Extending the Service Life of Furnace Wall Tubes Using Thermal Sprayed Coatings

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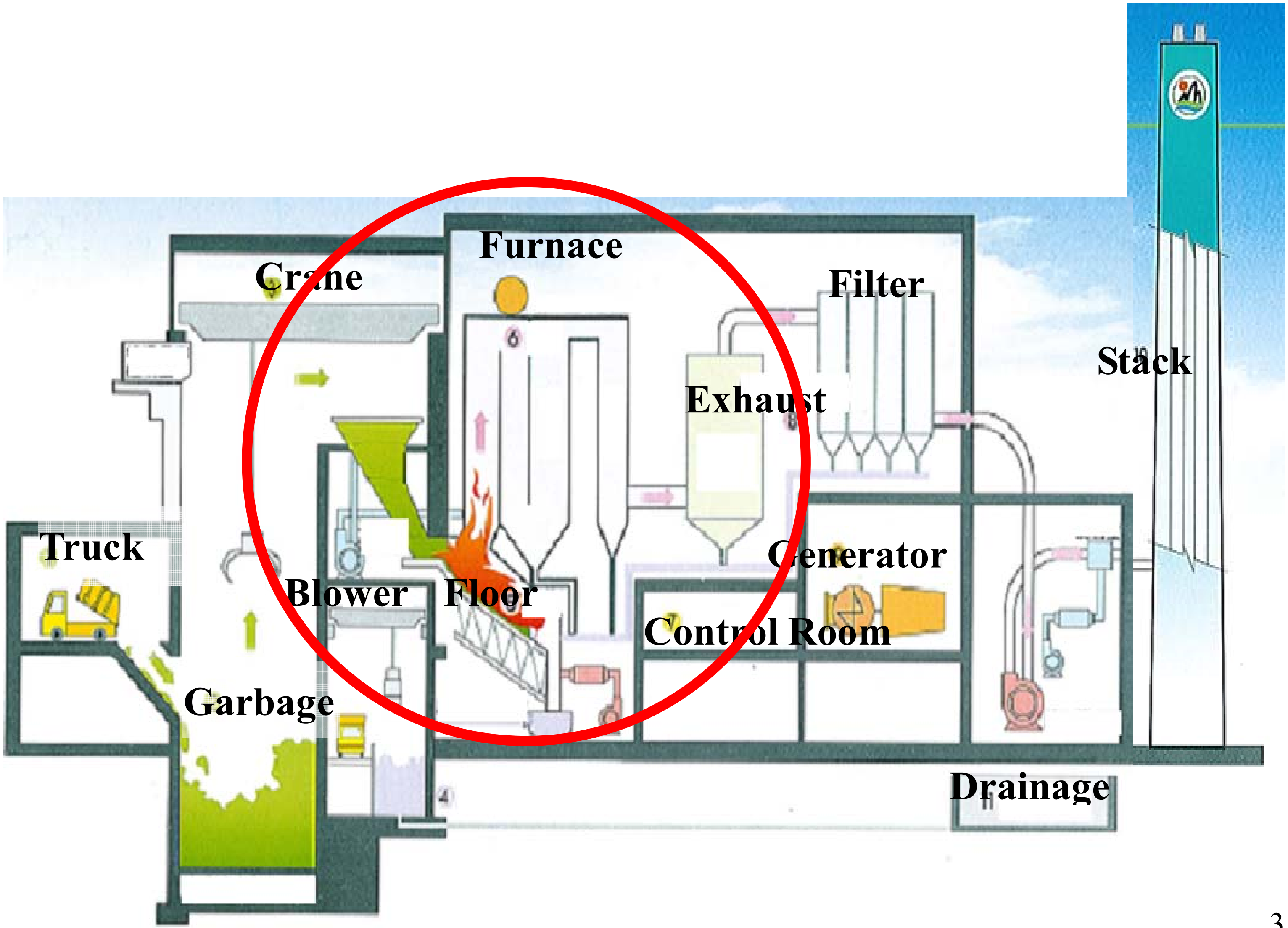
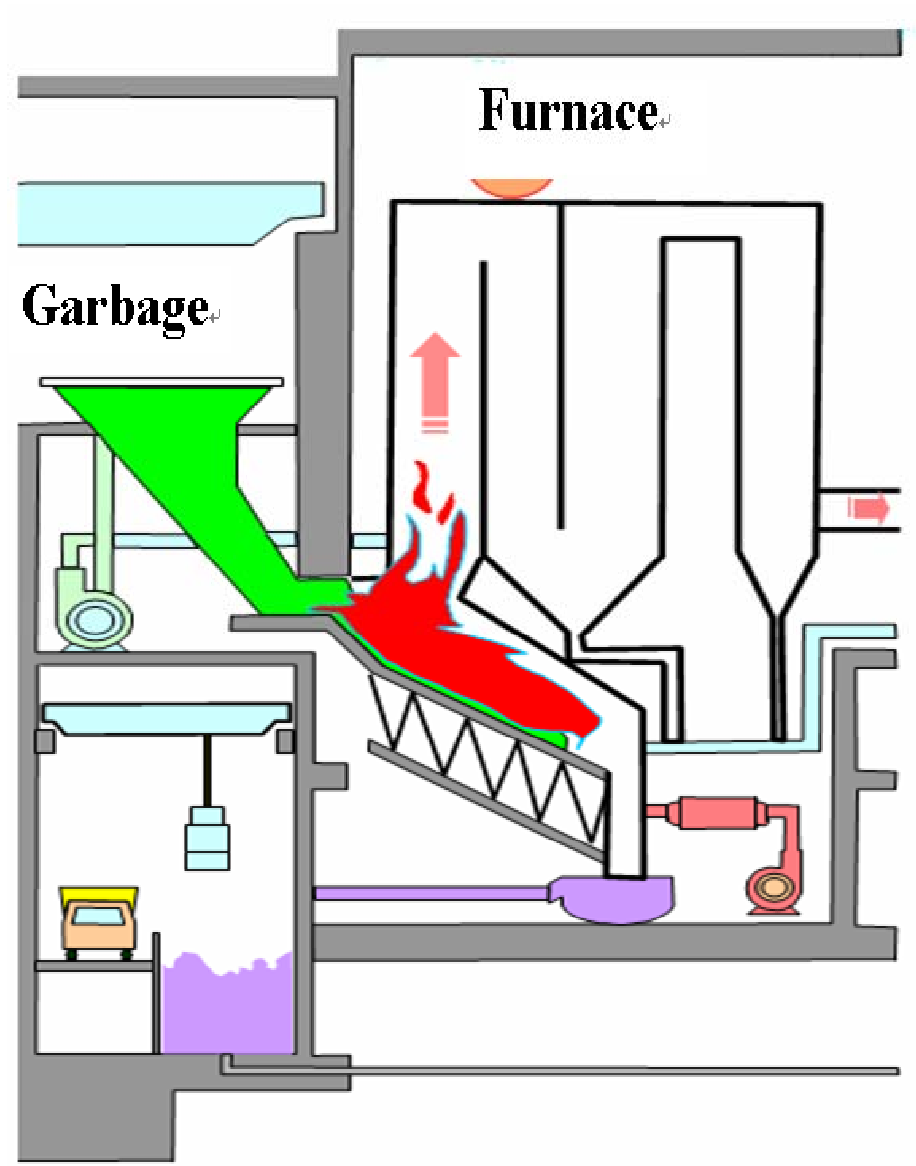
Outline

- **Furnace Wall Tubes at Waste Incineration Plants**
- **First Experimental Application of Furnace Wall Tubes**
- **Second Experimental Application of Furnace Wall Tubes**
- **Application of Furnace Wall Tubes**

Schematic Diagram of Incineration/Power Plant



Schematic Diagram of Furnace



Nickel Based Self-fluxing Alloy Coatings

Conventional Coatings

Corrosive substances:

- **penetrate these coatings**
- **corrode the base metal**
- **disintegrate coatings**

Nickel Based Self-fluxing Alloy Induction-fused Coatings:

- **strengthen metallurgical bond.**
- **minimize inclusion pores.**
- **are cheaper than welded coatings.**
- **minimize distortion, facilitating final assembly.**

First Experiment Procedures

1. **Specimen Tubes: 76.2mm x 990mm x 6mm**
2. **Thermal Spraying Process:**
   - **blasted by steel grit**
   - **sprayed with J3^{tm}**
   - **fused by induction heating**
3. **Tested Under Industrial Conditions**

Figure 1: Schematic Diagram of Furnace.

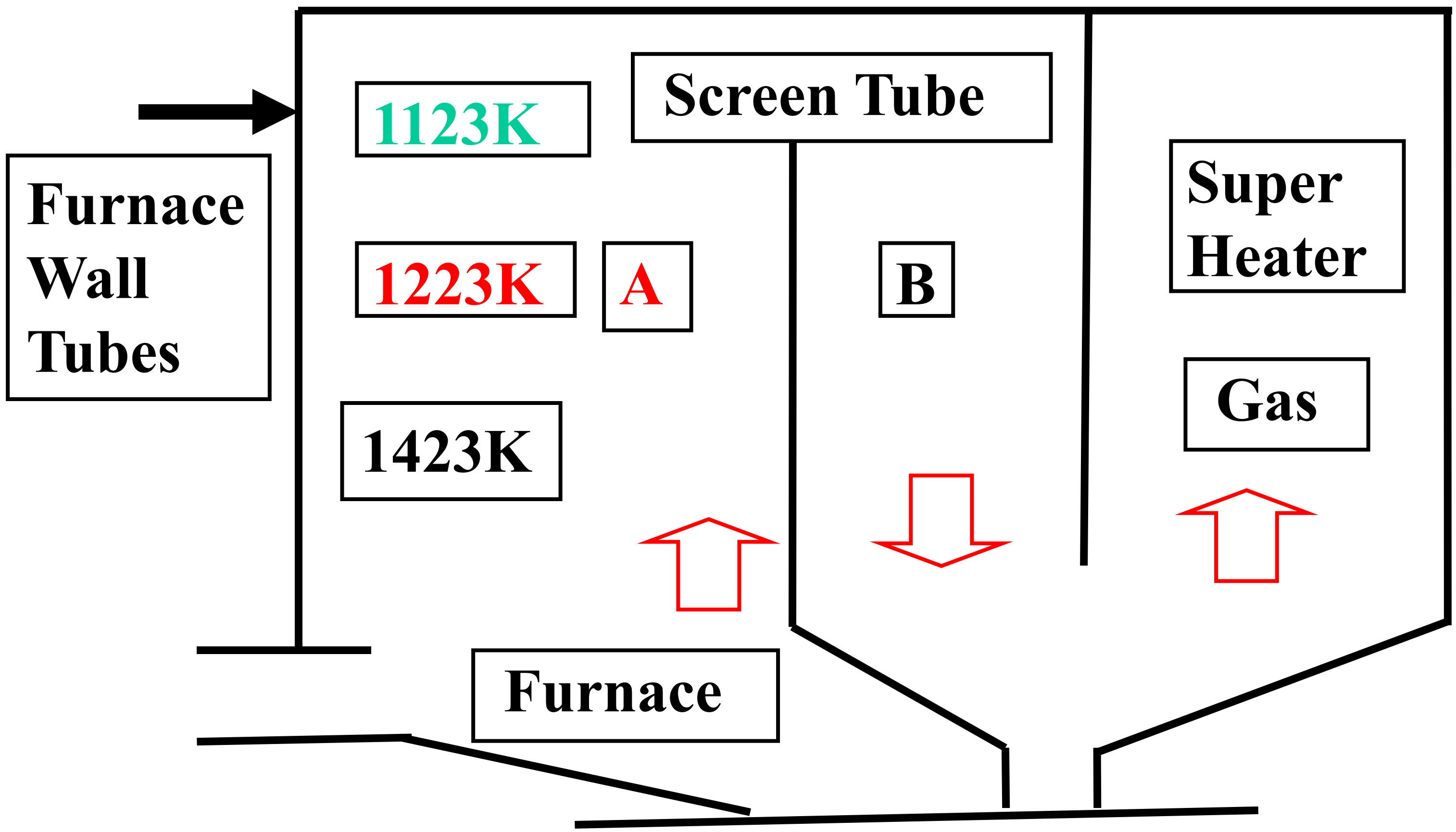


Figure 2: Dimensions of Test Unit

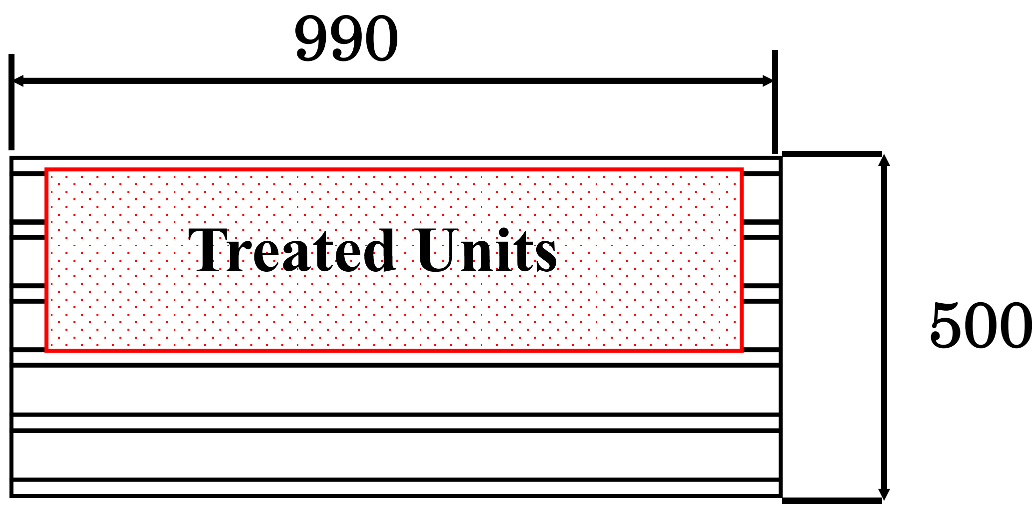


Table 1:
Chemical Compositions of Powder and Substrate
(Weight%)

Powder	Ni	Cr	Si	B	Mo
Powder A	Balance	15	4.3	3.1	2.5
Substrate	**Fe**	**C**	**Si**	**B**	**Mn**
ASME SA192	Balance	0.1	0.2		0.4

Table 2:
Flame Spraying and Induction Heating Conditions

Flame Spraying Conditions			Induction Heating Conditions	
Operation Gas	O_2	0.22M Pa, 45 l/ min	Frequency	2kHz
	C_2H_2	0.10M Pa, 28 l/ min	Input Power	145kW
Powder Feed Rate		76 g/min	Temperature	1273-1323K
Spraying Distance		205 mm	Coil Moving Speed	1.5mm/s
Coating Thickness		1.5 mm		

Table 3: Incinerator Conditions

Waste Type	Household Garbage
Furnace Temperature	Max1323K
Tube Pressure	5.0MPa
Tube Temperature (Outer Tube Surface)	Max 623K
Tube Temperature (Inner Tube Surface)	Max 533K

Figure 3: Appearance of Furnace Wall Tubes after Service

Treated Tubes

Untreated Tubes

Table 4: Thickness of Wall Tubes after 24 Months

Thickness (mm)	Untreated Tubes	Treated Tubes		
	a b c	d e	f g	h
Before Service	5.4	6.9	7.2	7.2
After Service	4.4	6.9	7.0	7.1
Loss	-1.0	0	-0.2	-0.1

Figure 4: Cross Section of Wall Tubes

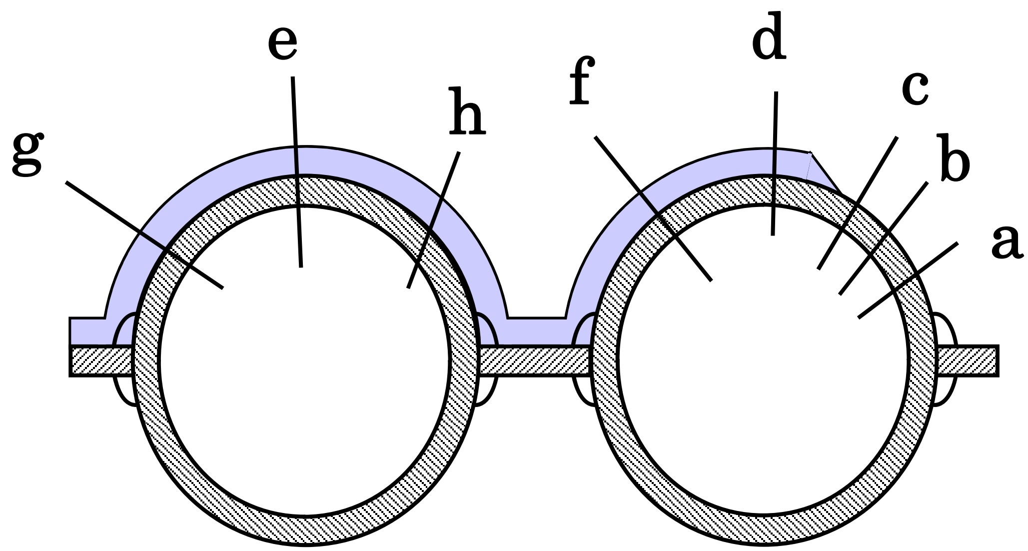
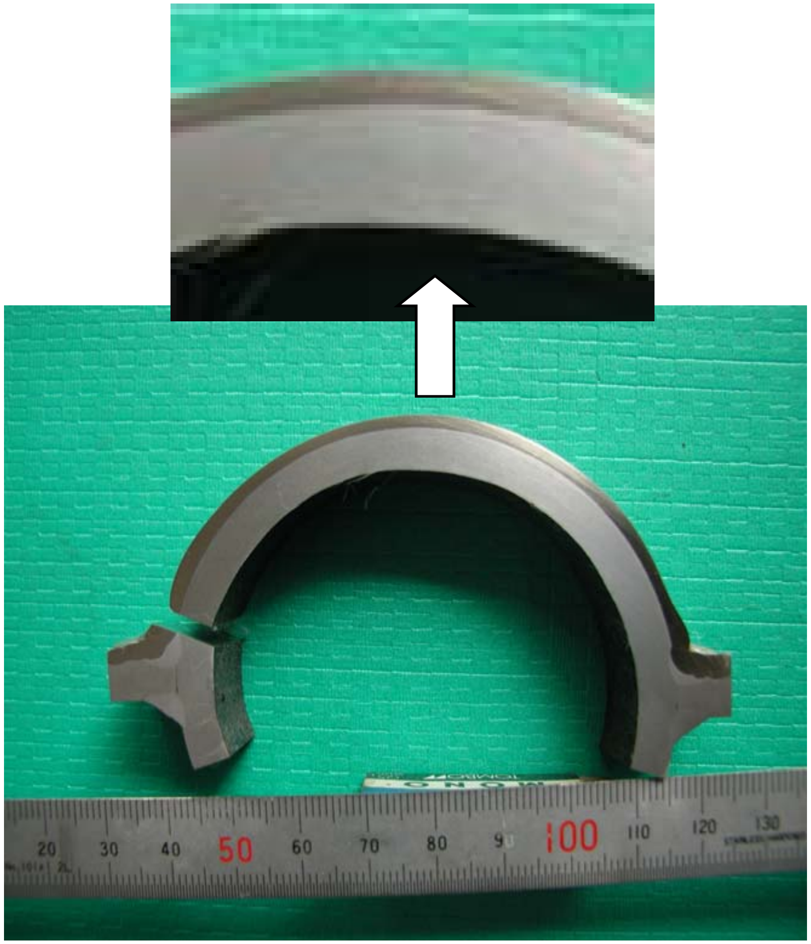
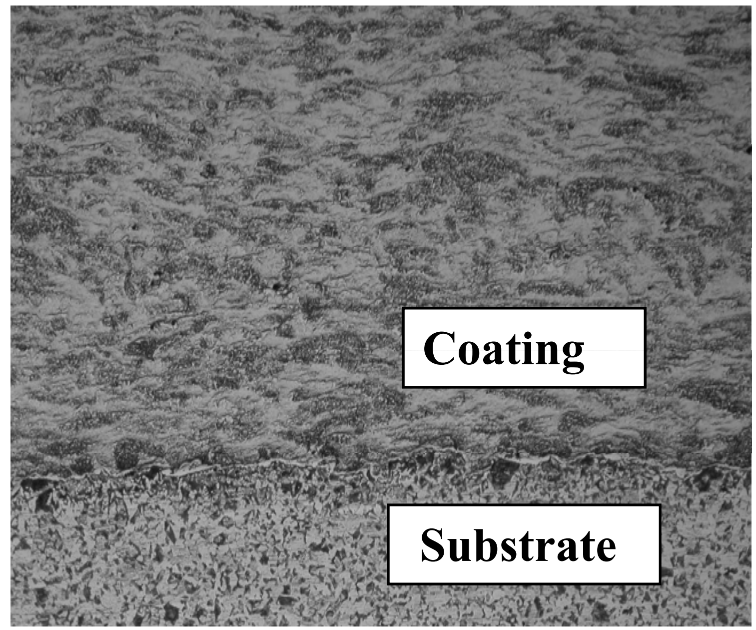


Figure 5: Microstructure of Induction Fused Coating.



Cross Sections of Tubes



100µm

Figure 6a:
Principle of Corrosion Mechanism by Active Oxidation

(Flue Gas) O_2 NaCl KCl SO_2 O_2

（Ash Layer） (1) $2NaCl+SO_2+O_2=Na_2SO_4+Cl_2$

$2KCl+SO_2=K_2SO_4+Cl_2$

(Corrosion Front) (2) $FeCl_2 = Fe+Cl_2$

（Scale Layer）

(3) $2FeCl_2+1.5O_2==Fe_2O_3+2Cl_2$

$3FeCl_2+2O_2=Fe_3O_4+3Cl_2$

(4) $FeCl_2+O_2+Fe_3O_4=2=2Fe_2O_3++Cl_2$

（Metal Surface） Fe

Figure 6b:
Analysis Samples of Oxide on Wall Tube

Oxidized and Corroded Wall Tube

Scale Outer Surface

Scale Inner Surface

Figure 7a: Electron Probe Micro Analyzer Analysis of Wall Tubes (Ash Layer)

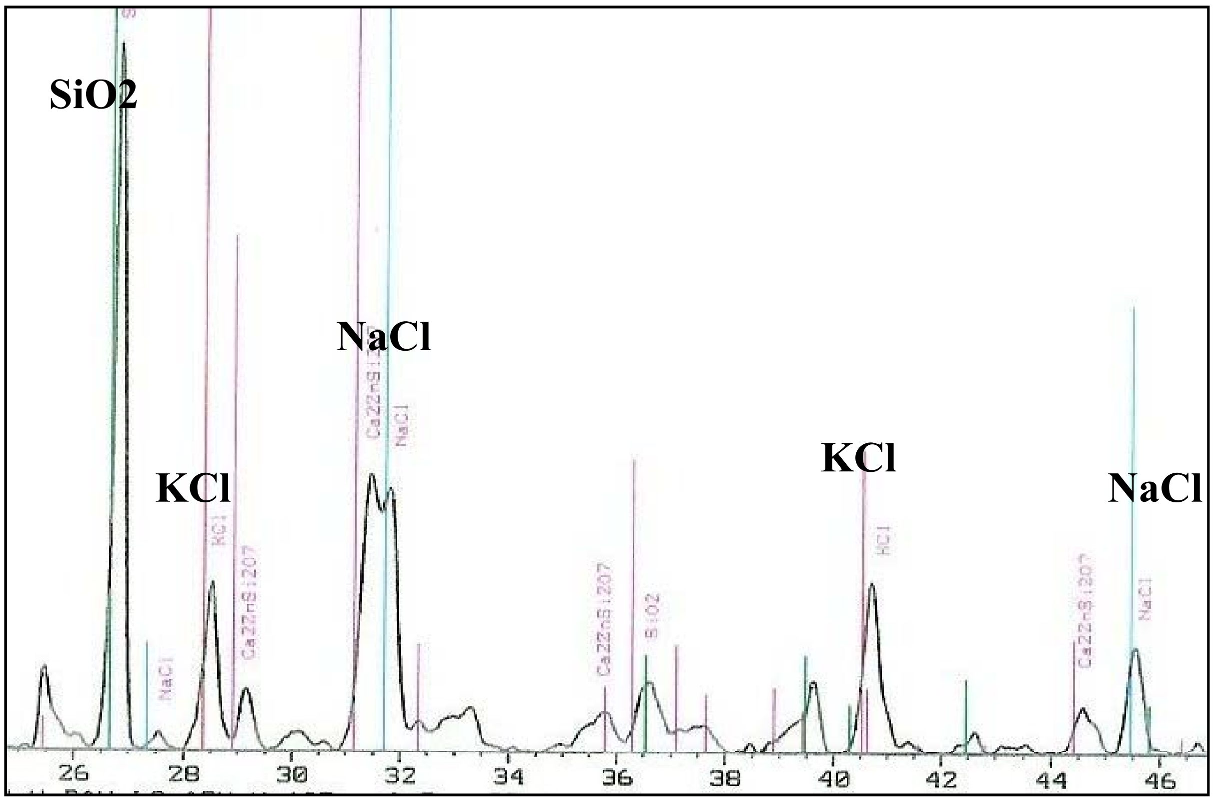


Figure 7b: Electron Probe Micro Analyzer Analysis of Wall Tubes (Outer Surface of Scale Layer)

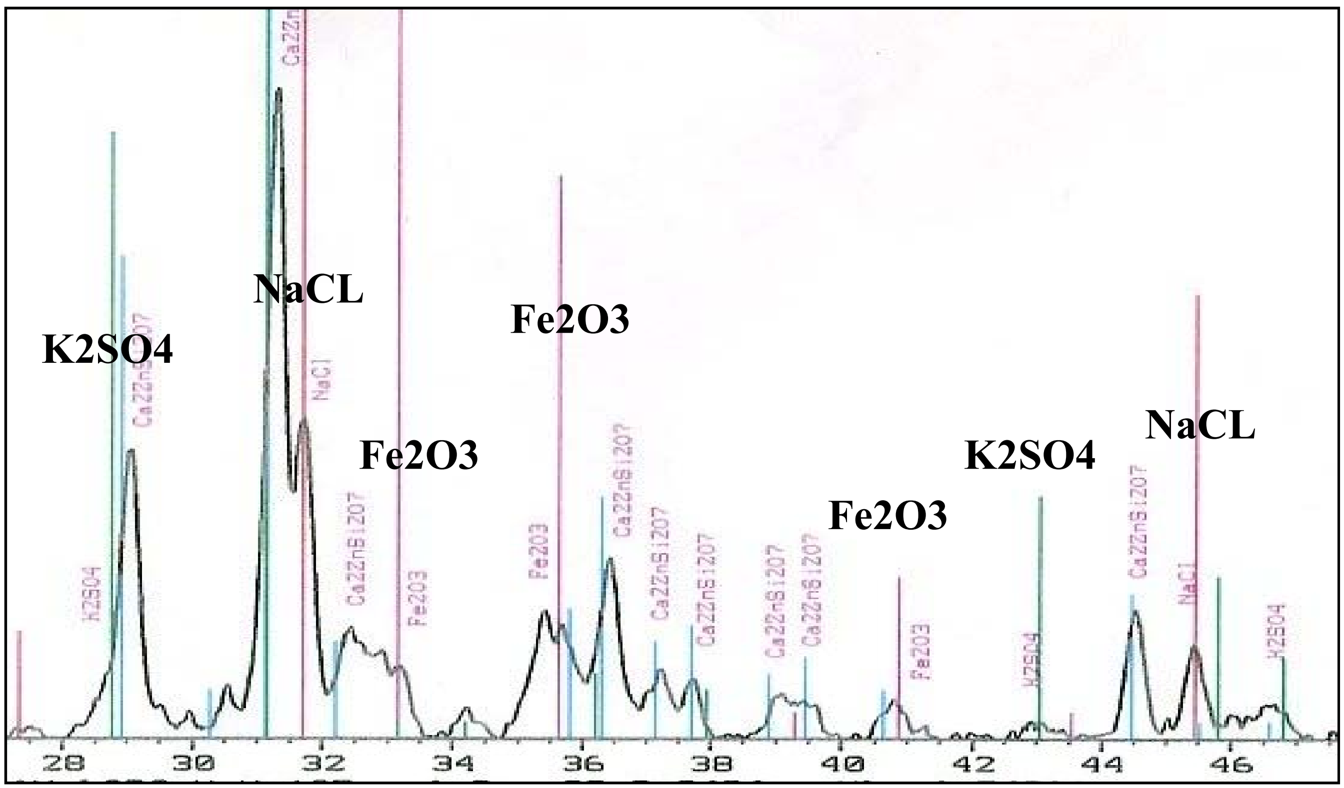


Figure 7c: Electron Probe Micro Analyzer Analysis of Wall Tubes (Inner Surface of Scale Layer)

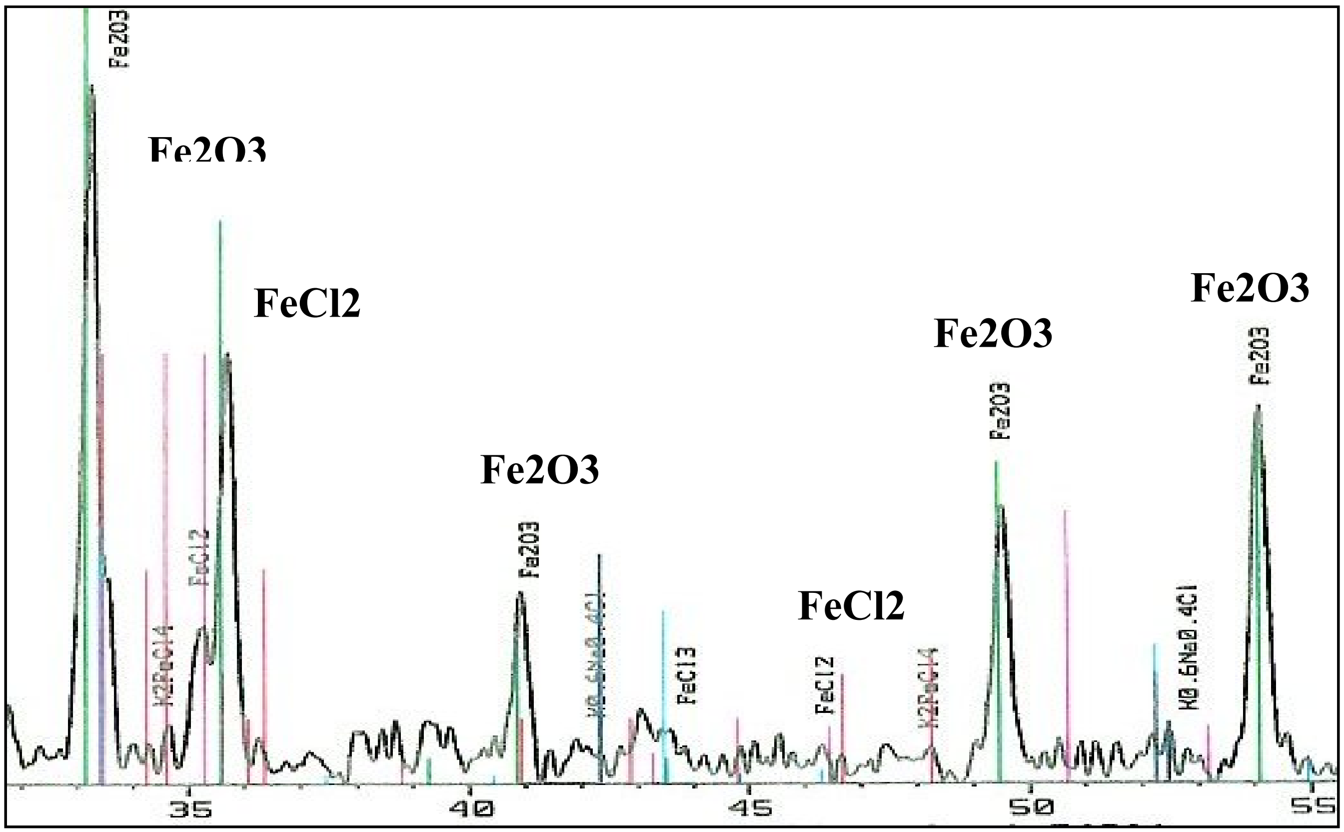
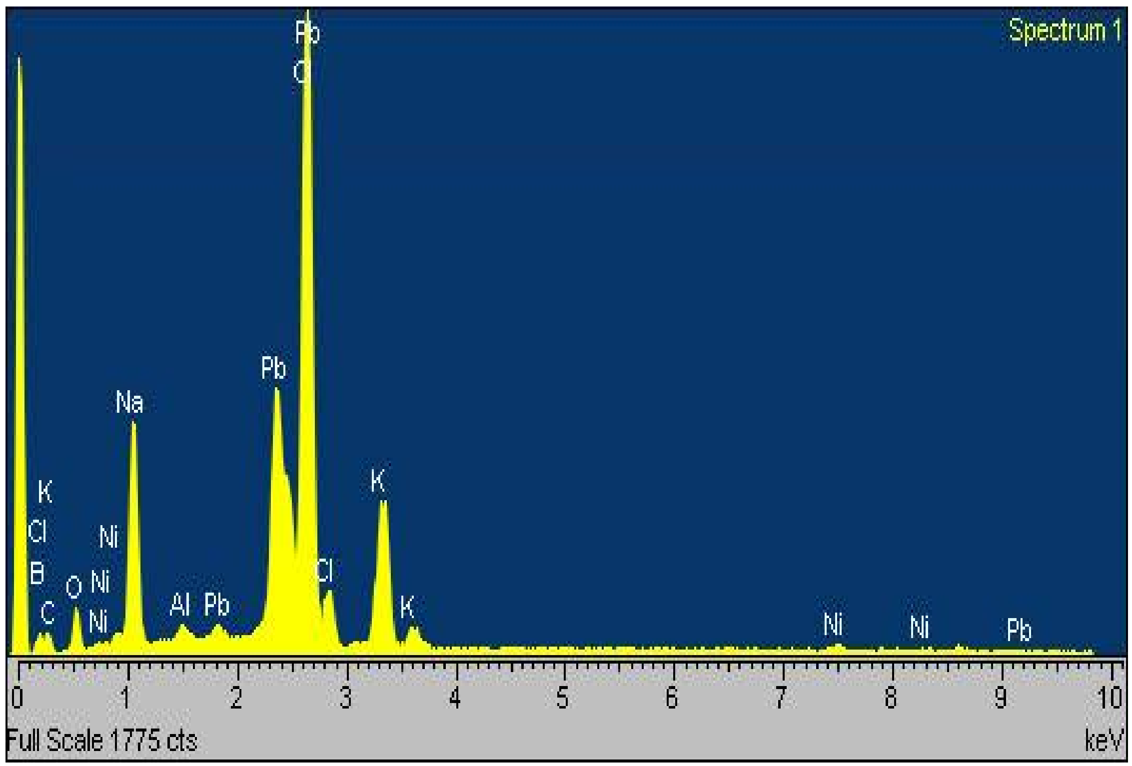


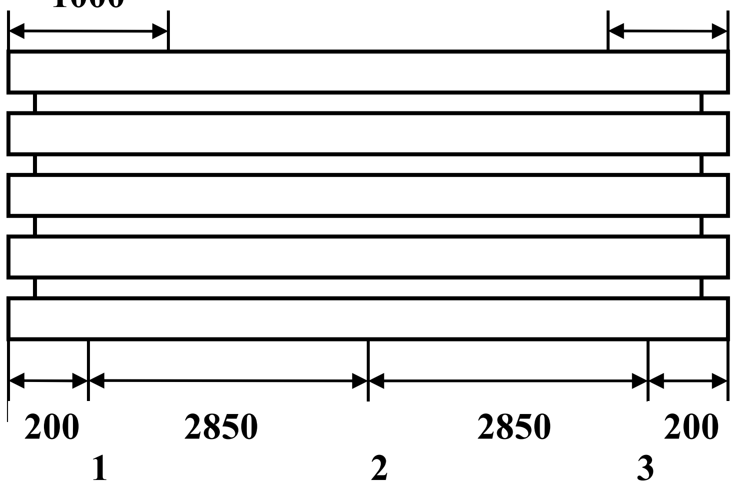
Figure 8: Energy Dispersive X-ray Analysis of Treated Tubes After Service



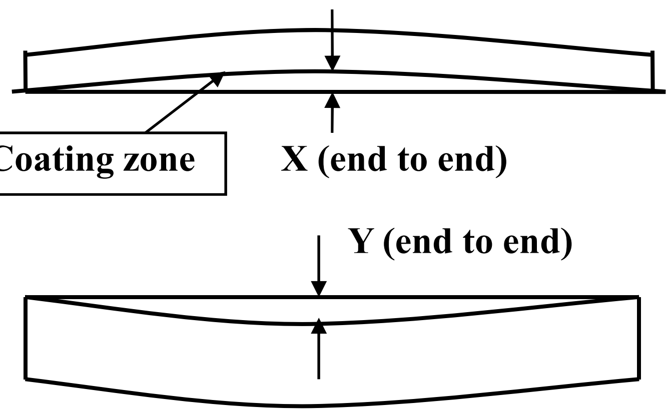
Second Experiment Procedures

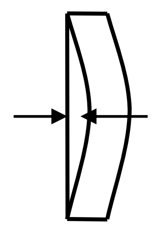
1. 11 Specimen Units:500mm x 6000mm x 6mm
2. Thermal Spraying Process:
   - blasted by steel grit
   - sprayed with J3™
   - fused by induction heating
3. Tested Under Industrial Conditions

Figure 9: Dimensions of Furnace Wall Tubes



Specifications
X<6mm, Y<4mm, Z<3mm
Length<6mm, Width<3mm
Coating thickness>1.2mm





Z (side to side)

Figure 10a: ΔX;
Example of Dimensions of Furnace Wall Tubes

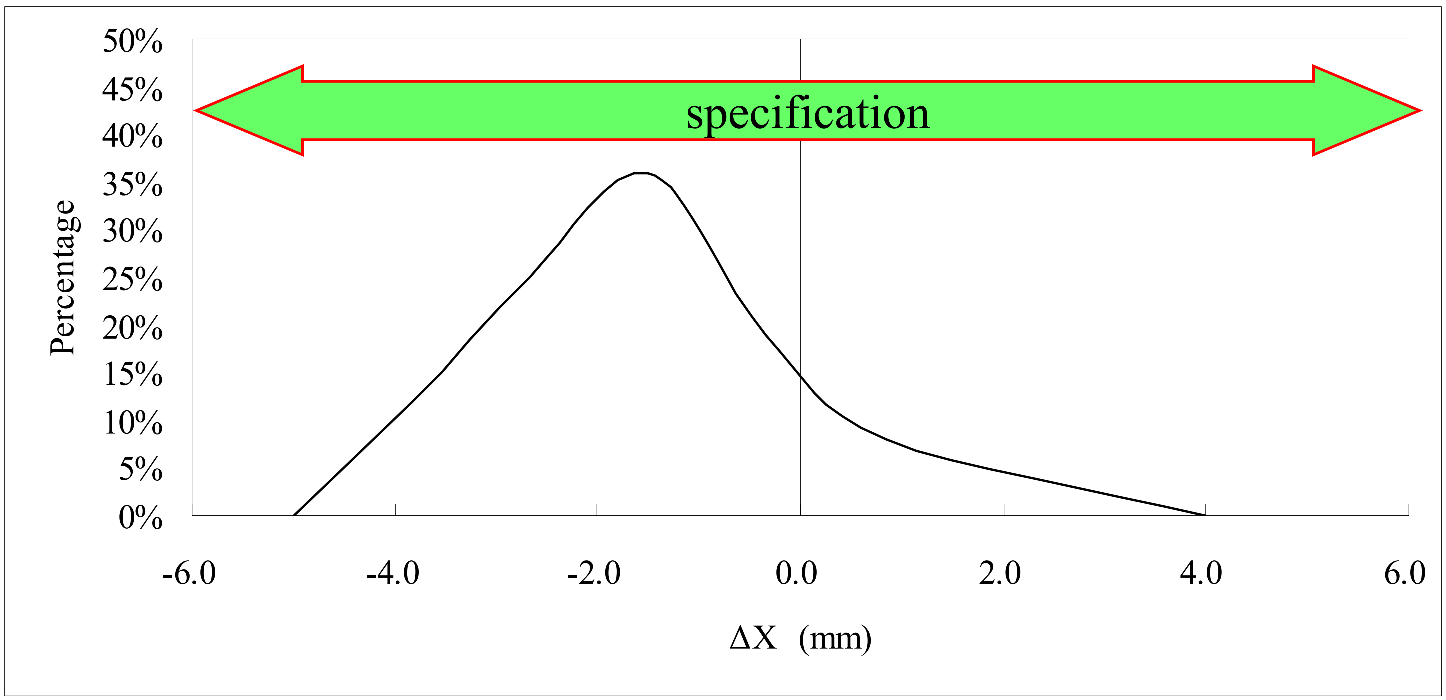
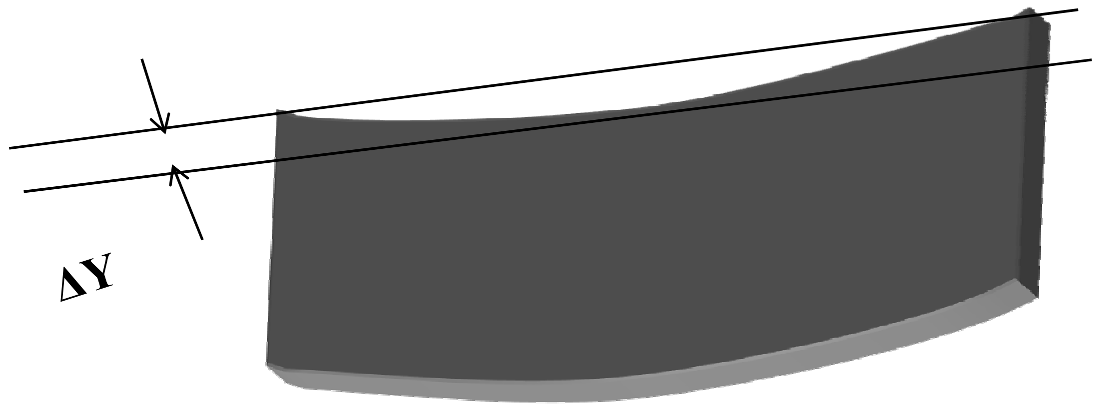


Figure 10b: ΔY;
Example of Dimensions of Furnace Wall Tubes



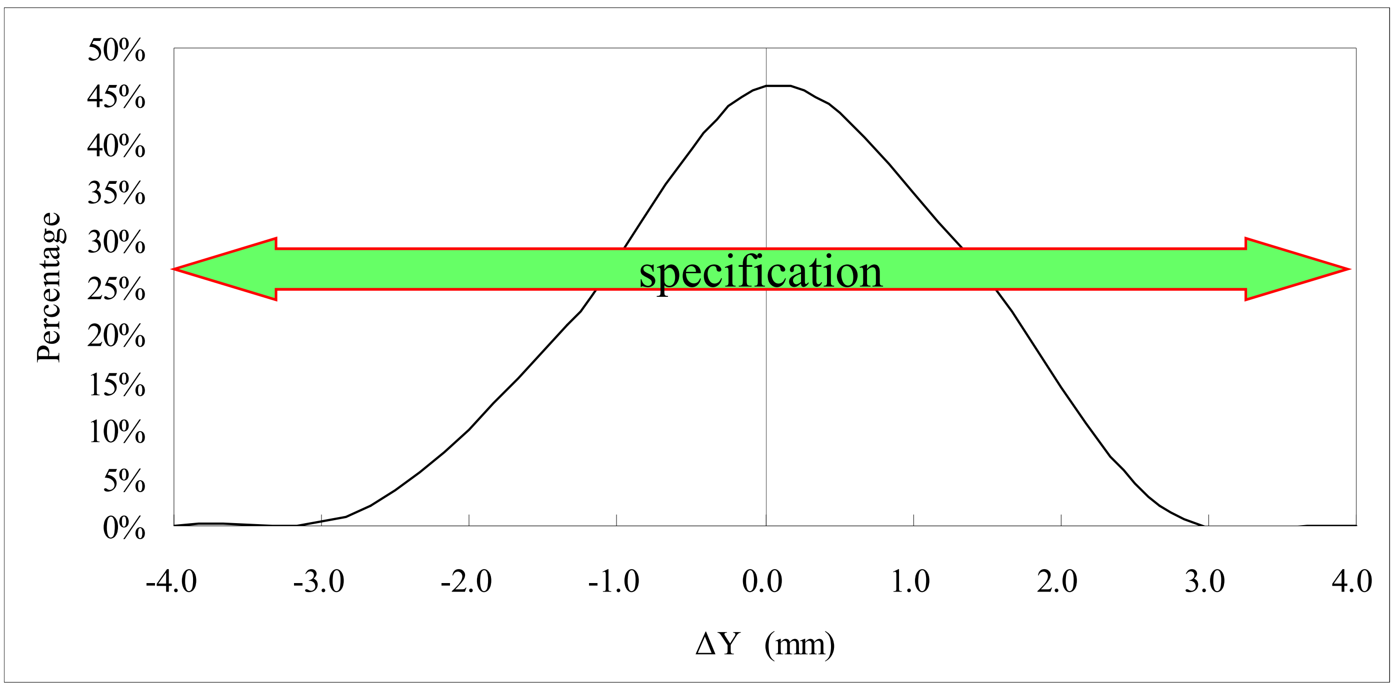
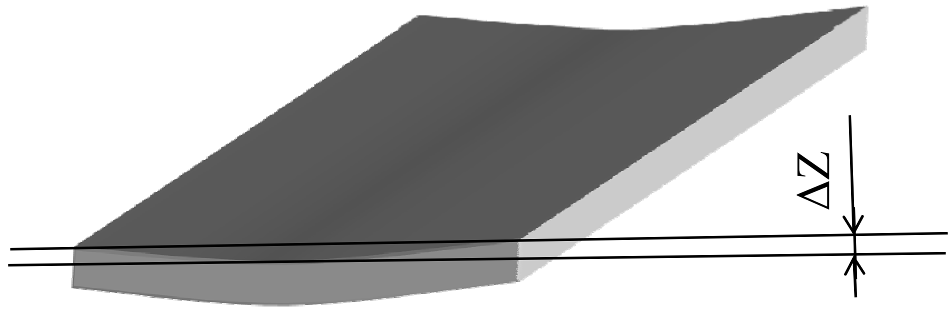


Figure 10c: ΔZ;
Example of Dimensions of Furnace Wall Tubes



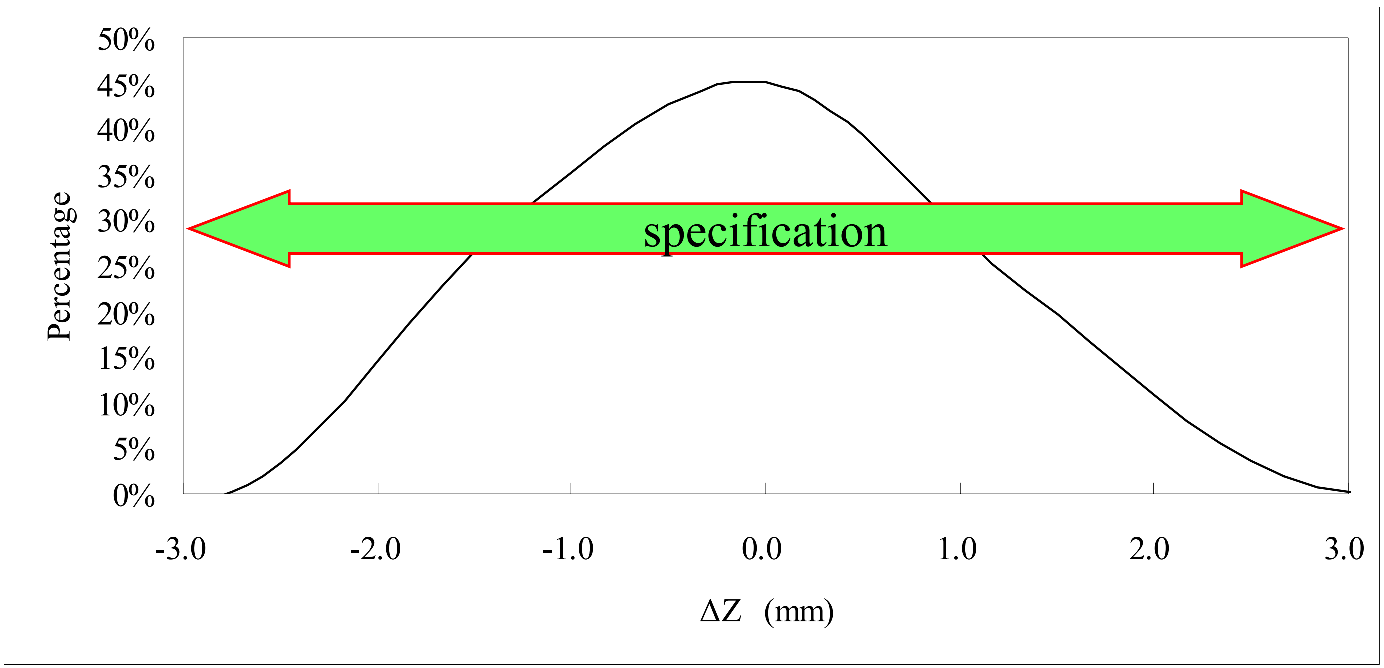


Table 5:
Flame Spraying and Induction Heating Conditions

Flame Spraying Conditions			Induction Heating Conditions	
Operation Gas	O_2	0.22MPa 45 l/ min	Frequency	2 kHz
	C_2H_2	0.10MPa 28 l/ min	Input Power	150 kW
Powder Feed Rate		76 g/min	Temperature	1273-1323K
Spraying Distance		205 mm	Coil Moving Speed	1.5 mm/s
Coating Thickness		1.2-1.5 mm		

Figure11:
Treating Procedure of Units

Figure11a: Appearance of Furnace Wall Tubes Before Treatment

Figure 11b: Appearance of Blasting

Surface Roughness Ra≧15μm

Figure11c: Flame Spraying

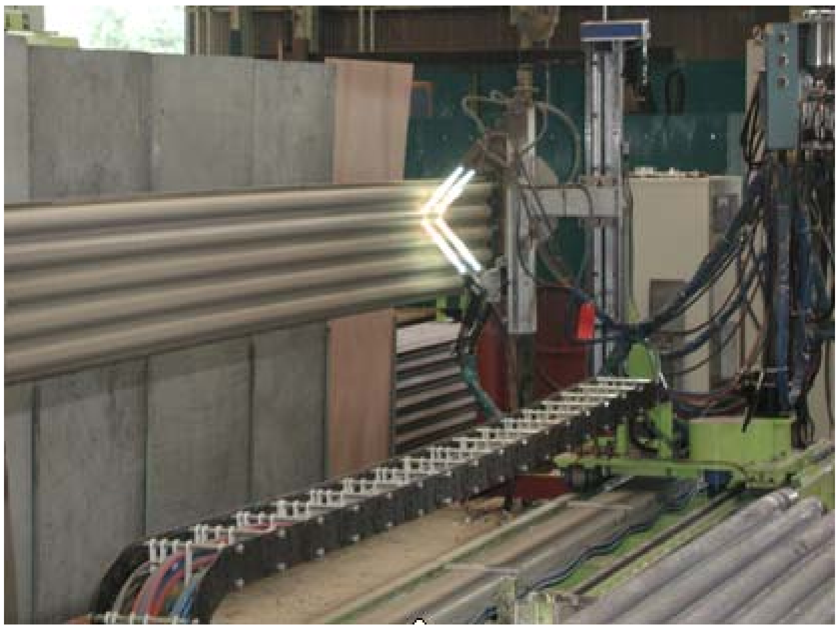


Figure11d: Induction Fusing

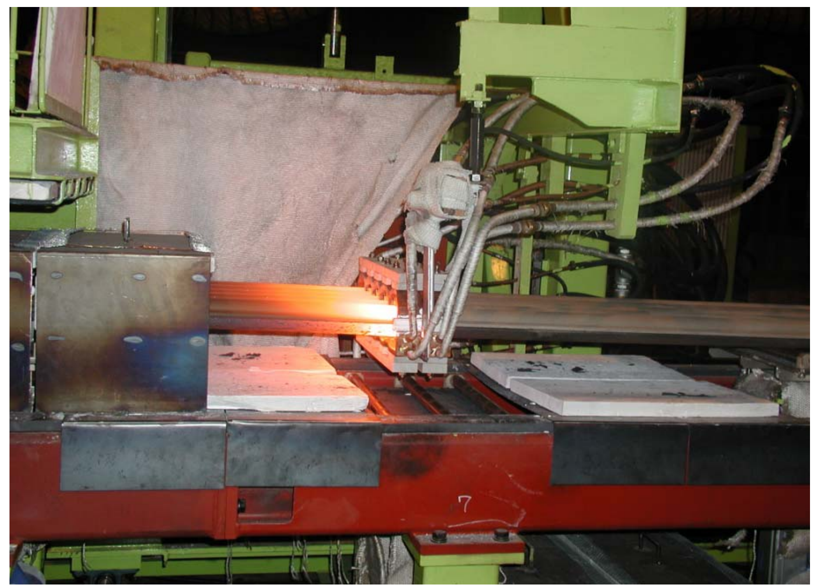


Figure 11e: Induction Bending of Units for Roof Section

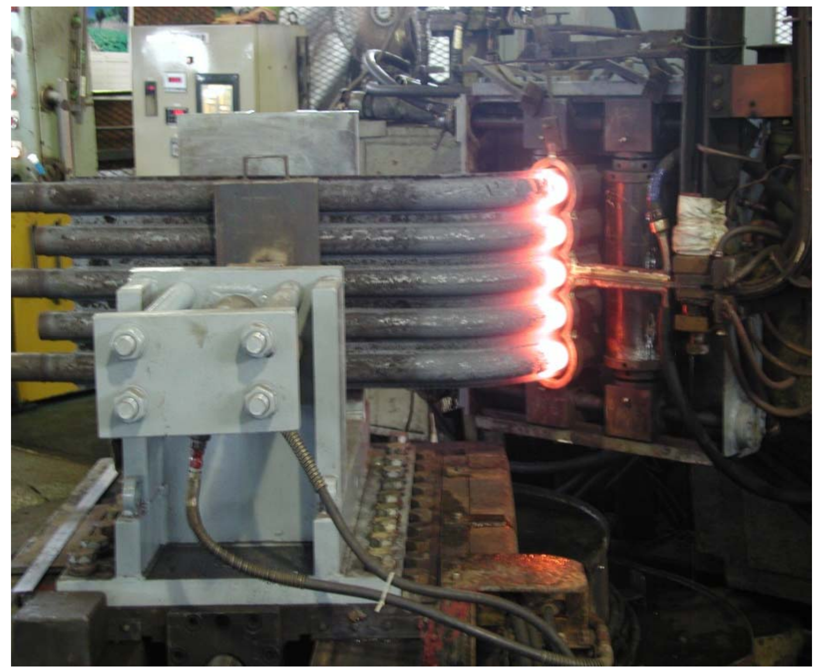
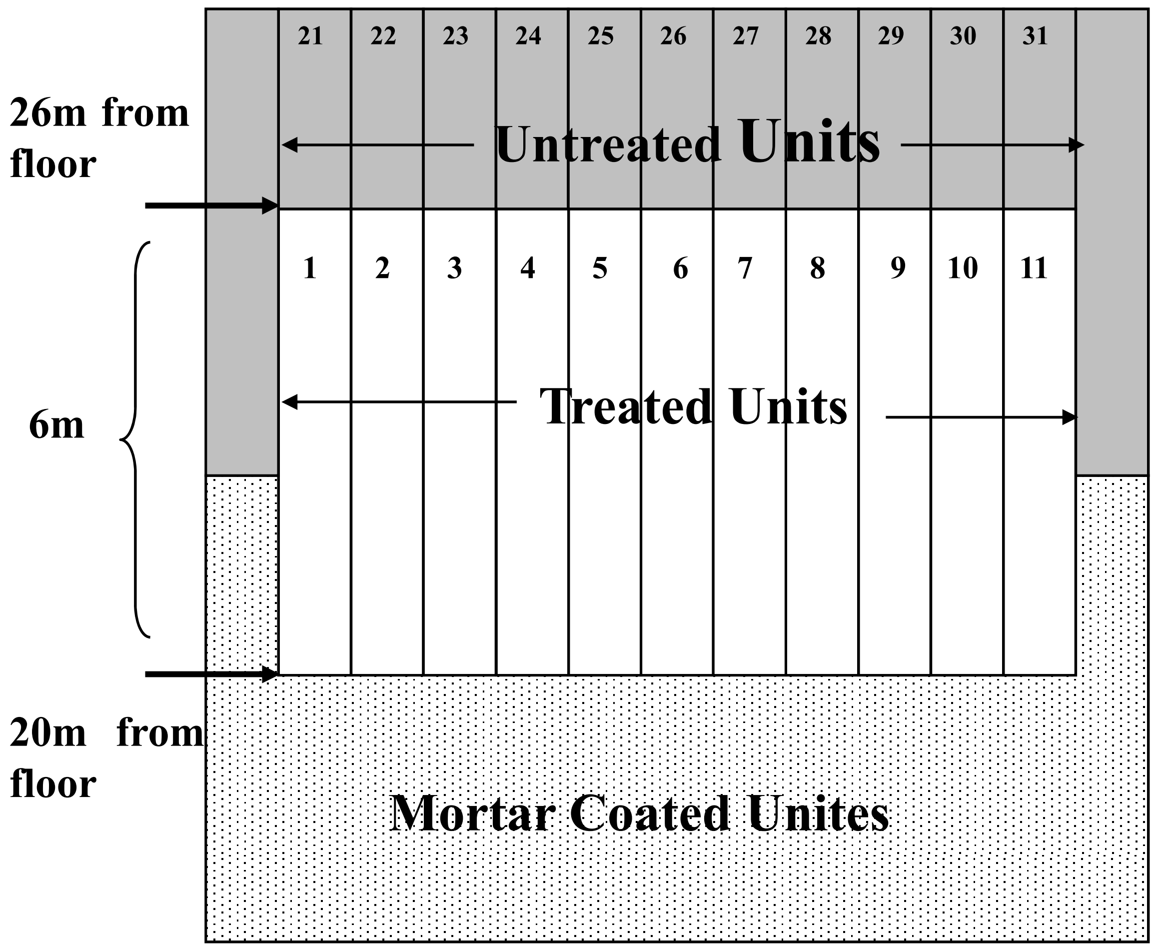


Figure 12: Position of 11 Units in Front Furnace Wall



Treated Units

Table 6: Thickness of Units after 2 and 3 Years (mm)

Unit Numbers	21-23	1-3	24-31	4-11
Inspection year	Untreated Units	Treated Units	Untreated Units	Treated Units
2003.4	6.7-6.9	8.2-8.4	6.8-6.9	-
2003.10	5.6-5.9	8.2-8.3	5.9-6.3	-
2004.4	5.0-5.4	8.1-8.4	5.2-5.5	8.7-9.0
2004.10	3.9-4.2	8.2-8.4	4.0-4.3	8.7-9.1
2005.4	2.9-3.2	8.2-8.3	3.2-3.6	8.7-9.0
2005.10	2.1-2.3	8.1-8.4	2.2-2.5	8.7-9.0
2006.4	Replaced	8.1-8.4	Replaced	8.6-8.9
2006.10	-	8.1-8.3	-	8.7-9.1

Application on Furnace Wall Tubes

1. Treated Panels: 450m2 at LuTsao Plant
   Tubes: 60.3mm x 5mm x 4.8-8.6m (SA210)
   Waste Type: 50% Industrial Waste
2. Treated Panels: 500m2 at Hsintien Plant
   Tubes: 76.2mm x 6mm x 6m (SA192)
   Waste Type: Domestic Garbage

Table 7:
Chemical Compositions of Powder and Substrate
(Weight%)

Powder	**Ni**	**Cr**	**Si**	**B**	**Mo**
Powder A	Balance	15	4.3	3.1	2.5
Substrate	**Fe**	**C**	**Si**	**B**	**Mn**
ASME SA210GrC	Balance	0.1	0.2		0.4

Figure 13: Schematic Diagram of Furnace (Lutsao Plant)

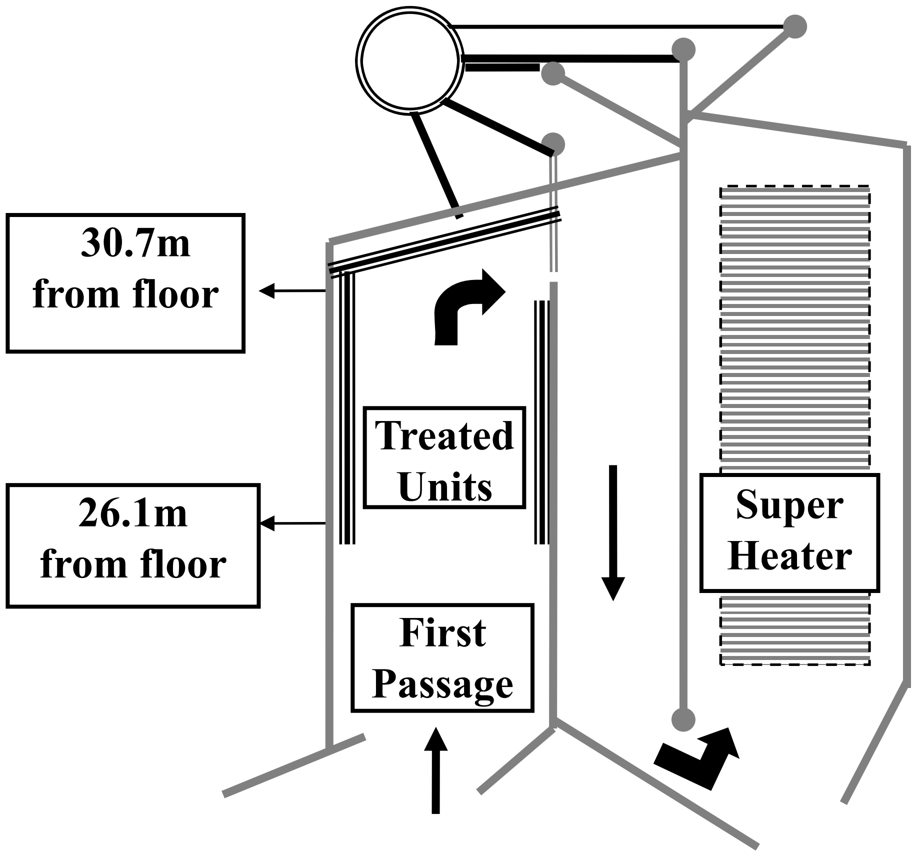


Figure 14: Schematic Diagram of Furnace (Hsintien Plant)

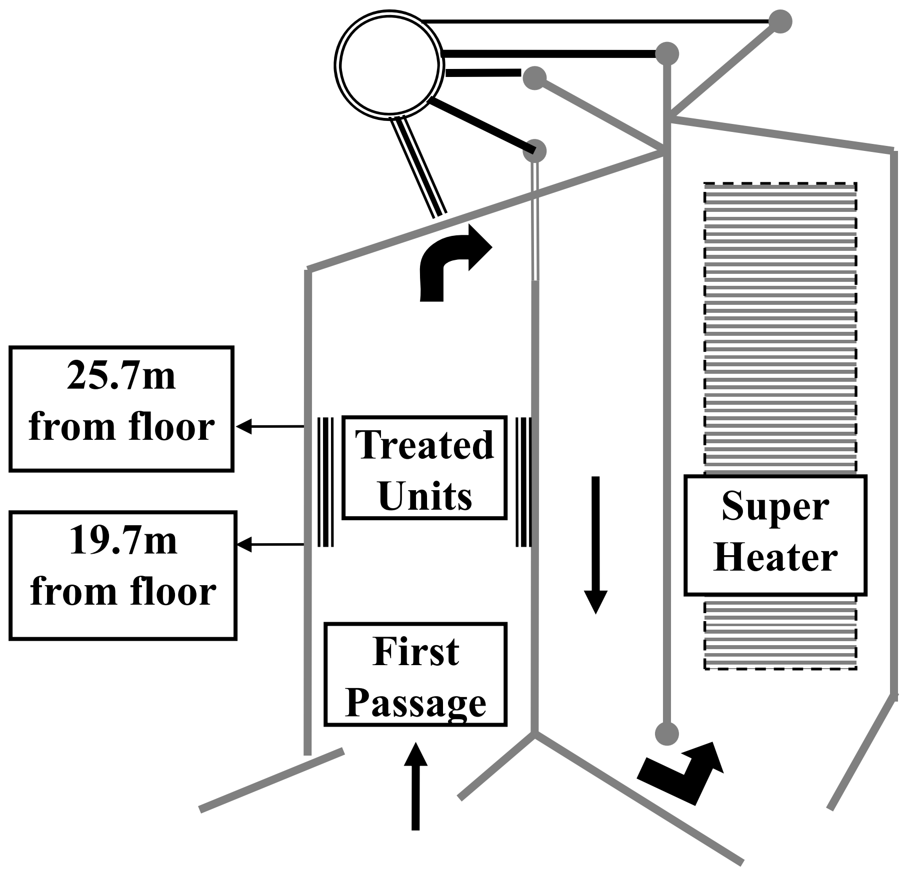


Figure15a:
Appearance of Waste Incineration Furnace
(5m x 7m in Width and 35m in Height)

Figure 15b:
Appearance of Roof and Front Units

Roof
32 m
from floor

Front
Units
30 m
from floor

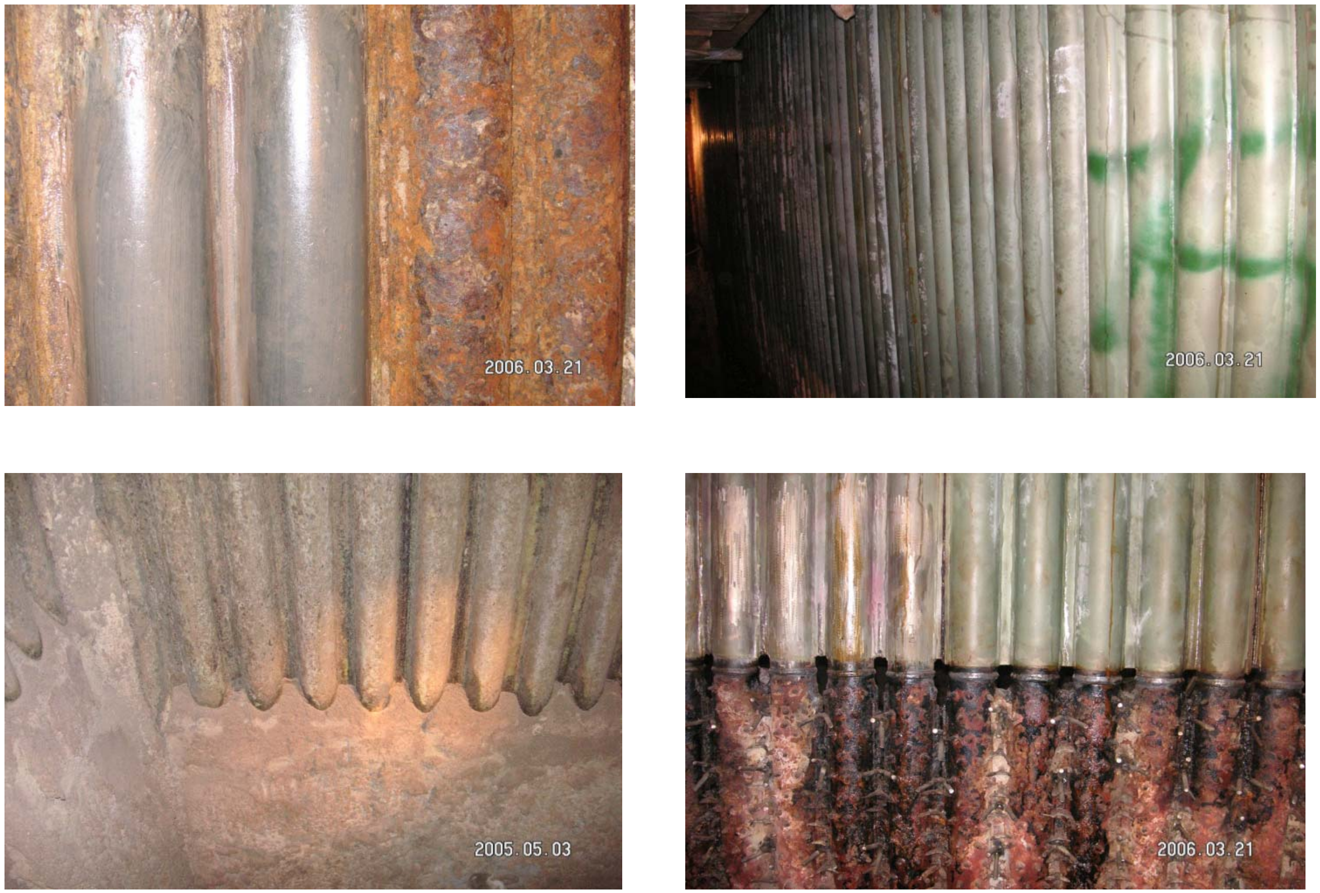
Units After Service

Units Before Service

Figure15c:
Appearance of Front and Mortar Coated Units

Front Units 26m from floor

Front Units 20 m from floor



Units After Service

Units Before Service

Figure16: Furnace Temperature and WTE Conversion Rate

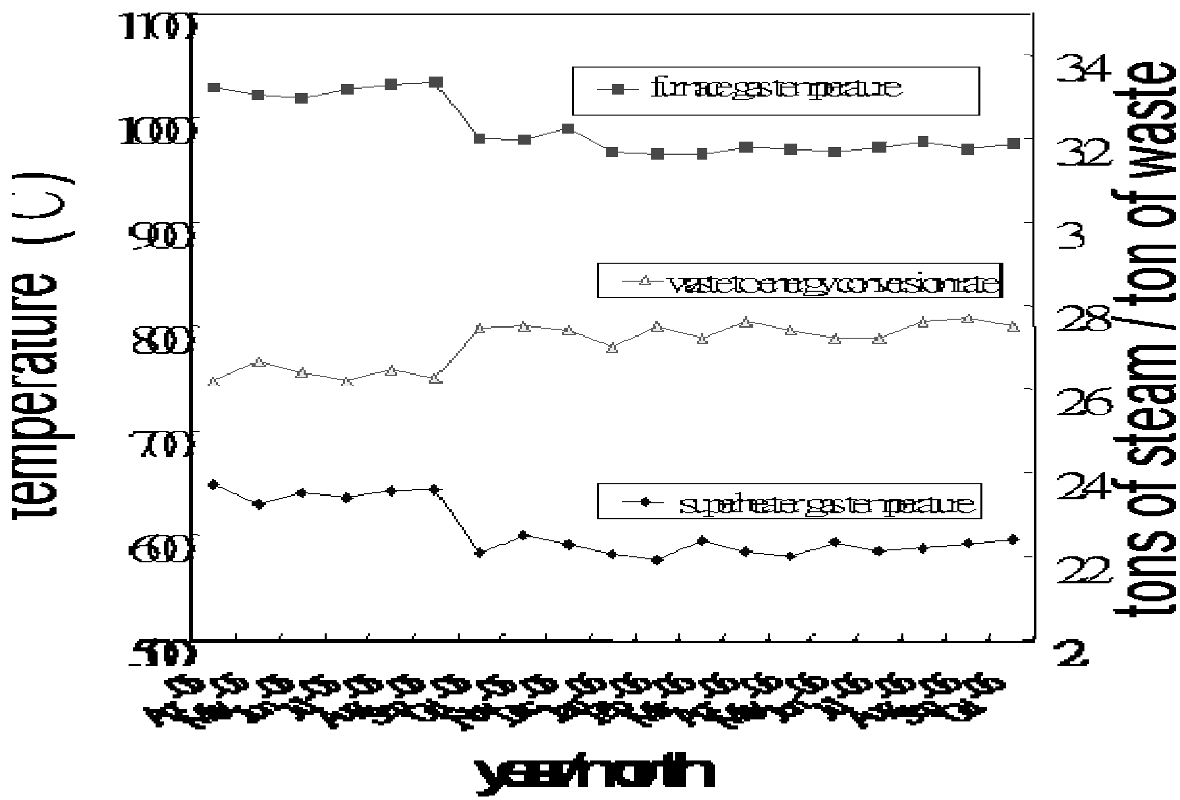


Figure 17a: Thickness of Furnace Wall Tubes After Service at 26.2m from Floor

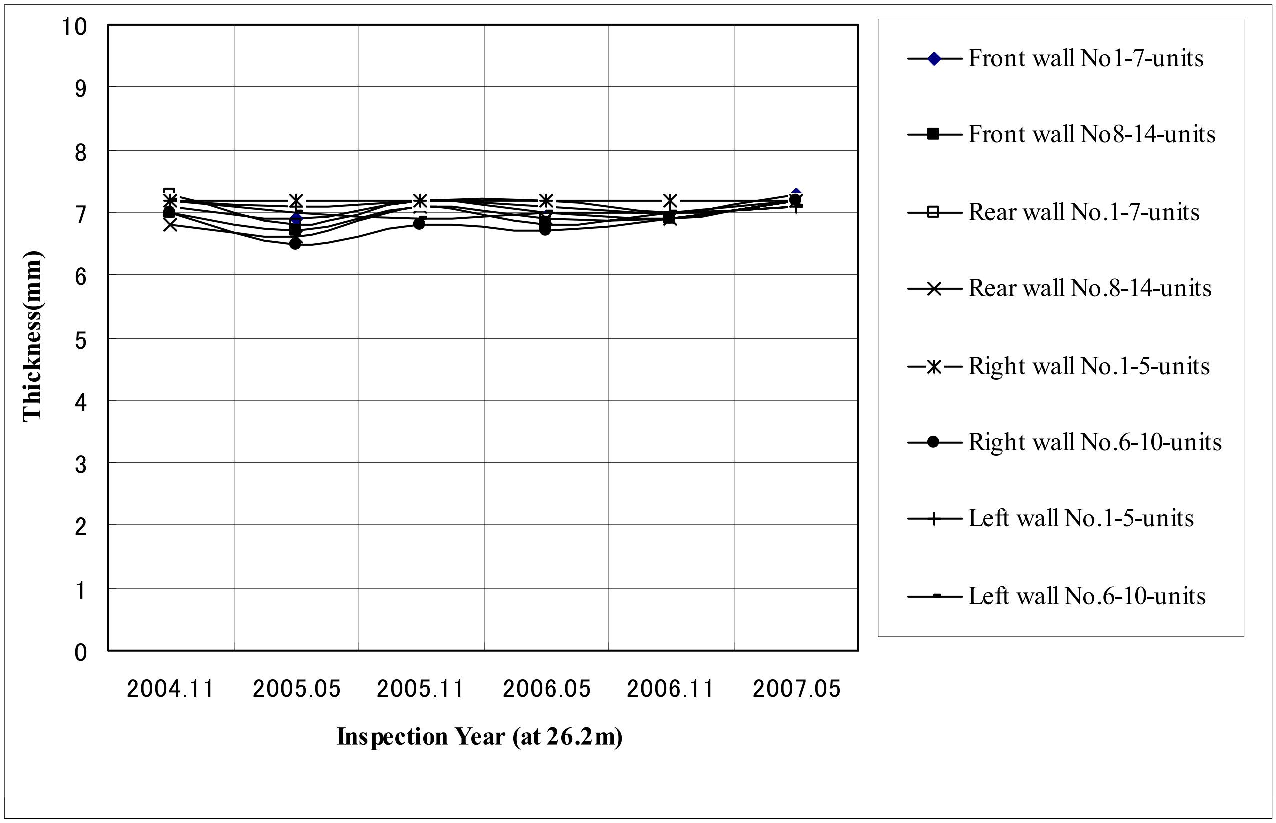


Figure 17b: Thickness of Furnace Wall Tubes After Service at 27.2m from Floor

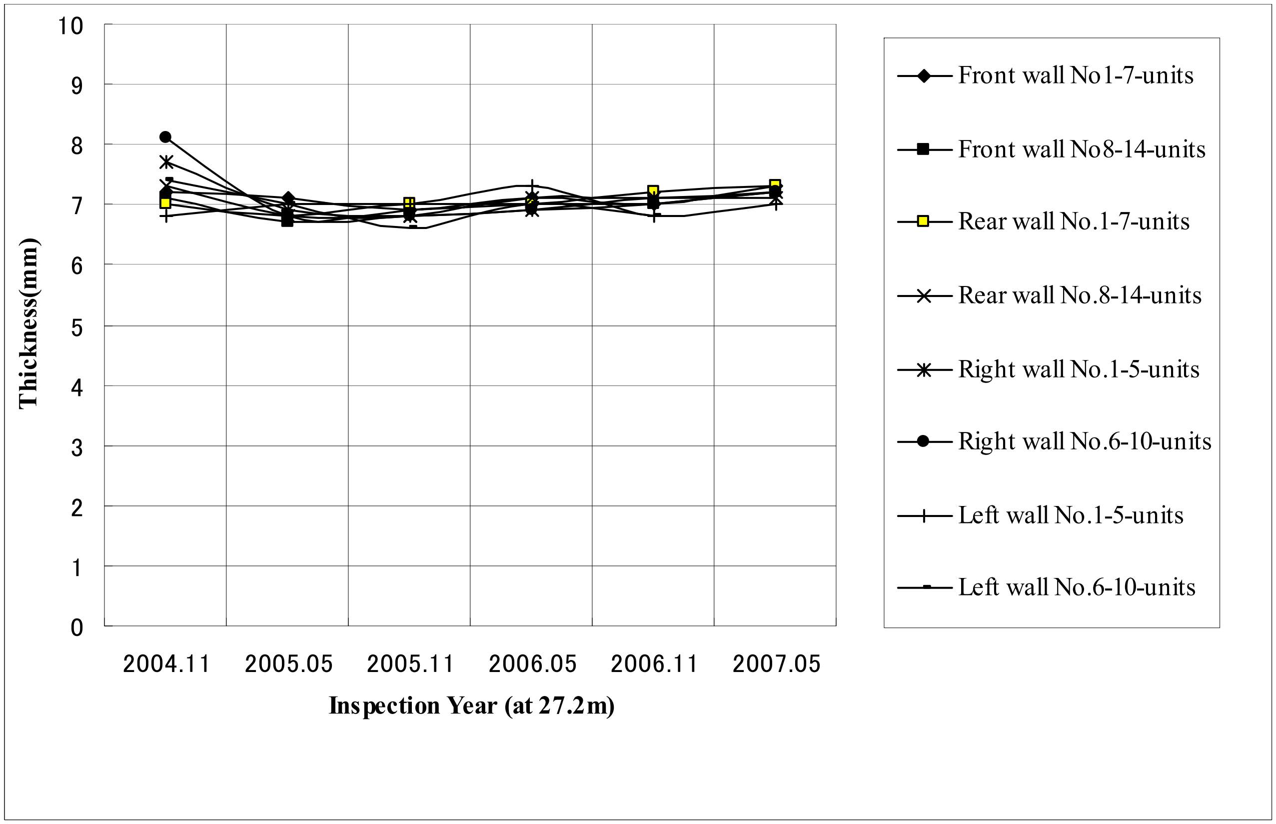


Table 8: Distribution of Treated Panels in WTE Plants in Taiwan

Supply Year	WTE Plant	Capacity (Ton/Day)	Units (Numbers)	Area (m^2)
2004	Shulin	1350	10	44
2004	Lutsao	900	132	450
2004-2005	Houli	900	90	180
2005-2006	Hsintien	900	92	500
2005-2006	Taoyuan	1350	80	282
2006	Shulin	1350	70	469
2007	Wurih	900	132	432
2007	Renwu	1350	50	103
Totals			656	2460

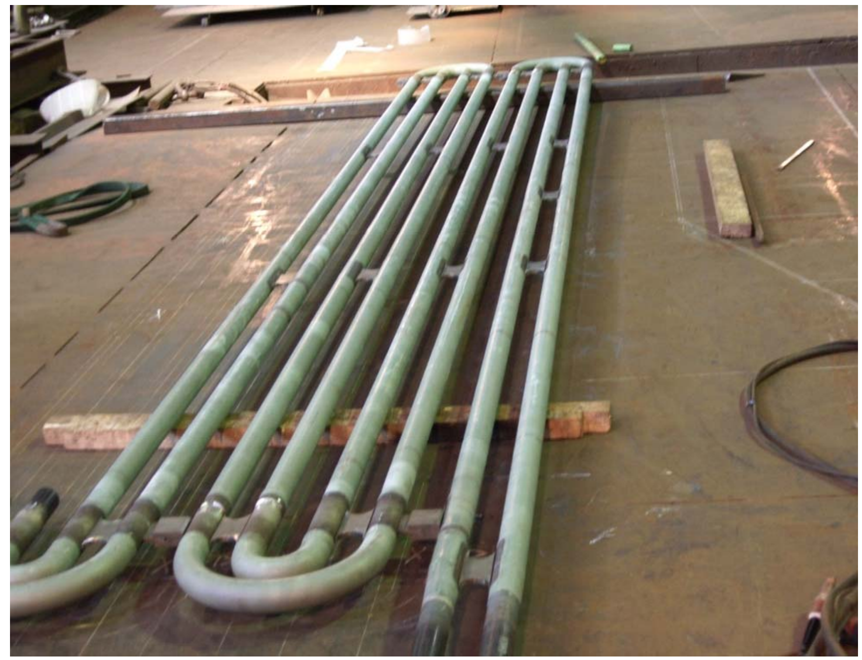
Conclusions

- greatly extends service life.
- inexpensive process
- reduces distortion for final assembly.
- displays no decrease in thickness of tubes after 40 months' use

Latest Developments

1. Products & Process of ACT&P
2. Supply Record of ACT&P Boiler Tubes
3. Corrosion Test Results of ACT&P

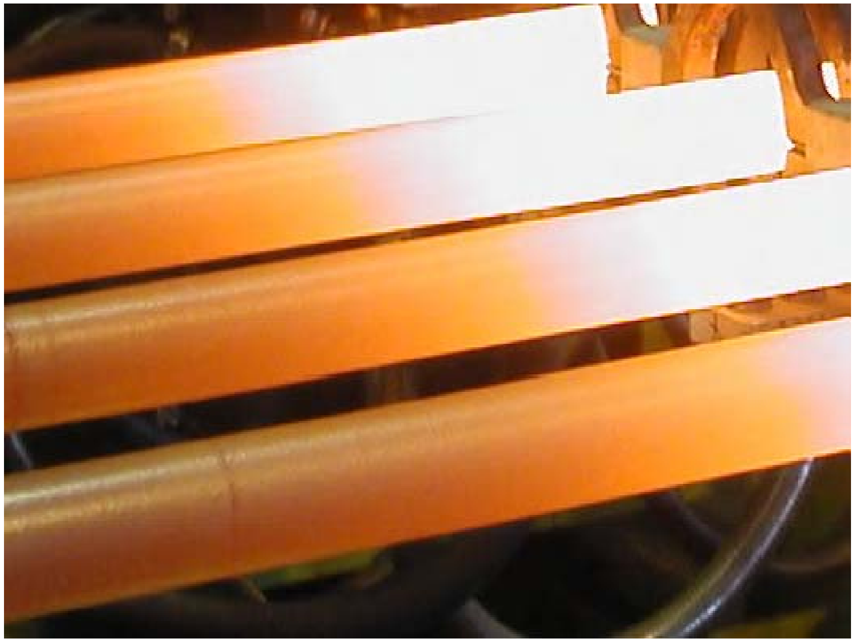
ACT&P : Super Heater



Super Heater of Coal Combustion Power Plant

Super Heater of Waste Incineration Plant

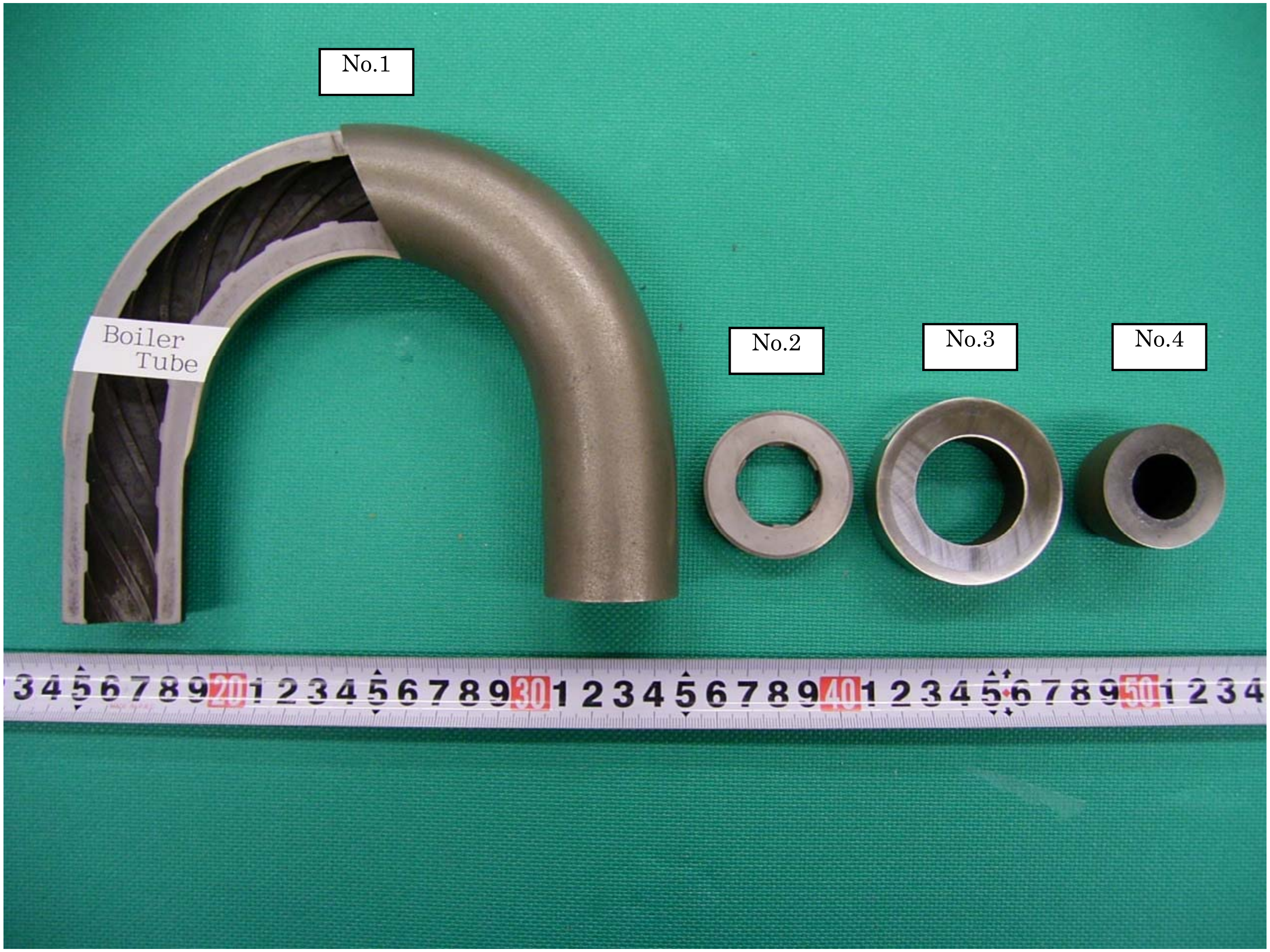
ACT&P : Induction Fusing & Bending



Straight Tube-
Induction Fusing

Bent Tube-
Induction Bending

Partial Section of ACT&P, Coated and Bent



Supply Record of ACT&P Boiler Tubes

Supply Year	Boiler Plant	**Boiler Tube**	Tube Material	Tube Size	Coating Thickness	Tube Numbers
1993	**PFBC**	**HE,SH**	**STBA24 SUS310**	**50.8-54x2400**	**1.0mm<**	**730**
1994	**Coal Combustion**	**HE,SH**	**STBA24 SUS347**	**45x3400-3500**	**1.0mm<**	**810**
1995-1996	**PFBC**	**HE,SH**	**STBA22,24**	**39.1-63.5x 1500-3000**	**1.5mm<**	**1756**
1997-2002	**PFBC**	**HE,SH**	**STBA22,24 SUS310**	**38.1,45,50.8, 1500-5000**	**1.5-2mm<**	**1408**
2000	**Sulfuric Acid**	**Water**	**STB340**	**38.1x5000**	**1.5mm<**	**245**
2003-2005	**Biomass**	**HE**	**STB340**	**75.2x4700 60.3x4200**	**0.8mm<**	**188**
2002-2007	**Recovery Heat**	**HE,SH**	**STBA12,22 STB340**	**38.1,50,60.3 1200-6000**	**0.3-0.8mm 0.5-1.2mm**	**2422**
2004-2007	**Waste Incineration**	**SH**	**STB340**	**38.1,42.7 x1700,4500**	**0.5-1mm<**	**415**
2007	**CDQ**	**HE**	**STB340**	**31.8x9500**	**0.3mm<**	**2934**

Laboratory Corrosion Test Results of ACT&P

Fig.1 Schematic Illustration of Laser-detecting Thermogravimetric Apparatus

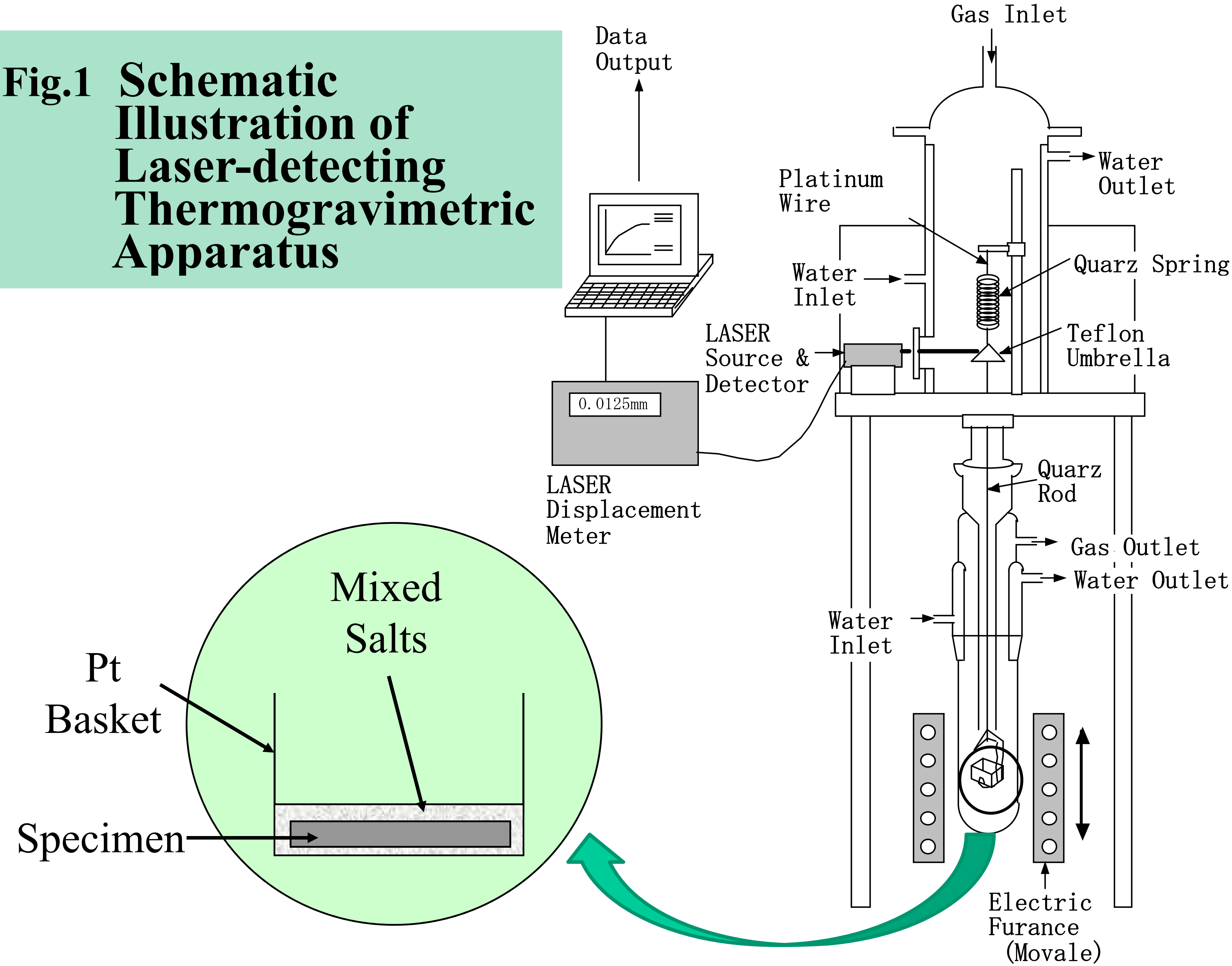
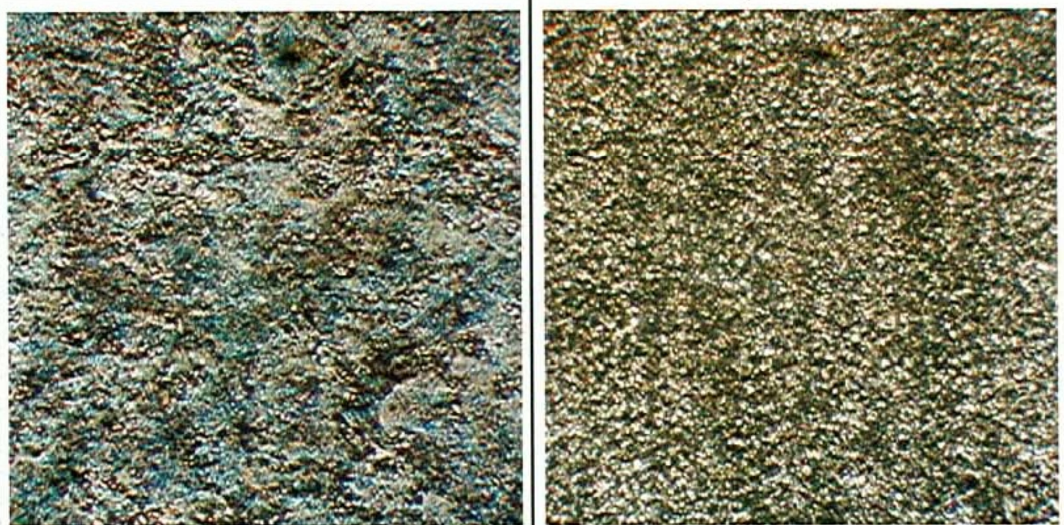


Table 1: Conditions of High Temperature Corrosion Test

Gas	Composition	1%HCl-50%O2-N2
	Flow rate (cm3/min)	40
Salts	Ash from WTE plant in Taiwan	Composition undetermined
	Prepared salt	40mol%NaCl-40mol%KCl-20mol%Na2SO4
Specimen	Powder A	10mm × 10mm × 1mm Surface polished by sand paper #800
	Inconel 625	
Temperature	K (Kelvin)	923

Table 2: Chemical Compositions of Powder A and Inconel 625 (Weight%)

Material	Ni	Cr	Si	B	Mo	Fe	C	Cu	Al	Nb + Ta	Ti
Powder A	balance	15.0	4.3	3.1	2.5	-	-	-	-	-	-
Inconel 625	65.7	21.7	0.08	-	8.1	0.4	0.02	0.1	0.2	3.33	0.3



Powder A | Inconel 625

Fig.2 : Microstructure of Samples before Test (etched)

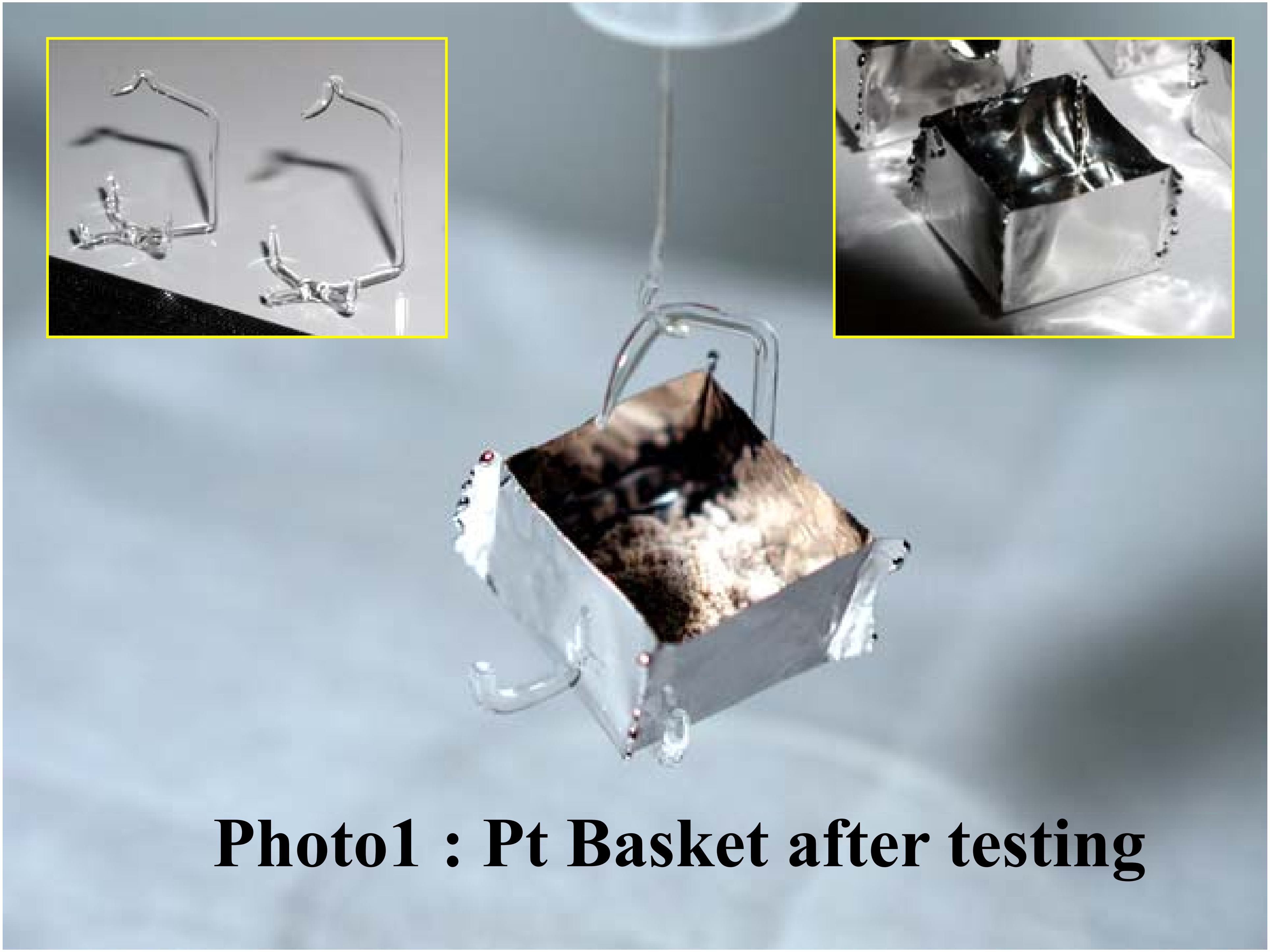


Photo1 : Pt Basket after testing

Powder A	Inconel 625
	

Fig.3 : Appearance of Corroded Sample after Testing at 923K for 72h

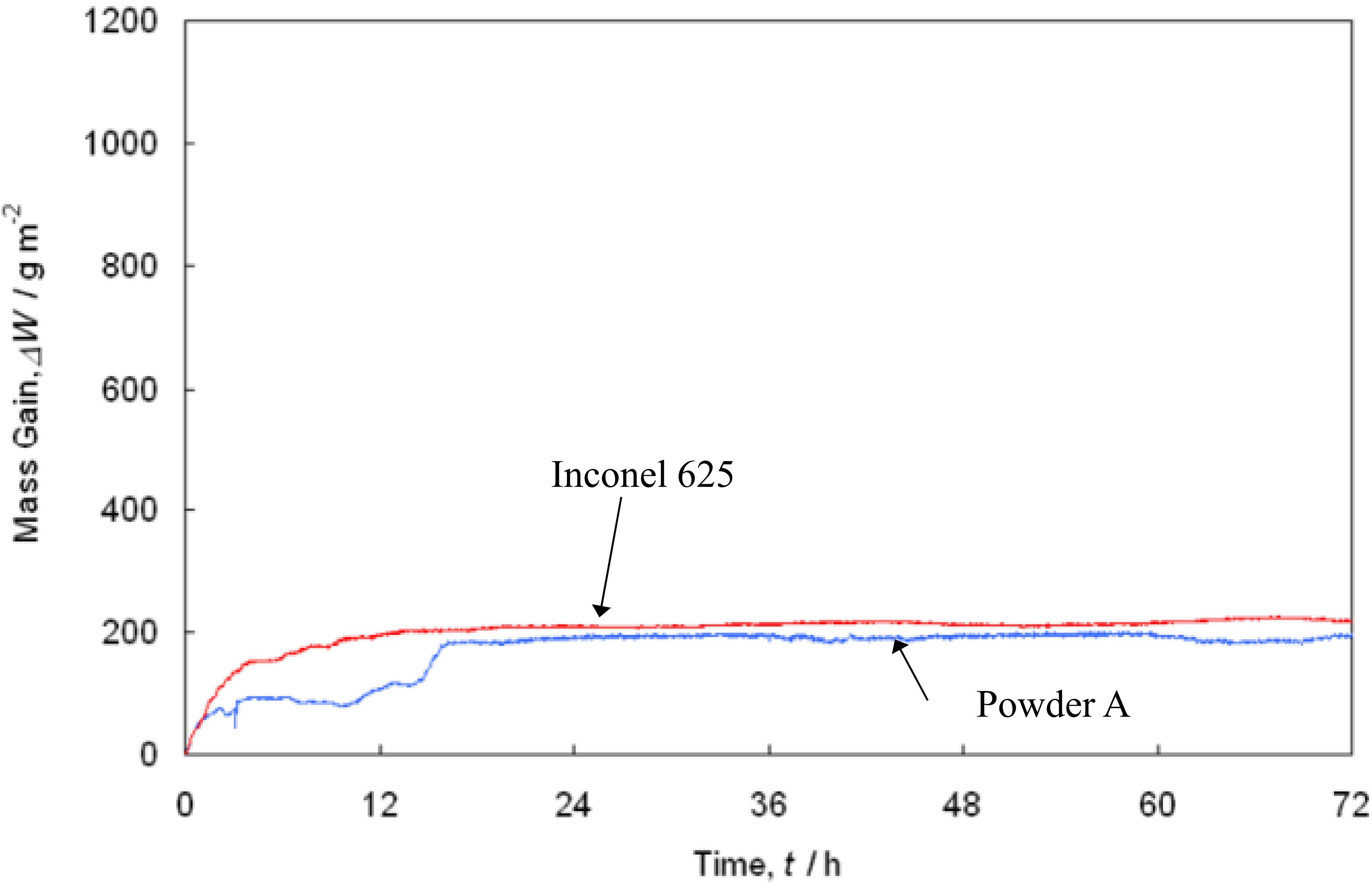


Fig.4 : Mass gain curves on specimen tested with Ash from WTE plant in 1%HCl-50%O2-N2 at 923K

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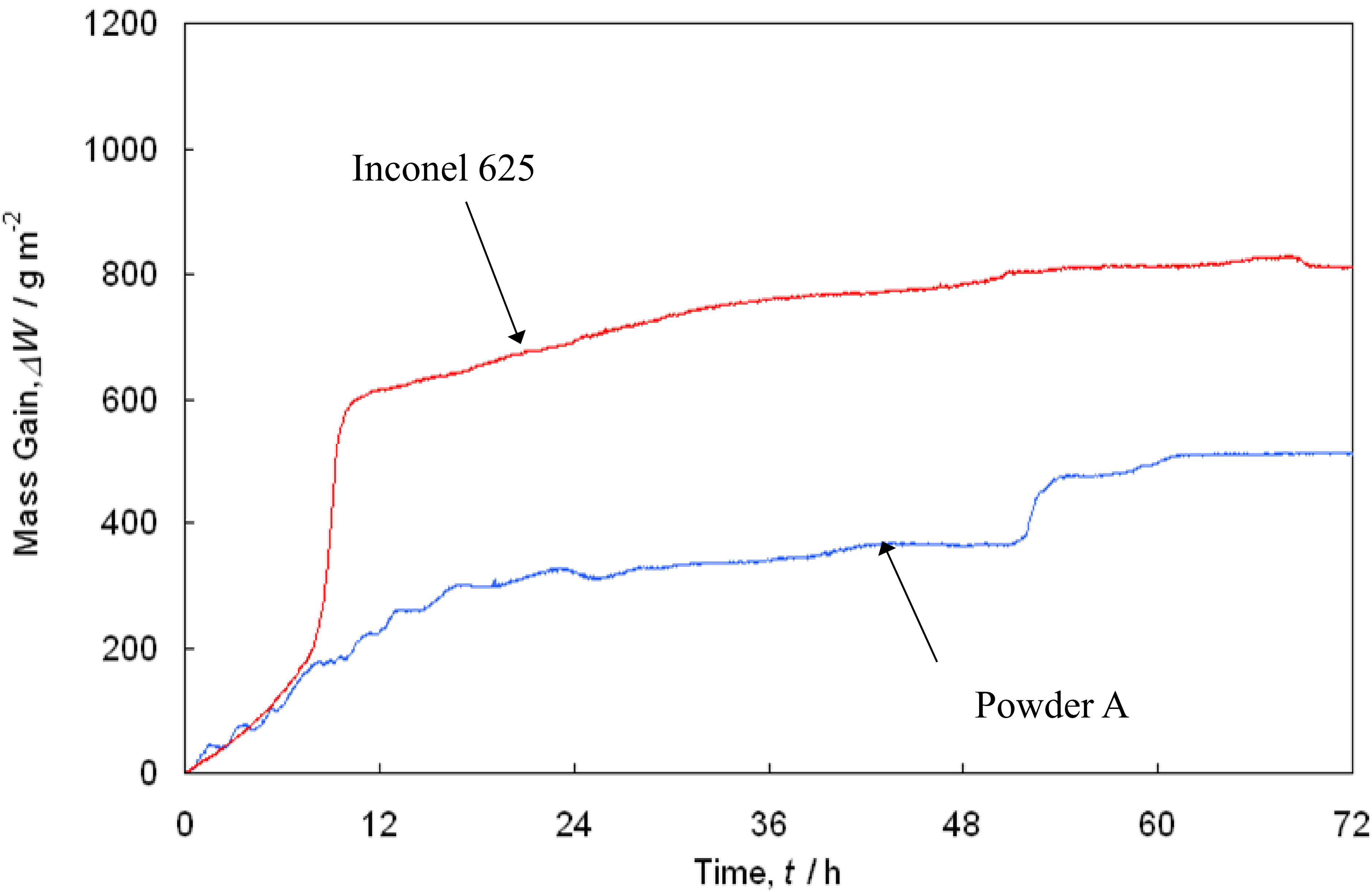

Fig.5 : Mass gain curves on specimen tested with prepared salts from WTE plant in 1%HCl-50%O2-N2 at 923K

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Thank you