Contribution to the Control of Corrosion Problems on Incinerators with Water-Wall Steam Generators

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ABSTRACT

Starting with the course of development of the incinerator plant of the city of Düsseldorf, the paper presents the experience with tube corrosion during the operation period of 6 1/2 years. The causes and control methods for corrosion are presented. Finally there is demonstrated by the example of the fifth incinerator unit at Düsseldorf, which is in a final stage of construction, how by the close cooperation between boiler manufacturer and operator the incinerator units with heat recovery have reached a state of the art which allows the statement:

In spite of corrosion problems, economical energy recovery in the form of high pressure high temperature steam generation is possible by refuse incineration in practically normal water-wall units.

INTRODUCTION

The incinerator plant of the city of Düsseldorf was planned and built in the years 1961 to 1965. The experiences of the pilot plant which was operated during the same period, furnished the basis for the design of the final plant. The construction period, which began in 1963, ended with the start of the first unit in November 1965.

In Düsseldorf as in other cities of the Federal Republic of Germany where incinerator plants in the sixties were put into operation, the main objective was the development and construction of a grate system, safe in operation and with a good burn-out.

An example for these developments is the “Roller-Grate-System-Düsseldorf” that was designed by the municipal utility of Düsseldorf and constructed and tested in close cooperation with two boiler manufacturers at Düsseldorf. The good results obtained in tests with this incineration facility at that time contributed to the construction concepts incorporated into the new full size plant which is well known. This plant today has passed an operating time of about 43,000 h for each of the four units and has burned a total amount of about 1.6 million metric tons of solid waste.

In Düsseldorf as in other plants the well known grate-systems have reached a “state of the art” by long-time experience and further development. For the time being, no substantial improvement is necessary in this field.

TUBE CORROSION

A quite new problem emerged, however, with the onset of corrosion at different parts of the steam generators which were incorporated with the refuse incinerators. For different reasons, among others the economy, the construction and operation of large incinerator plants in Germany has been put into the hands of municipal power plants or similar institutions. This had the result that in the design of the incinerator plants, the same design elements have been used as in the design of coal-fired power-plant steam boilers. For example, to save construction costs and volume, the incinerator steam generator was built directly on top of the furnace, instead of separating the furnace from the so-called waste heat boiler as practiced in former times. In addition it was desired to
Fig. 1 No. 1-4 incinerator with roller grates system, Dusseldorf.

utilize the steam for power generation and district heating. Therefore the steam conditions were matched to those of the power plants. In some plants large power plant boilers were incorporated and operated with combined refuse and oil or coal fired combustion chambers.

In 1966 for the first time a large plant reported tube corrosion in the first boiler pass behind the incinerator furnace. Subsequently in other large plants the same phenomenon appeared with temporal displacement according to the operating conditions and times [1,2].

The experiences accumulated at Dusseldorf (Fig. 1) may be used as an example.

For the first time after about 1000 h of operation time we experienced comparatively severe corrosion on the tubes of the first stage superheater at the side of the direction of gas flow (Location 1). The uppermost rows of tubes of the superheater carried, under a relatively small scale of deposits, a heavy layer of corrosion products. By the thickness of this layer it had to be concluded that rapid wastage of these tubes could be expected. However, as operations continued, the corrosion rate declined and has reached a level which causes a barely measurable waste of material. The tubes now are covered with a hard layer of deposits.

In 1967 after more tube failures had been reported at other incinerator plants, in Dusseldorf the tubes just above the furnace were inspected and at the lower area of the side walls, the first indications of corrosion were found (Location 2). The appearance of corrosion products pointed to destruction of the material by reducing gas atmosphere in combination with hydrochloric acid. As a means of protection, additional secondary air nozzles were installed to build up a curtain of excess air in front of the tubes. Furthermore, the endangered area was studded and covered with a 1/2 in. layer of silicon carbide refractory. In other plants this method of protection already has been applied, with similar good results.

In 1968, a tube rupture occurred in one of our boilers. The cause was investigated and found to be corrosion by the flue gas. Subsequent extensive inspections of the boilers demonstrated that corrosion observed the year before had continued and reached the tube surface above the protected area (Location 3). Not only the side walls but now the front wall was affected. Ultrasonic measurements showed that it was necessary to renew about 30 to 40 tubes in each boiler for a length of about 7 ft. A considerable number of the remaining tubes had to be reinforced by welding. Moreover an extended area of tube surface was studded and concealed.

In 1970, we experienced for the first time a tube failure on the final stage superheater which hangs in the upper part of the first boiler pass (Location 4). The side of the tubes facing the gas flow showed severe corrosion. At first, the same causes were presumed as found in the lower part of the gas pass. Samples and tests of the flue gas proved, however, that in this case another mechanism was involved: erosion. To protect the tubes against the gasflow, flat steel bars were fixed to the affected side of the tubes. This preventive measure has had good results for 1 1/2 years. However we are testing tubes of a material which shows promise of withstanding the attack.

CAUSES AND CONCLUSIONS

In past years various institutions and people have tried to find the causes for corrosion on boiler tubes in refuse incineration plants. A number of theories were brought forward and published, but all theories missed the sure evidence and offered no solution to this problem. Recently the VGB-laboratory has supported the hypothesis that the cause for all corrosion is a reaction between the tube material or the iron oxide protective scale and hydrochloric acid. A great number of tests on tube samples taken from refuse incinerators have proved this assumption [3,4].

The often assumed influence upon the corrosions by alkalisulphate, alkaliyrosulphates or alkalisulphates could not be proved in any case. The reason can be traced to a fast reaction between the alkali compounds
and the sulphates of calcium, magnesium, lead and zinc to complex sulphates of the following kind.

\[(K, Na)_2 (Ca, Pb)_2 (SO_4)_3\]
\[(K, Na)_2 (Mg, Zn)_2 (SO_4)_3\]
\[(K, Na)_2 (Pb, Ca, Zn) (SO_4)_2\]
\[(K, Na) (Al, Fe) (SO_4)_2\]

The composition of low melting compounds of sulphates and chlorides on the tube surfaces is prevented by the formation of a chlorosulphate of the type

\[(K, Na)_2 (Pb, Ca) (SO_4, Cl)_2\]

The waste of tube material at different parts of the boiler can be based on three different reactions:

1. In the first boiler pass corrosion occurs due to the absence of \(O_2\) in the flue gas. In this case, \(FeCl_2\), which evaporates at operating temperatures, is formed on the tube surface.

2. The corrosion on the superheater tubes is caused by chlorine ions or chlorine in “status nascendi” set free by the formation of sulphates from condensing alkali compounds:

\[2 K Cl_2 + SO_3 + 1/2 O_2 \rightarrow K_2 SO_4 + 2 Cl\]

3. Other observed tube defects especially in the second or third pass are mainly caused by a combination of erosion and corrosion.

This proven knowledge from the chemical side fits the conclusions reached by looking at the combustion technique from a practical point of view. The increase of the amount of paper and plastics in the refuse goes together with the increasing content of volatiles in the refuse (see Table 1). These components naturally are forced out on the first part of a grate. This zone not only works as a gasifier but the drying process takes place too. Here an atmosphere is generated, with a high content of unburned gas mixed with inert vapor. This gas mixture cannot burn out in the front part of the furnace, as there is insufficient combustion air and the temperatures are relatively low. The unburned gas travels on into the first flue where a deferred combustion takes place with areas of oxygen deficiency. Extensive flue gas tests have proved this theory to be correct. In these tests the furnace and first pass were divided in several horizontal and vertical measuring levels. Twenty-four samples were taken at each level. As a result of a great number of samples we found a reproducible pattern of oxygen concentration in the gases. For the pictorial presentation in the different measuring levels the points of oxygen equivalence where connected (Figs. 2, 3). As the picture shows, this method produced a useful survey of the gas atmosphere in the furnace and first pass. The identified areas with low excess air coincided with the corroded tube surfaces. Another question to submit is: What influence has the protective covering of the tubes by silicon carbide? A directly chemical influence upon the gases is not apparent, leading to the conclusion that this measure tends to expand the available combustion space. The protected area becomes part of the furnace without the danger of corrosion. The above mentioned results and conclusions have demonstrated the following demands (addressed to the designer and manufacturer) to avoid or reduce tube corrosion:

1. The combustion must be controlled to avoid eddys of unburned gas with lack of oxygen. The combustion process must be completed under most convenient operating conditions.

2. The furnace and gas pass must be long enough to ensure that the gas is as far as possible mixed and burned-out before the impingement on the tube surfaces.

3. The fuel should be available in a most homogenous form. Extreme components of the waste must be mixed with household refuse. Wood, tires and eventually cardboard boxes should be shredded and blended with refuse of lower calorific value to avoid violent variations in the combustion conditions.

4. The refuse feeder device must ensure a most uniform feed rate to the grate.

### Table 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Drying Time, h</th>
<th>Drying Temp., °C</th>
<th>Volatile Cont., %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper (newspaper)</td>
<td>2</td>
<td>110</td>
<td>84.98</td>
</tr>
<tr>
<td>Paper (wrapping: brn)</td>
<td>2</td>
<td>110</td>
<td>88.95</td>
</tr>
<tr>
<td>Cardboard (brown)</td>
<td>2</td>
<td>110</td>
<td>85.94</td>
</tr>
<tr>
<td>Wood (soft)</td>
<td>2</td>
<td>110</td>
<td>86.56</td>
</tr>
<tr>
<td>PVC</td>
<td>2</td>
<td>60</td>
<td>95.30</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>2</td>
<td>60</td>
<td>99.99</td>
</tr>
<tr>
<td>Rubber (tires)</td>
<td>2</td>
<td>60</td>
<td>69.80</td>
</tr>
</tbody>
</table>

OPERATIVE AND CONSTRUCTIVE MEANS

In the incinerator plant at Düsseldorf this knowledge is taken into account as follows.

The municipal and private trucks are directed alternately to various tipping places for a better distribution of the material with high and low calorific value. By the holding capacity of about 10,000 m³ of the bunker it is possible to carry the total arriving refuse.
upon the storage pile, thus a fairly good mixture is achieved. The bulky material, litter, tires, wood etc. is crushed by a hydraulically operated shearing machine.

Shortly a supplementary shredder will be installed for the same purpose and to rip up the great amount of cardboard boxes before incineration.

The experience with the refuse feeder at the existing furnaces shows that it cannot fulfill the demand for a uniform charge to the furnace in any case. This goes together with the change of the volume and decrease in weight of the refuse. On the new unit of the Düsseldorf plant a ram type feeder is installed. Similar devices are already installed at other plants and an improvement can be expected.

To guarantee a better burn-out and mixture of the flue gases in the existing units, the following changes were accomplished. The overfire secondary air was increased to about 25-30 percent of the total air. But the experience is, that with the overfire air by itself a complete mixture of the gases can not be obtained. The relatively cold air does not blend with the gas but pushes it aside.

The first step to change the configuration of the furnace was done by the construction of a fire guiding-wall. This is an arch-like wall of firebrick, built in at the end of the furnace front-roof. This guiding-wall hinders the direct flow of the gases along the roof into the first flue. Furthermore, it is a contraction of the profile of the furnace throat by which part of the gas with high excess air from the end of the grate is forced into the front part of the furnace. Because the secondary air nozzles are located directly in front of the wall a better vortical intermixture of air and gas is achieved. The arch-like configuration of the wall contracts the gas flow in the center of the first flue which results in a more uniform directed gas stream.

The experience with this guiding-wall is very good. Since its erection in the years 1968 and 1969, tube corrosion in the first pass has not continued or spread out. Stream tests with a watertank model and extensive gas analyses have proved the efficiency for the uniformity and burn-out of the gases (See Figs. 4, 5, 6, 7, 8, 9).

Because in this field a close cooperation exists between the “Stadtwerke Düsseldorf” (Municipal utility of Düsseldorf) and the boiler manufacturers, similar explorations were made for another plant. The stream test for this boiler furnished another possibility in the configuration of the first flue for a better direction of the gas. This constructive change is already realized on a new unit (Fig. 10, 11).

Quite recently gas analysis again showed a deterioration of the gas composition in the first pass. The reason
Fig. 4 Water-Tank model of incinerator without guiding wall.

Fig. 5 Water-Tank model of incinerator with guiding wall without overfire air.

Fig. 6 Water-Tank model of incinerator with guiding wall with overfire air.

Fig. 7 Tendency of $O_2$-dispersion cross-section of furnace and lower first gas pass with guiding wall.
is a higher exploitation of the capacity and a steady increase of the calorific value of the refuse in the past two years. The apprehension is that corrosion may begin again. Regular ultrasonic inspections of the tubes are necessary in order not to lose control of this condition. For the new unit of the Düsseldorf plant, the change of the configuration of the furnace was consequently extended. The furnace outlet is now placed above the end of the grate (Fig. 12). By this step the whole principle of the furnace is reversed. While in the former stage the combustion was directed in a so-called counter-flow where the gas streamed against the transport direction of the fuel bed, now fuel and gas streams are guided in the same direction.

The counter-flow furnace has had its justification as long as the hot gas is necessary for the drying process and for ignition of a fuel with relatively low calorific value. With an increased heat value of about 3200-3600 Btu it seems safe to reverse the direction of the gas stream. Hereby with the same construction volume of the furnace and boiler, an essential elongation of the gas pass is achieved, whereby we expect adequate time for burn-out and thorough mixing of the gas before the stream enters the first flue with unprotected tube surfaces. Long experience with a similar shaped furnace in another plant proves the correctness of this hypothesis.

The present operating method of an incinerator permits, with a large enough amount of air, the burning of more or less constant amounts of refuse with various calorific value. In this manner, naturally periods of high air excess and oxygen deficiency are generated. To achieve a more uniform process of combustion, at the Düsseldorf plant an automatic combustion control was tested as an experiment. This facility controls the various components which are of influence to the combustion (Figs. 13, 14), for example: the feed rate; primary and secondary air rate and the speed of the grates.

The tests have shown that in spite of the heterogeneous fuel and the slow combustion process, an automatic control is possible within certain limits. On the other hand it is desirable to achieve more uniform conditions in the furnace. On the fifth unit at Düsseldorf a control system of this kind will be incorporated which, in addition to improving combustion, is also expected to contribute to the control of corrosion.

SUMMARY

This report demonstrates by the presentation of the latest knowledge in the field of corrosion
Fig. 10 125-ton/h power plant boiler with incinerator. Original configuration of furnace.
Fig. 11 125-ton/h power plant boiler with incinerator. Altered configuration of furnace and gas pass.
research and the conclusions and measures derived from it, how refuse incinerators can profitably be employed and operated without these serious problems. By taking into account the demands for improved combustion and by giving careful attention to the configuration of the furnace, it is possible to reliably generate high-pressure, high-temperature steam by refuse incineration. This can be utilized in economical power generation and district heating utilities. This approach to energy utilization is not only economical but is also a contribution to environmental protection. For instance, at this time about 4.3 percent of the primary energy consumption of the city of Dusseldorf for electrical power and district heating is provided by the refuse incinerator. Thus the natural resources are preserved and the emission of noxious gases is reduced.

REFERENCES