moving grate because this system caused much less wear to the grate and enhanced the service life considerably. In due course it was discovered that the application of a water-cooled continuous moving system, and injection of combustion air from above the grate, solved the firing problem.

The cause of flue gas leakage from the boiler casing was traced to a length of missing weld, 50 m X 2 mm from an overall total of some 15 km of welded length in the unit. Waste incineration boilers are never 100 per cent leak tight, though this is not a problem under normal operating conditions of negative pressure. Installing the missing weld alleviated the flue gas leakage problem.

The plant was returned to operation again after a 4 month outage and renovation of the building commenced immediately afterwards.

2.2 Extent of the damage

It was observed that the boiler house had sustained considerable damage, see Figures 1-4.
The steel outer walls of the building were corroded severely and had to be replaced and steel construction girders had to be renovated, as did galvanised gangways.
It was determined that the cable trays required replacement.
The whole building was cleaned with water to remove the acid, which necessitated that the 40 m building height needed to be scaffolded, and the cleaning itself implemented and supervised.
Electric process equipment also had to be checked. Fortunately, most of the instrumentation and switchgear housings were watertight and damage to these components was limited.
However, it was found that spring discs, from which the boiler was suspended, had sustained stress corrosion cracking and had to be removed completely.

The total corrosion material damage was approximately 7.72 million euros. Consequential losses due to the unplanned outage amounted to approximately 11 million euros, were not insured.

The corrosion damage was not the result of normal operation, and therefore a claim was made from the insurance company under the provisions of the construction all risk (CAR) insurance policy, which is not an easy case to prove and the insurance company refused to accept the initial claim.

The refusal was based on the following assertions:

- the operator had a boiler that leaked flue gas;
- the operator had not exercised due care because the boiler was not shut down immediately after the seal leak; and
- the operator should not have taken the boiler back into operation.

However, it was not clear why the steam leak had resulted in excessive corrosion. The insurance company suggested that fly-ash in the boiler house was acidic and became very corrosive as a result of the steam leakage, but fly-ash deposits were not present because the removal of the dry fly-ash was part of the normal cleaning of the boiler house and the costs for such an operation. If present, such corrosion should be evident as "under-deposit attack", but this mechanism had not been observed.

A detailed study of the corrosion mechanism was necessary in order to clarify the cause of the damage.

Figure 1 Corroded galvanised gangways

Figure 2 Corroded ventilator

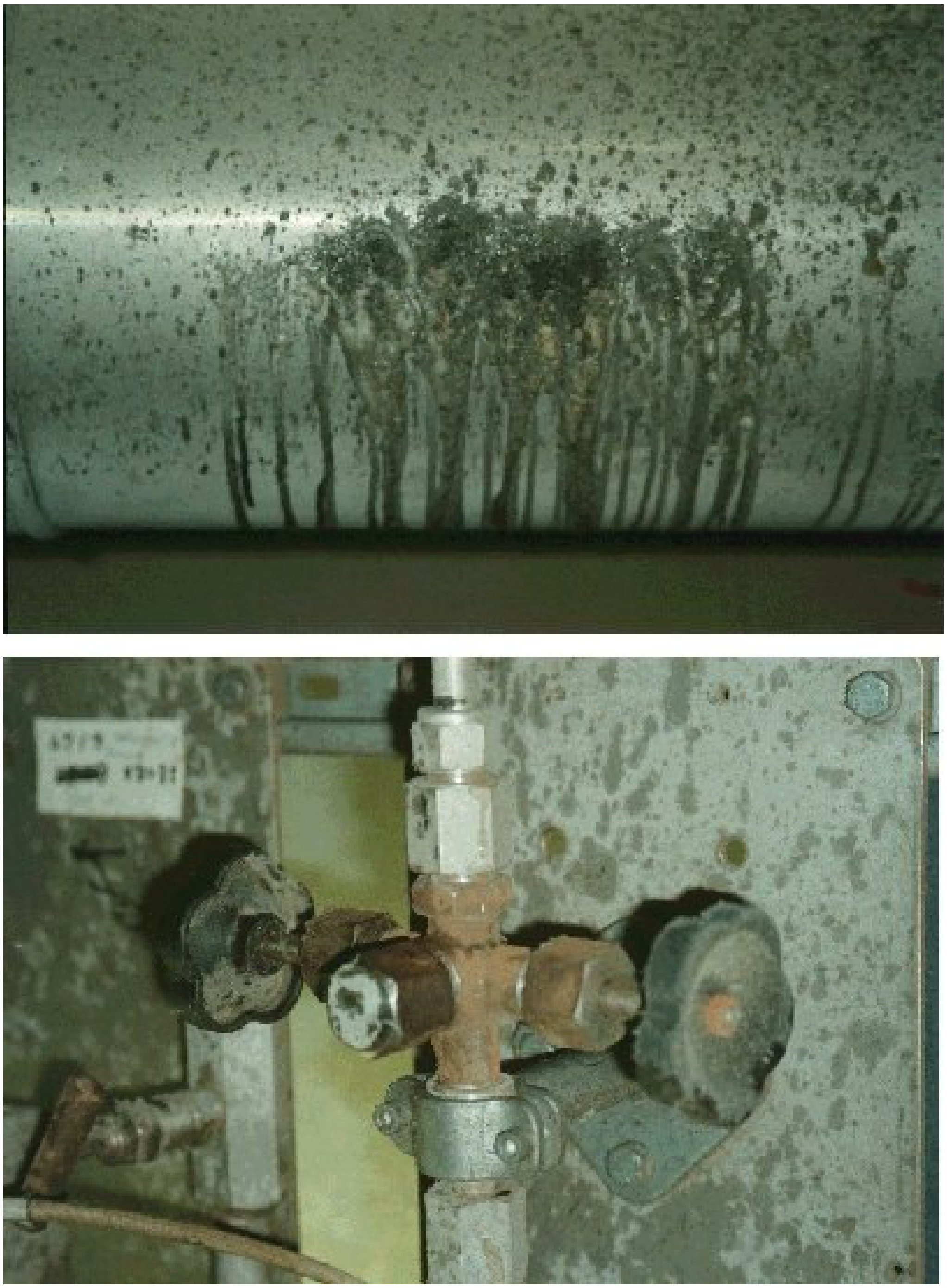

Figure 3 Corroded aluminium isolation plates and steel valves

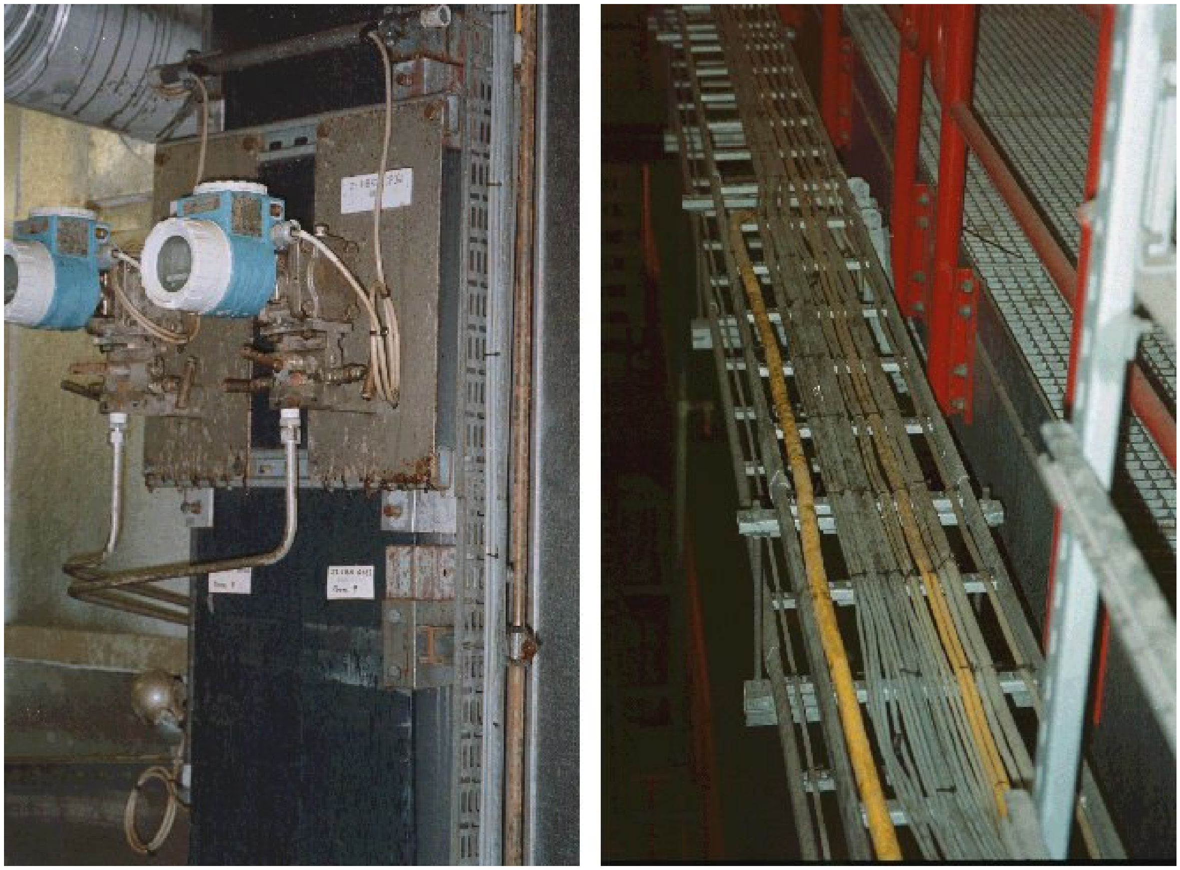

Figure 4 Corroded switches and damaged cable trays

3. Background

In order to understand the excessive corrosion damage, KEMA were requested to model various scenarios before and after the steam leakage.
The following calculations were made:

- estimation of the flue gas concentration in the boiler house;
- prediction of the dew points of the gases at the isolation wall and within the boiler house;
- estimation of the pH value of condensed moisture after the steam leakage;
- estimation of the expected corrosion which might result from the condensed acidic moisture.

3.1 Estimation of flue gas concentration

The maximum flue gas concentration in the building as a result of the leakage in the boiler and the overpressure peaks was calculated approximately. The boiler was operated under negative pressure of 2 mbar, and the pressure peaks were about 2.5 mbar. There was an overpressure of about 0.5 mbar during approximately 10 per cent of the time. Because of the missing section of the casement weld 50 m x 2 mm, the flue gas leakage into the building amounted to - 134 m^3 /h.

The ventilation in the building was 72,000 m^3/h. The increase of the flue gas concentration in the building was calculated by means of the equation:

C =leakage/ventilation x (t/(1 + t))

The ultimate composition of the flue gas in the building is presented in Table I.

Table I

Gas	Boiler	Building
$S0_3$	18 vppm	0.033 vppm
SO_2	140 vppm	0.260 vppm
HCI	871 vppm	1.6 vppm
H_2O	125 mbar	7.2 mbar

It can be assumed that the flue gas spread homogeneously throughout the boiler house and that local acid condensation would not occur. It was assumed that a higher flue gas concentration would be present in direct proximity of the leakage than would be the case at the sidewalls of the building.

3.2 Calculation of dewpoints

The dewpoints of the gases S03, SO2 and HCI were calculated by means of the equations of Verhoff and Kiang.

A: Dewpoint equation Of S03 according to Verhoff:

$$Td = 1000/\{2.276 - 0.0294\ln(_{PH2O}) - 0.0858\ln(P_{S03}) + 0.0062\ln(P_{H2O} \times P_{SO3})\}$$

B: Dewpoint equation of HCl according to Kiang:

$$Td = 1000/\{3.7368 - 0.1591 \ln(_{PH2O}) - 0.0326\ln(P_{HCl}) + 0.00269\ln(P_{H2O} X P_{HCl})\}$$

C: Dewpoint equation of S02 according to Kiang:

$$Td = 1000/ \{3.9526 - 0.1863\ln(PHZo) + 0.000867\ln(P_{SO2}) - 0.00091\ln(P_{H2O} \times P_{SO2})\}$$

Pressures in the equations are given in mm Hg.

The dewpoints directly behind the steel membrane wall of the boiler (still within the isolation) at 12.5 per cent H20 and those in the building (at a water vapour pressure of 7.2 mbar) are presented in

Figures 5 and 6 and are summarised in the Table II. The water vapour pressure in the building of 7.2 mbar was obtained at a relative humidity of 60 per cent and an outside temperature of 10℃.

Table II

Gas	Boiler	Building	Dewpoint (℃)	Dewpoint (℃J
$S0_3$	18 vppm	0.033 vppm	146	58
$S0_2$	140	0.260 vppm	48	2
HCI	871	1.6 vppm	42	1
H_2O	125	7.2 mbar	-	

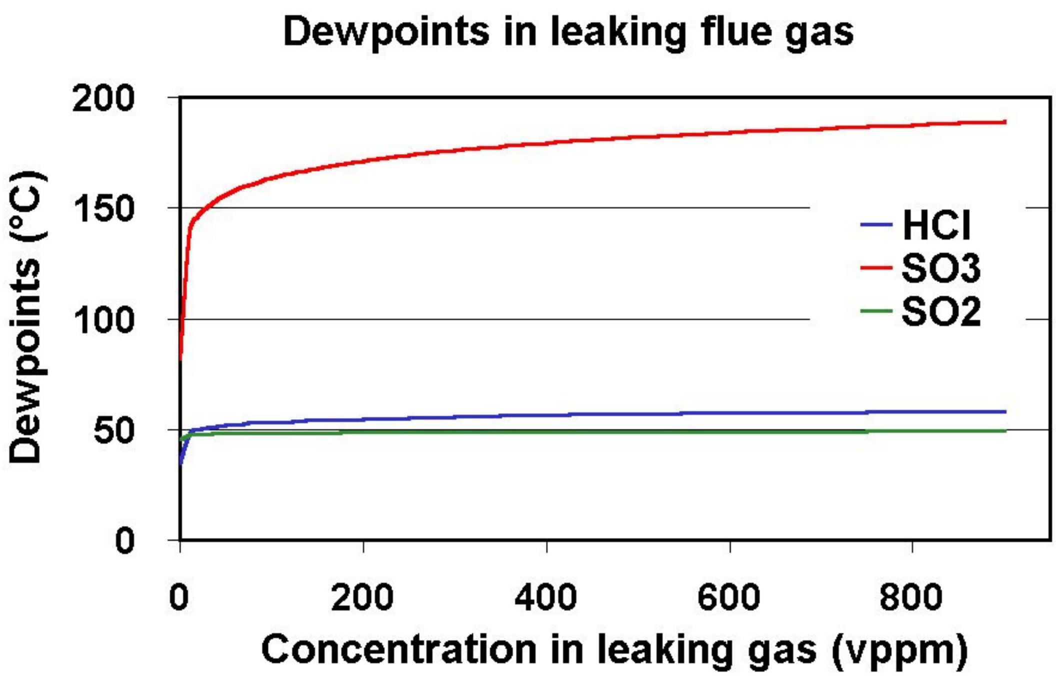

Figure 5 Dewpoints of the leaking flue gas inside of the isolation

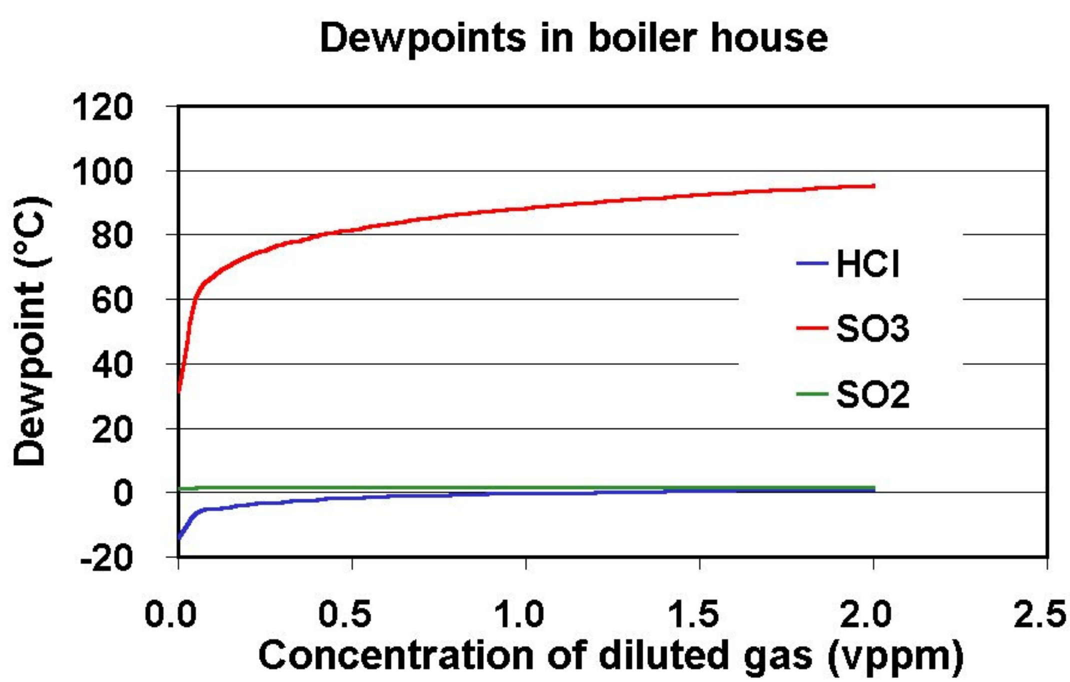

Figure 6 Dewpoints of the diluted flue gas in the boiler house.

3.3 Local environment behind the aluminium sheeting

Within the local environment between the membrane wall of the boiler and the aluminium sheeting the temperature was estimated to have fallen from about 300℃ down to about 45℃. The temperature in the boiler hall was about 30℃ when the boiler was in operation.

The effects of sulphur trioxide (S03) and hydrochloric acid (HCl) were the corrosive gases to be considered in the escaped flue gas.

ints; in leaking flue gas

0.5 1

3.3.1 $S0_3$/Sulphuric acid

The $S0_3$ concentration decreased as a result of dilution in the lagging void from a maximum of 18 vppm at the membrane wall down to the calculated value of 0.033 vppm (diluted flue gas in the boiler house). The calculated dewpoints for these concentrations were 146 and 58℃, respectively. As soon as the flue gas escaped from the boiler, droplets of 80 per cent sulphuric acid were formed.

Condensation of sulphuric acid arose already would have formed before the flue gas reached the aluminium plates.

Insulation retention fittings that were installed within the area inside the aluminium cladding exhibited severe attack of the nylon instrument control airlines already from the start of the boiler. Because of the hot flue gas and the condensed sulphuric acid the nylon lines leaked.

3.3.2 Hydrochloric acid

The dewpoint temperatures for the hydrochloric acid in the flue gas at the membrane wall and in the boiler house were very low. The hydrochloric acid concentrations amounted 871 vppm (undiluted flue gas) and 1.6 vppm hydrochloric acid (diluted flue gas). The dewpoints at the corresponding water vapour pressures were 58 and 1℃, respectively. In the consequence, therefore, it could be concluded that hydrochloric acid did not condense in the isolation space or on the inside of the aluminium sheeting. Dry hydrochloric acid was present in the boiler house as a gas and would normally be removed by the boiler house ventilators.

However, hydrochloric acid is able to dissolve in sulphuric acid concentrations lower than about 60 per cent. In the more concentrated 80 per cent sulphuric acid droplets directly behind the membrane wall, the hydrochloric acid could not dissolve.

3.4 Local environment in the boiler house.

The boiler was in operation when the boiler house was filled with condensed moisture as a result of the steam leak. In the consequence, the escaping hydrochloric acid would dissolve instantaneously in the condensing water droplets. The ventilation fans would not remove the condensed acid droplets which would settle onto the nearby metallic surfaces.
The acid therefore remained within the boiler house and this explained the observed severe corrosion damage. Corrosion was noticeable mainly as general corrosion of the cooler steel boiler house walls and the galvanised gangways. However, the hardened carbon steel spring discs were also cracked after the steam leakage.

3.4.1 Calculated pH value of the condensed moisture

If the following assumptions are made it is possible to calculate how quickly the condensed water droplets would become acidic.

- The amount of moisture will decrease slowly, and Figure 7 gives the assumed decrease in amount of condensed moisture.
- Hydrochloric acid will play an important role; the amount of HCl is a factor of six times larger than that of SO_2. SO_2 does not dissolve easily in condensed water. By contrast, hydrochloric acid is a strong acid and will therefore be the dominant factor affecting the pH value.
- Because of the high dewpoint of $S0_3$, sulphuric acid would already have condensed in the isolation void.

The pH value of the condensed water resulting from the dissolution of the hydrochloric acid was calculated by means ofthe equation:

$pH = -\log(L_g X C_{Cl}/L_{mol} X t/C_w)$

where

C_w amount of condensation in the boiler house (L, decreases according the line in Figure 2);
C_{cl} concentrated HCl in flue gas (10^{-6} vppm);
L_{mol} amount of litres per Mol gas (22.41/mol);
L_g leakage of the flue gas (134.0001/h)
t - start of the water condensation in the boiler house (hours).

The results of the calculations are given in Figure 7. This shows that the water droplets would have become very acidic within a short time. This explains the extensive corrosion 3amage.

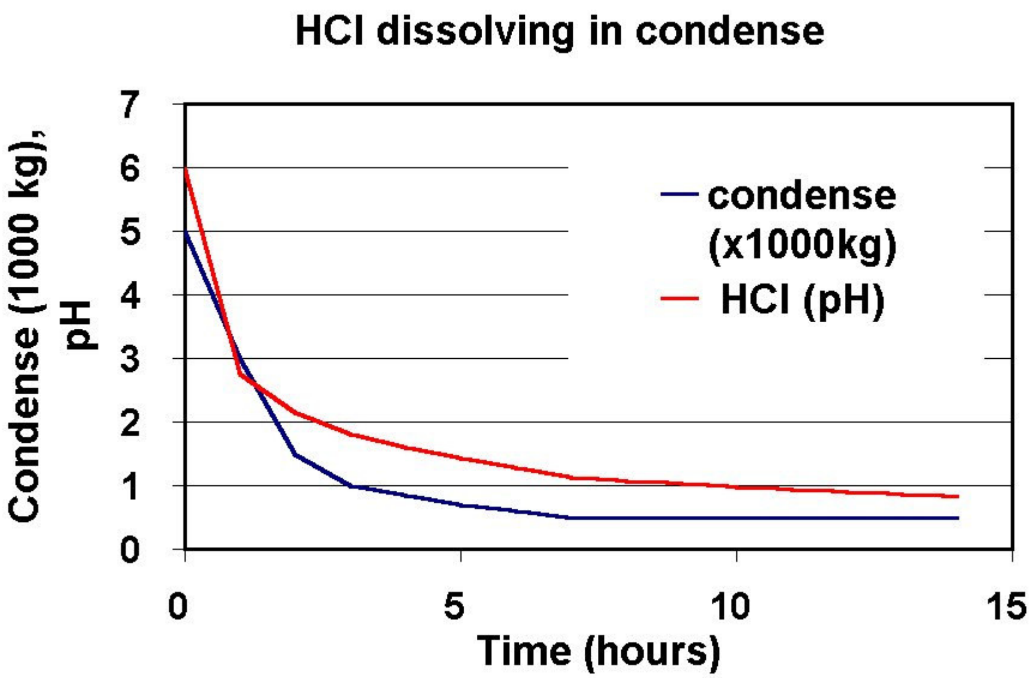

Figure 7 Decrease of pH value of the condensed moisture, depending on the assumed decrease of amount of condensed moisture in the boiler house

3.4.2 Calculation of the corrosion rate

The maximum corrosion can be calculated by applying the equation presented below, «-ith the assumptions that hydrochloric acid and SOZ would dissolve 100 per cent and 15 per cent, respectively, in the condensed moisture.

Corrosion rate= $V_k(2f_1C_{so2} + C_{HCl})$ X $10^{-6}/L_{mol}$ X M_{Fe}/n X t/(A X sd)

Where

V_k	ventilation in boiler house (72,000,0001/h);
C	concentration of SOZ and HCl in the boiler house, before the gasses dissolve in the condensed water (vppm);
L_{mol}	amount of litres per mol (22.41/mol);
f_1	fraction of SOZ that dissolves in the condensed water (0.15);
M_{Fe}	Molecular weight of Fe (56.000 mg);
n	electron valency of Fe ion (n=3;
t	operation time (1,400 h);
A	surface in boiler house that is assumed to be corroded (mmZ); sd - specific density of steel (7.8 mg/mm3).

The calculated corrosion rate of steel after a period of 1400 h of operation is given in Figure 8.

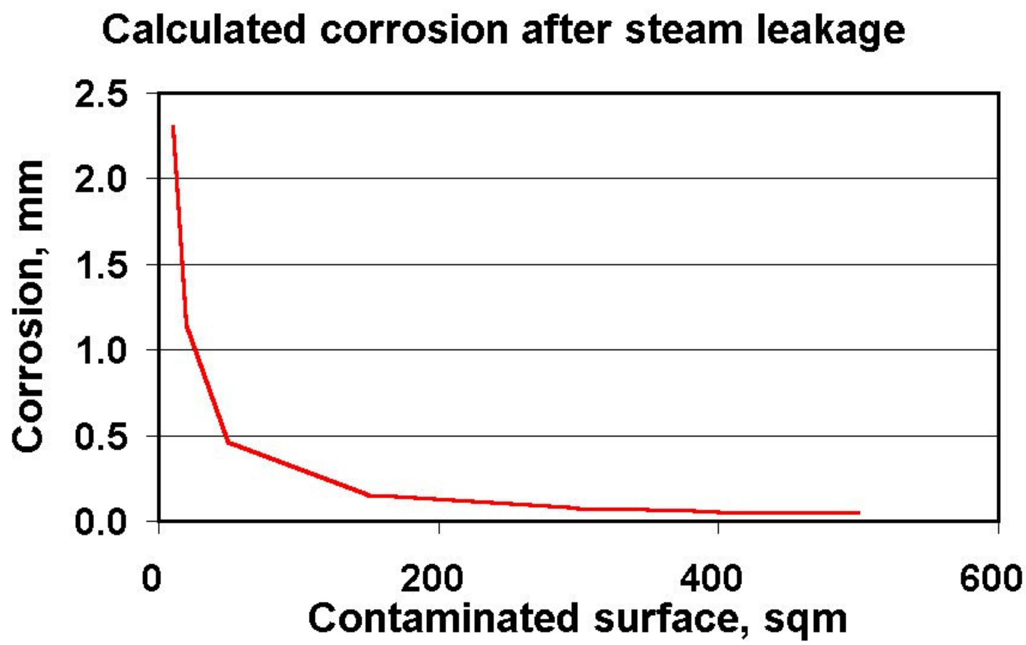

Figure 8. Calculated corrosion rate of steel after a period of 2 months.

3.4.3 Cracking of the spring discs

The upper part of the boiler was hung on the steel support framework, many spring discs and hanger bars were required for this purpose. The spring discs were mounted as packages as a very strong spring system. The material of the discs was hardened/stress relieved carbon steel.

Directly after the steam leakage it was discovered that many of the discs were fractured as a result of the acid mist in the top of the boiler house. Under normal operating conditions, the atmosphere in the boiler house is dry and warm and condensation is not noticed. Microscopic examination of the coils indicated that cracking was the result of cathodic SCC or hydrogen embrittlement.
The calculated corrosion of carbon steel after 1,400 h of operation is given in Figure 8.

4. Improvements

After the incident had taken place, the following modifications were introduced to ensure that a repeat of the episode would be avoided.

Flue gas leakage was prevented by the following actions:

- repair of the missing membrane seal weld;
- installation of a continuous moving firing grate to prevent sudden pressure increases during the firing process;
- introduction of additional firing air from the sides above the grate in order to ensure optimal combustion efficiency.

5. Conclusions

1. Corrosion damage to external walls, boiler sheeting and galvanised gangways was the result of the steam leakage: hydrochloric acid from the leaking boiler made the condensed moisture very acidic in a short time.

2. Under conditions of normal operation, any dry hydrochloric acid that escaped from the boiler would be removed from the boiler house by means of the boiler house ventilators.

3. The $S0_3$ gas in the flue gas, leaking from the boiler, condensed as sulphuric acid inside the aluminium sheeting on the inside of the isolation void.

4. ARN B.V began an arbitrage to appeal the claim refusal of insurance in 1997. (The CAR-policy prescribed arbitrage in the case of parties not reaching agreement.)

5. In early 2002, the arbiters concluded that the damage sustained by the plant was covered by the CAR policy.