

Ceramic Coating in a High-Pressure WtE Steam Generator - Operational Experience in ZABALGARBI plant in Bilbao

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SUMMARY :

The Zabalgarbi urban waste-to-energy system is an industrial process that adapts the technology of combined-cycle gas plants to modern waste-to-energy facilities.

This plant have been supplied and delivered in 2005 by a joint venture made by CNIM and SENER.

In order to fulfill with the ambitious plant efficiency, the steam parameters and mainly the pressure value used in the WtE boiler is higher than usually obtained in modern waste-to-energy plants, which cause an increase of corrosion rate on evaporator section.

Conventional protection has been originally installed in the WtE boiler by Inconel 625 application in the first unprotected tiles refractory section.

Despite the satisfactory result demonstrated by the original protection which has been extended afterwards, tests have been made on single tubes using ceramic coating protection developed by Kera-Coat company. Started in 2014, the test is always on going with additonnal improvement made on material and application technology.

The results obtained are very positive with none corrosion attacks and with positive effect on fouling behavior.

- I. VALUE CHAIN (COMPANIES & PRODUCTS) INVOLVED.***
- II. PRODUCT CHARACTERISTICS.***
- III. DESCRIPTION OF THE 3 YEARS TEST.***
- IV. RESULTS.***
- V. CONCLUSIONS.***
- VI. POTENTIAL POSITIVE APPLICATIONS IN THE PLANT.***
- VII. OTHER POTENTIAL APLICATIONS OF THE TECHNOLOGY IN WtE PLANTS AND INDUSTRY.***

I. ZABALGARBI PLANT

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Figure 1 : Artigas-Arraiz Special Plan Area in Bilbao

It is a single integrated process in which the facilities' size and features are determined by the following:

- The plant's required UW treatment capacity.
- Fine-tuning the thermo-electric performance.
- Reducing the environmental impact per kWh generated by the plant.

Zabalgarbi occupies a plot measuring just over five hectares within the Artigas-Arraiz Special Plan Area in Bilbao. The industrial facilities cover 2.7 hectares, with the rest being taken up by roads and gardens.

Overall, the Artigas-Arraiz Special Plan Area extends over 108 hectares. In addition to the urban waste-to-energy plant, it houses a mechanical biological treatment (MBT) plant, a composting facility, a landfill, and a leachate treatment plant.



Figure 2 : Artigas-Arraiz Special Plan Area in Bilbao

General process features

Slight superheated steam at a temperature of 328 °C and a pressure of 106 bar is produced in Zabalgardi's incineration-line furnace-boiler designed by CNIM and combined with MARTIN type A grate. One line with the nominal capacity of the WtE package is 30t/h of waste for a thermal heat yield of 80 MW.

This boiler has an higher pressure than usually obtained in modern waste-to-energy plants (400 °C at 45/60 bar).

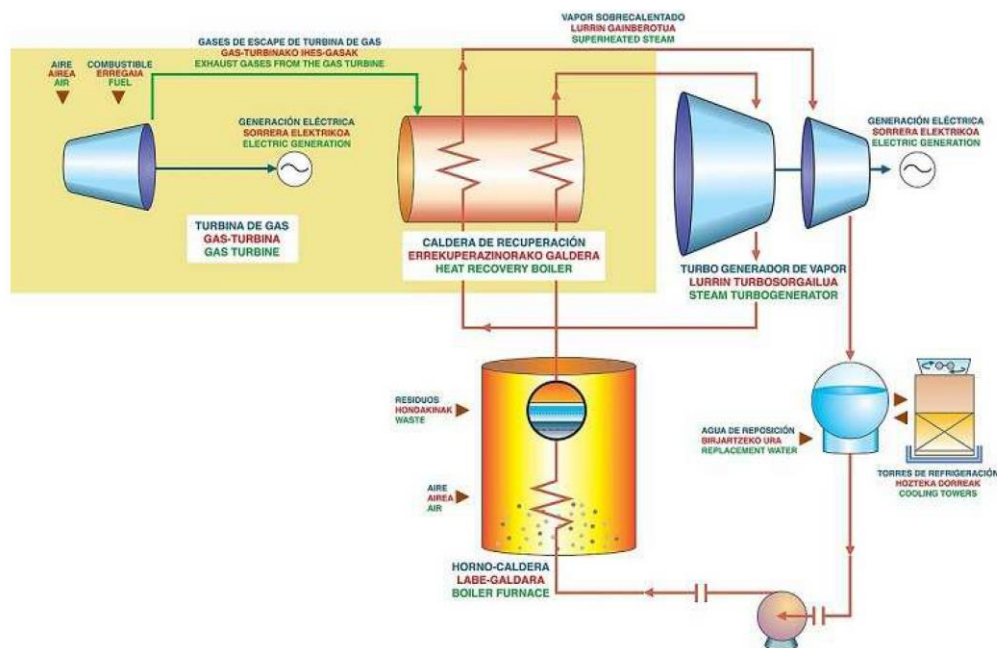


Figure 3 : Schematic process diagram

This saturated steam from the furnace-boiler is superheated to 540 °C in a recovery boiler (CNIM design) using heat from the flue gases of a 43 MW gas turbine (GE LM6000), while maintaining pressure at 100 bar in conditions similar to those of a power plant using conventional fuels. The superheated steam is used to drive a 56.5 MW turbo-generator(GE, Novopinione).

Gross power yield is 99.5 MW, and the net output after the plant's own consumption is 94 MW.

Higher energy yield

Today's state-of-the-art power-generating waste-to-energy (WTE) plants record a net yield of approximately 23%.

However, the Zabalgardi plant's innovative design, adapting combined-cycle gas plant technology to modern WTE plants in a single integrated process, means it records a net yield of 42%.

The EU's THERMIE Programme – DG 17 – has recognised this improved performance and energy efficiency by granting Zabalgardi its maximum subsidy for increasing energy performance, saving and efficiency, as well as for reducing its environmental impact..

Saving fossil fuels and reducing CO2 emissions per kWh generated

The use of UW instead of fossil fuels and its highly efficient plant enable Zabalgardi to deliver significant primary energy savings.(47%)

Moreover, the renewable fraction of UW entering the plant –biomass- amounts to 63%, similar to the figures recorded throughout the EU.

The plant's WTE process, together with its performance and overall efficiency, also help to reduce atmospheric CO2 emissions per kWh generated (175% less than the emissions from a landfill).

Power is generated at a facility whose efficiency and environmental protection measures ensure the effective reduction of emissions per kilowatt-hour of electricity produced.

This reduction is achieved through the following measures:

- combustion control measures in furnace and burners
- effective scrubbing of combustion gases
- highly efficient technology
- Improved operating conditions reduce corrosion in the furnace-boiler because of the lower temperature of the steam produced, resulting in lower operating and maintenance costs
- Increased plant availability.
- The size of the Zabalgardi treatment plant combines a processing capacity of around 220,000 to 240,000 t of UW per year with a net installed power-generating capacity of around 95 MW.

II. VALUE CHAIN (COMPANIES & PRODUCTS) INVOLVED

1. **KERA-COAT** : www.kera-coat.com

- *Develops, manufactures & supplies tailor made special (high resistance) ceramics (powder /slurry) to be applied on metallic substrates with a world exclusivity agreement for tubular goods to.*



2. **TUBACOAT** : www.tubacoat.com

- *Produces and supplies CERAMIC COATED TUBULAR SOLUTIONS to the WtE and many other sectors (Power Gen, Chemical, O&G... etc.).*



3. **ZABALGARBI**: <http://www.zabalgardi.com/en/>

- *WtE plant in BILBAO, pilot tests and end user.*



4. **CNIM**: <https://www.cnim.com>

- *Designs, Produce & Maintains WtE boilers and other systems and applications. Supply Waste Management solutions.*

III. PRODUCT CHARACTERISTICS:

CERAMIC COATING:

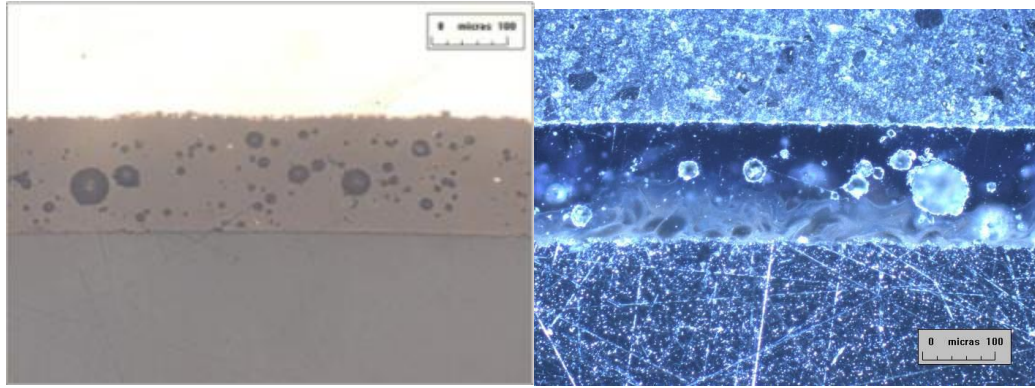


Figure 4 : Structural view

Typical coating thickness range: 100-200 μm

- Hardness: 64 HRC.
- Elongation: max 1'2 %.
- Roughness: Ra: 0'04 microns; Rz: 0'2 microns.

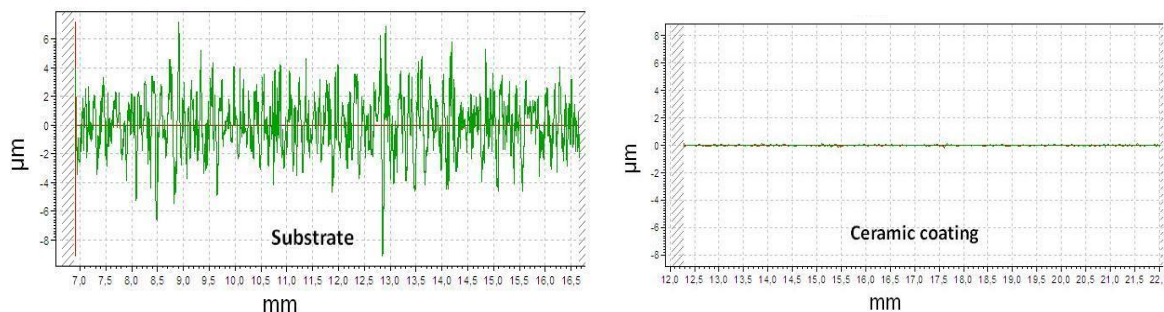


Figure 5 : Coating surface

THERMAL CONDUCTIVITY: .001 - 0.003 cal./sq. cm./sec/degree C.
Despite a certain thermal barrier effect, as the thickness is so small the real effect has demonstrated to be neglectable.

ABRASION RESISTANCE:

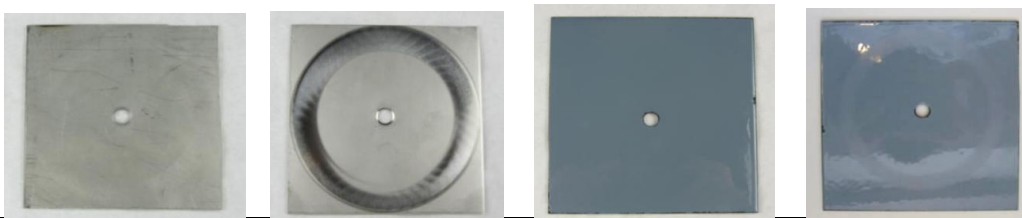


Figure 6 : Abrasion Test

Mass loss in 10,000 cycles:

Bare Substrate AISI 310: 58 mg Coated AISI 310 :3 mg

THERMAL SHOCK RESISTANCE:

- Samples are introduced in a furnace during 30'.
- After 30 min. at temperature samples taken from the furnace and directly introduced in a container with cold water 20°C (68°F).
- Reached up to 850°C (1762°F) – with NO DAMAGE, above that temperature, the ceramic starts to soften.



Figure 6 : Water quenched from 850°C to 20°C.

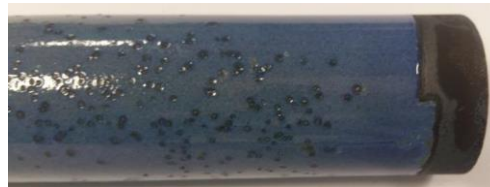
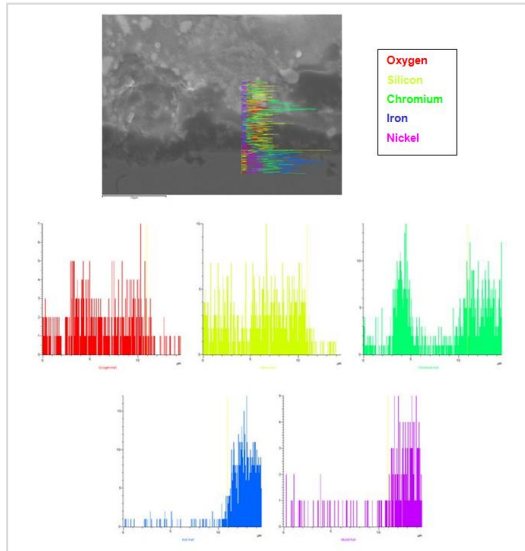


Figure 7 : Softening defects appear at 900°C.

MICROSTRUCTURE & CHEMICAL BONDING:

Microstructure:



Chemical Bonding

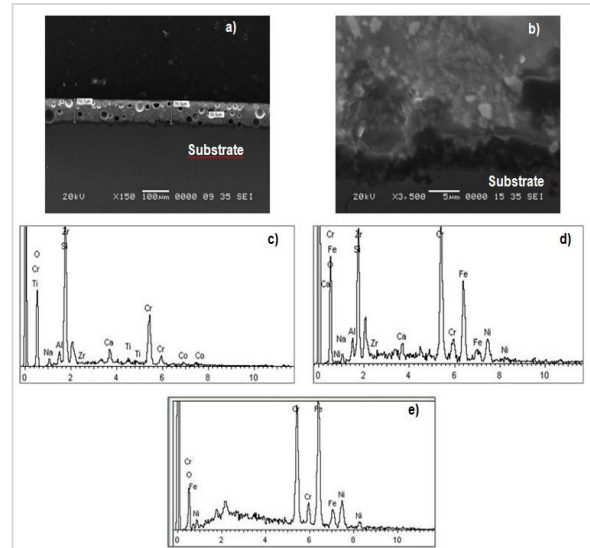


Figure 8: Structural analysis

SEM images of inner structure sintered in normal conditions. a) Ceramic coating micrograph, b) Micrograph of the interface between the steel substrate and the ceramic coating showing the diffusion area c) Ceramic coating EDX results, d) the interface e) Metal substrate.

This chemical bonding **AVOIDS CRACKS**, even in case of impact if the impact effect deforms the substrate above 1,2% elongation, the ceramic covering the deformed area blows up as powder, but the interface layer remains attached to the substrate. This layer has demonstrated to maintain a better chemical resistance than the substrate.

PREFERRED SUBSTRATES:

- Vitrification of the ceramic coating requires a 12-minute heat treatment of the tubes at 920°C for ceramics capable to keep their full properties at 650°C metal temperature.
- This treatment might affect the mechanical properties of some **LOW ALLOYED** steels currently used in WtE boilers.
- Austenitic steels **DO NOT LOSE** these properties so they are the most preferred to ensure many long years of high efficient performance (AISI 310, 347..).

Advantage:

- **RESISTANCE TO THERMAL OXIDATION/CORROSION:** Provide both protection of the metal and ease of cleaning.
- **Long run SURFACE METAL WORKING TEMPERATURE:** 650°C with peaks of 850°C.
- **THERMAL STABILITY:** Ability to withstand intermittent or prolonged heat. (YEARS).
- **THERMAL EXPANSION:** Designed to be the same as the substrate from : -140 to +850°C.

IV. DESCRIPTION OF THE LAST 3 YEARS TEST (2014-2017 in progress)

The Wte boiler supplied by CNIM is a vertical type boiler with convective bundles installed in a third pass.

In March 2014 few pieces of about 1m long of coated AISI 310 were inserted in a evaporator panel in the 2nd pass with a metal temperature estimated at about 350°C (flue gas at 720° and steam at 320°C).

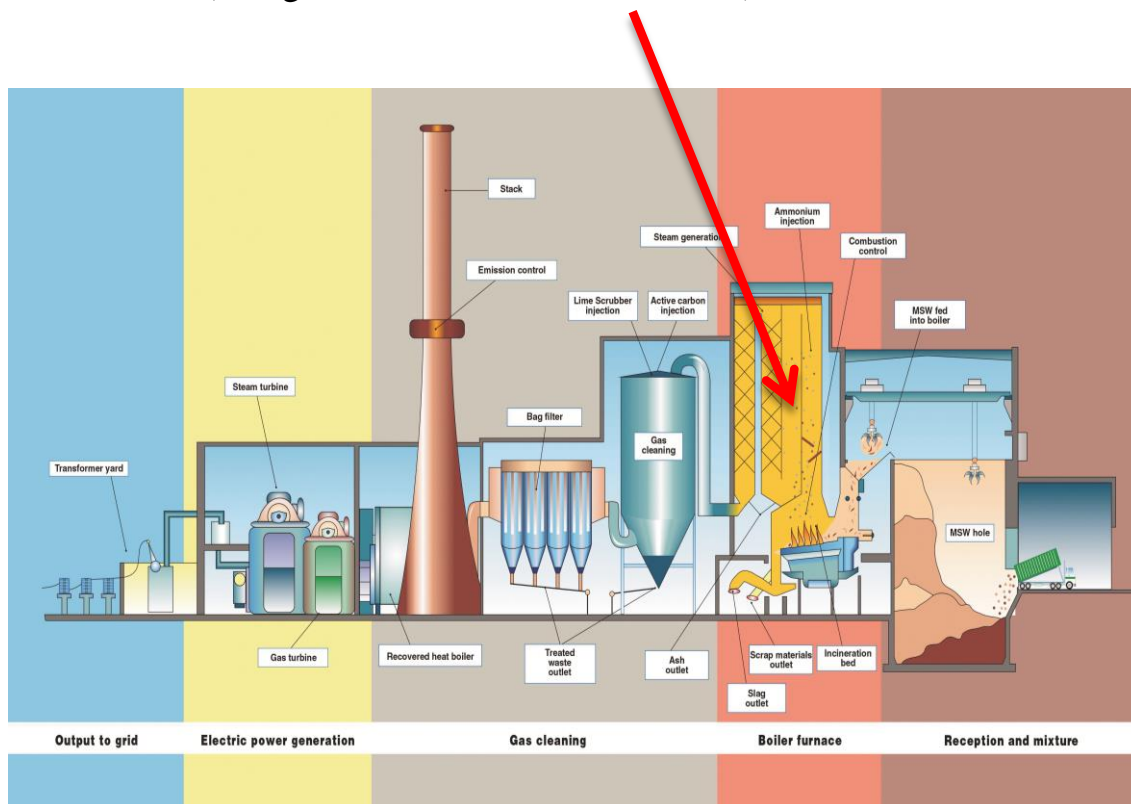


Figure 9: Schematic boiler view



Figure 10: Tubes coating aspect

V. RESULTS

After ONE -YEAR operation, the tubes were always brand new; ash was easily removed by hand as it was probably deposited by condensation at the cooling of the boiler and not in hot operation. The GLOSSY SURFACE indicates that not a single micron of coating has been neither eroded nor corroded during the year. The same still happens after three years operation.



Figure 11: Tubes after 1 year and after three years before and after cleaning the ash by hand with a glove

During these three years of practice it has been developed some ancillary. Processes that are building up a full-coated solution for existing and new boilers such the ones described below:

A) Plastic protection covers for shop and inside boiler operations:



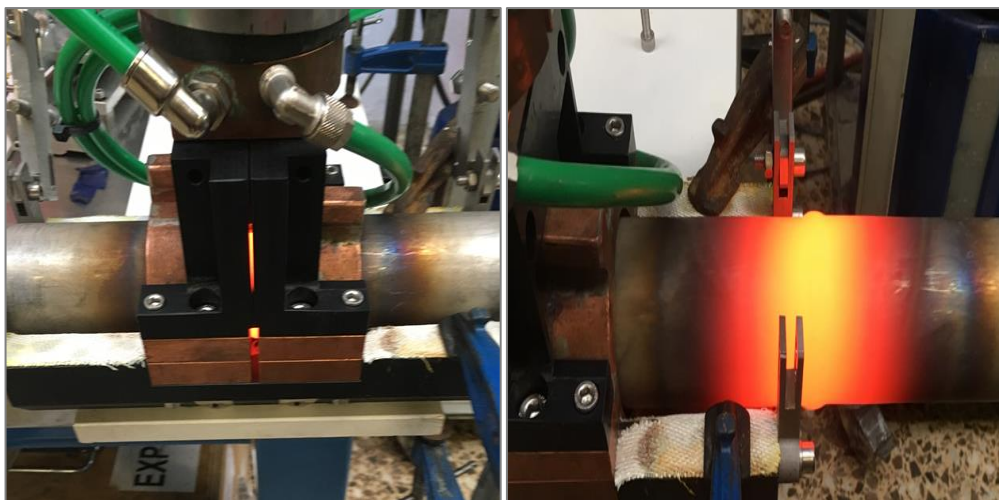
These covers resist perfectly the burning particles thrown away by grinding discs or during welding.

They also resist conventional shot blasting aimed for bare steel tubes.

Ceramic-coated tubes can be easily cleaned by water jet.

Actually the black fasteners aren't needed as the plastic cover shrinks against the tube, plastic covers are longitudinally open and can be easily be folded and unfolded on the tubes, by hand.

B) On site coating and vitrification of welded joints and eventual defects



The heating system based on induction technology is under development and final tuning is expected end September 2017.

VI. CONCLUSIONS:

The three years test in WtE boiler in Bilbao allow to conclude :

- Excellent corrosion resistance.
- Excellent coat bonding under thermal stress.
- Homogeneous performance.
- Very low ash adherence to outer surface.
- After 3 years can be estimated a long life.
- Reduces cleaning & maintenance.
- Improves boiler thermal efficiency.

a) Potential possible applications

Possible application on superheated part (higher metal temperature)

Once the ceramic application can be spread in different parts into the WtE not only in boilers, other exchangers, parts affected by corrosion, or a first full-coated boiler can start operating, it will be able to see and evaluate if the expected efficiency gain due to less ash deposition and less tube degradation might allow to design boilers working a) at higher steam temperature; reducing the boiler size for the same output; with lower maintenance costs, etc.

If this more optimised operation of the boiler is confirmed, there will be an automatic increase of efficiency just by avoiding the loss due to ash fouling.

This principle might apply to the whole boiler including the economizer passes and other parts like ducts, bag house filter, etc. Also to progress in complete water walls and panels with ceramic coating up to 12 m. long x 2'5 m. width.

b) Other potential applications in WtE plans and industry

- All types of bent tube, tube-sheet and other type of hear recovery exchangers, economizers, etc.
- Combustion grate parts coated to prevent high temperature abrasion-corrosion.
- Scrubber lining sheets and ducts.
- Pilot flue gas condensers capturing some gases at economizer outlet: to be tested this winter at the same Bilbao site. (A 5 Kw prototype has been successfully tested with gases after bag house filter).
- The target of this new heat exchanger made of internally ceramic coated carbon steel tubes is:
 - Observe evolution of emissions decreasing (SO_x, NO_x, etc.) by condensing the fumes down to 30°C.

- Observe reduction of particles content through the condensed water along the narrow tubes catching the flying particles and drain them down to the collecting tank for condensates.
- Study potential internal applications of fumes after the exchanger (sensible heat might be used to generate electricity via ORC, district heating or cooling, etc).
- Study quality of condensates for water recovery and treatment design; a big amount of condensed water could be recover, reducing water consumption.