



GLOBAL POWER GENERATION
INNOVATION

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Use cases definition for the evaluation of ultrasound technologies to mitigate scaling issues in heat exchangers and cooling/heating circuits

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INTRODUCTION

As mentioned during the introduction call ENEL is aiming to replace chemical treatment of cooling / heating circuit with non chemical technologies with the final scope to reduce the impact on the environment and if possible reduce the complexity related to chemical treatments (chemical purchase, chemical storage, authorization, safety aspects,...)

In this framework we would like to evaluate the feasibility of ultrasound technologies to properly operate our circuits in the following application areas:

1. Once through cooling circuit working with sea water
2. Heat exchangers working with geothermal brine

In all the applications the scope of the treatment is to limit heat exchange degradation caused by:

- Scaling formation
- Biofouling growth


For case 1 and 3 the standard treatment consist in dosing specific chemical products to avoid both phenomena. For Biofouling we generally dose an oxidant (sodium hypochlorite) to disinfect the water and avoid biofilm growth along the entire circuit. Biocide dosing is limited by discharge limits, storage constraints, product availability. To limit scaling formation we generally dose specific antiscalant product especially in closed cooling circuit where this dosing allow to increase concentration cycles and sensibly reduce water consumption. In once through we don't generally dose antiscalant but in some case we have scaling formation which can require dedicated offline cleaning.

For case 2 there some limitation concerning chemical dosing and in the actual operation no chemicals are used.

At this stage a possible application on once through (case 1) and on geothermal application (case 2) is more interesting so in the following paragraph a detailed description of the two cases will be proposed.


For the two cases we would like to ask you:

- If you already have experience in a similar application with the reported type of fouling;
- A preliminary evaluation of the effectiveness of your technology;
- A possible proposal of treatment with a rough estimation of expected benefits;
- A rough estimation of investment costs.

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For case 1 main driver to evaluate ultrasonic devices to keep clean the cooling circuit is related to the reduction of biocide use and then consumption and storage needs. In terms of heat exchange efficiency or needs of cleaning with the biocide treatment we don't have big penalties

In case 2 because of the limitation in using chemical products, the driver is to reduce the scaling rate, improving the reliability of the process and then the heat exchange efficiency

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1. Once through cooling system

In the south of Italy we have a power plant constituted of 4 Units of 660 MWe each which requires a high amount of cooling water. The plant is equipped with a once through system in which the cooling fluid is sea water. In Figure 1 a general view of the plant is reported highlighting the water intake section with the stilling basin and the cooling water discharge section. Cooling circuit is quite large both in terms of flow rate and in terms of extension.

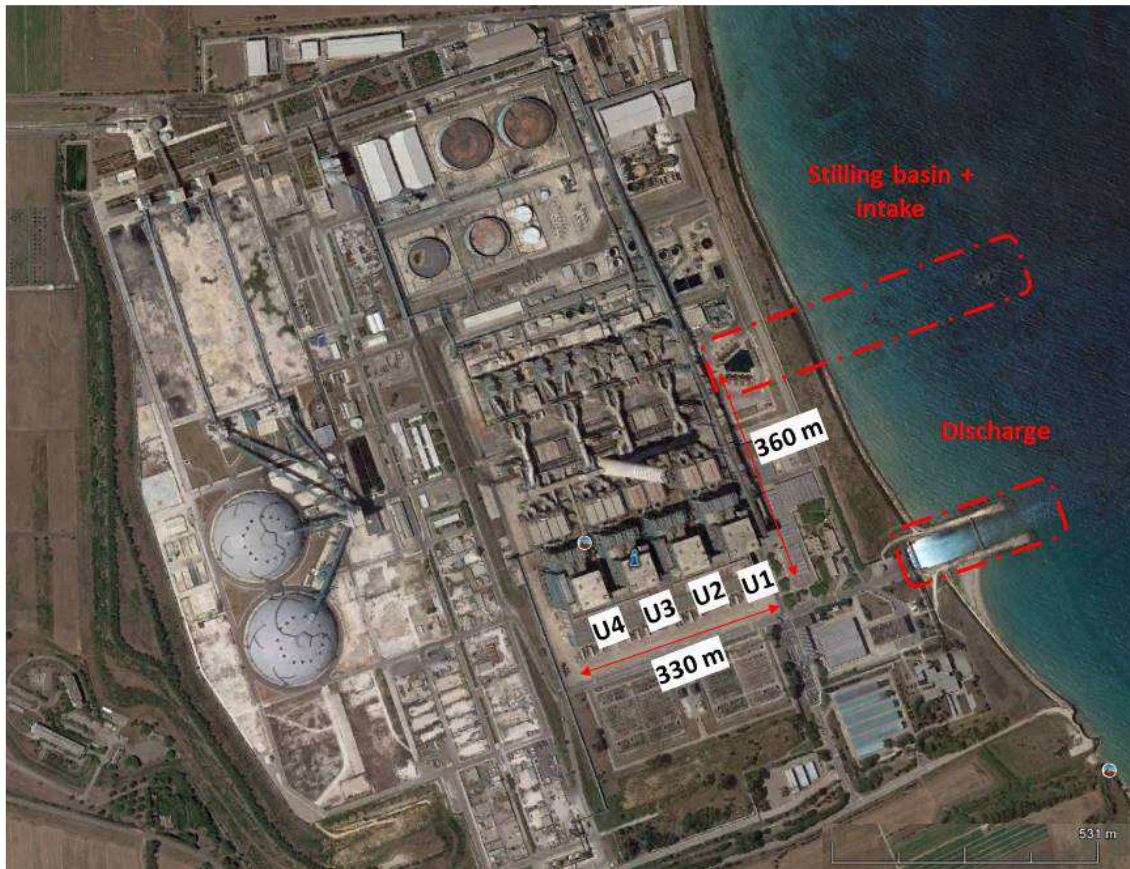



Figure 1 – Power plant aerial view

Each Unit is equipped with two (2) sea water cooling pumps (AC pumps) with a nominal flow rate of 12,5 m³/s each. In Figure 2 are reported respectively the intake section (on the left) and the discharge section (on the right). In the picture of the intake section are indicated the four (4) intake channels which collect the water from the sea into the stilling basin. In the basin are installed the AC pumps (highlighted by the blue circles) of the units. The picture shows also the biocide dosing point highlighted with the green box, which consists in four (4) dosing lines installed in the four (4) intake channels. On the discharge section is possible to distinguish the four (4) channels coming from the Unit condensers. Close to the exit to the sea is visible a sort of small bridge. In this bridge are installed four pumps, one for each channel, for the sampling of the water to be analyzed with the colorimetric method to constantly monitor the residual free chlorine at the discharge.

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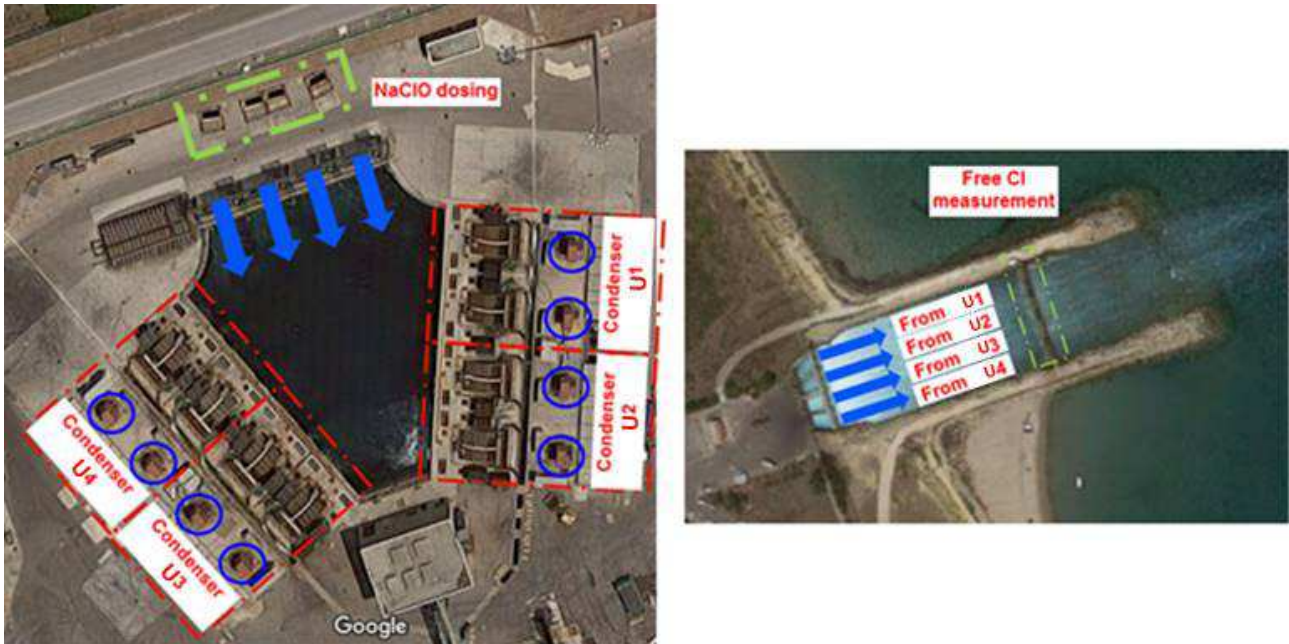


Figure 2 – Stilling basin (left) and discharge channel (right) details

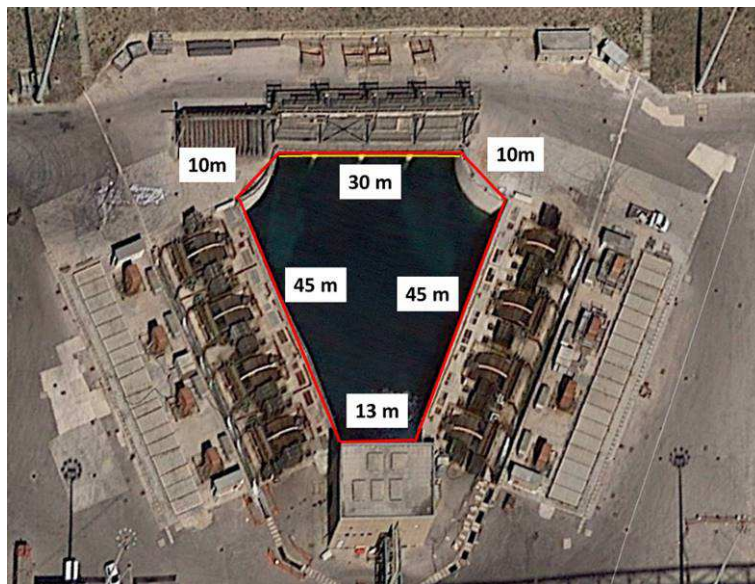



Figure 3 – Stilling basin dimensions

In Figure 3 main dimensions of the stilling basin are reported

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1.1 Condenser

Each of the four units is equipped with a dedicated condenser split in two chambers. Condenser of Unit 1 and unit 2 are the same model while condenser of Unit 3 and Unit 4 are another model from a different supplier and different tubes layout

1.1.1 Unit 1 & 2

Condenser Unit 1 and 2		
SUPPLIER		BELLELI
COOLING WATER		sea water
Cooling water flow rate	m3/s	22,50
Total exchange surface	m2	30.611
water passage	#	1
Hotwell volume	m3	268
Tubesheet number		2
Tubesheet material		ASTM B 171 ALLOY C 63000
Tubesheet thickness	mm	38
Tubesheet coating		/
Tubesheet type		rectangular
Tubesheet sizes	m	3,695 x 5,275
total number of tubes		16.752
tube length	m	18,4
tube material		Titanium
Tube diameter	mm	31,75
Tube thickness	mm	0,7
Water boxes material		FE 410 1KG UNI 5869
Water boxes coating material		epoxy
number of manholes		11
number of sacrificial anodes		112
sacrificial anodes material		zinc

Table 1 – Condenser 1 and 2 main design figures



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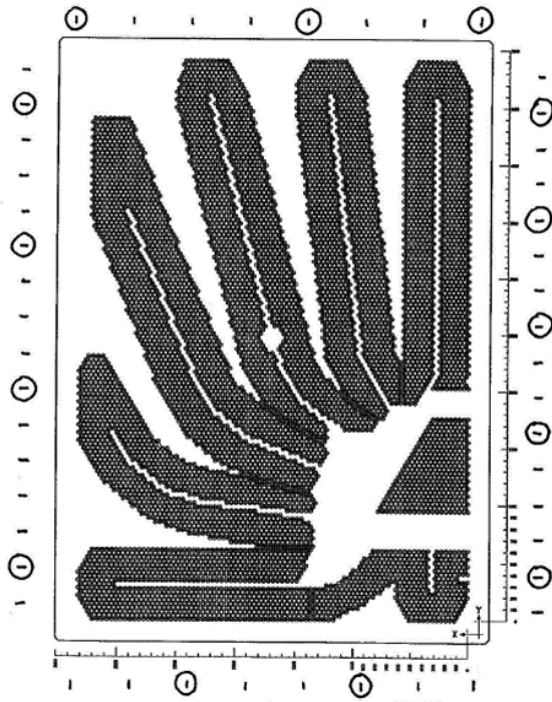
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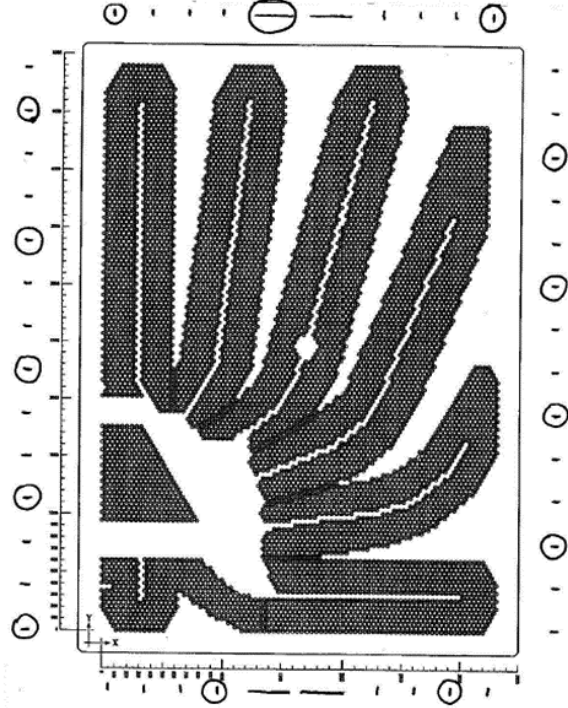
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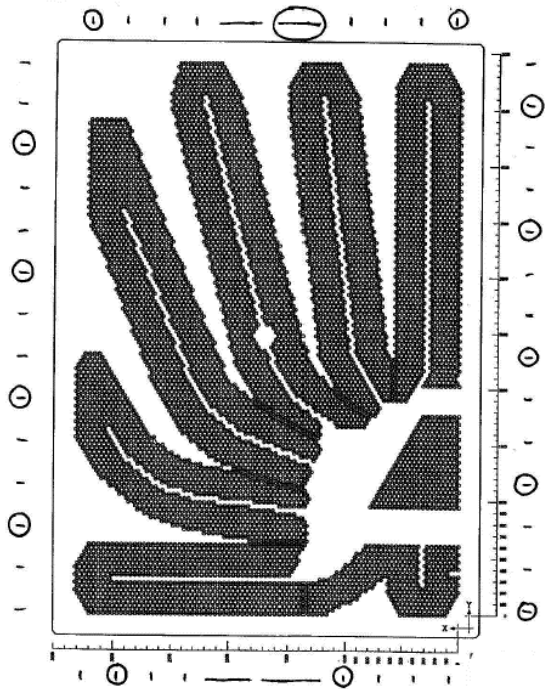
CTE BS CONDENSATORE Gr.1&2 (Belleli)
CASSA "B" - INGRESSO ACQUA MARE



CTE BS CONDENSATORE Gr.1&2 (Belleli)
CASSA "B" - USCITA ACQUA MARE



CTE BS CONDENSATORE Gr.1&2 (Belleli)
CASSA "A" - USCITA ACQUA MARE



CTE BS CONDENSATORE Gr.1&2 (Belleli)
CASSA "A" - INGRESSO ACQUA MARE

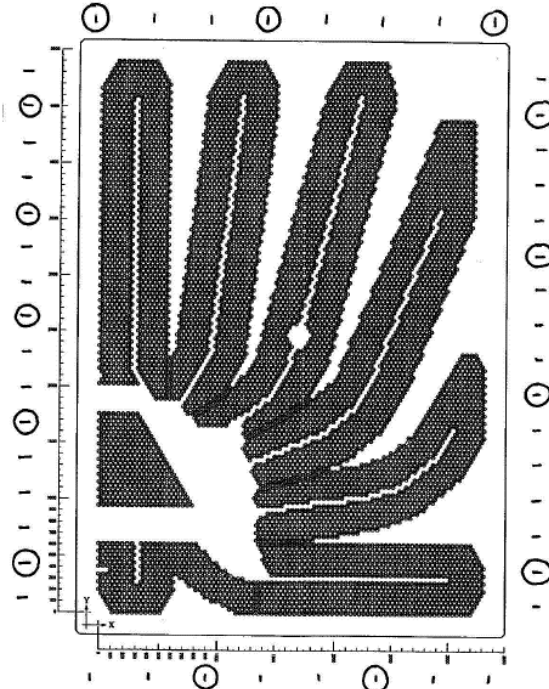


Figure 4 – Condenser 1 and 2 tubesheet layout

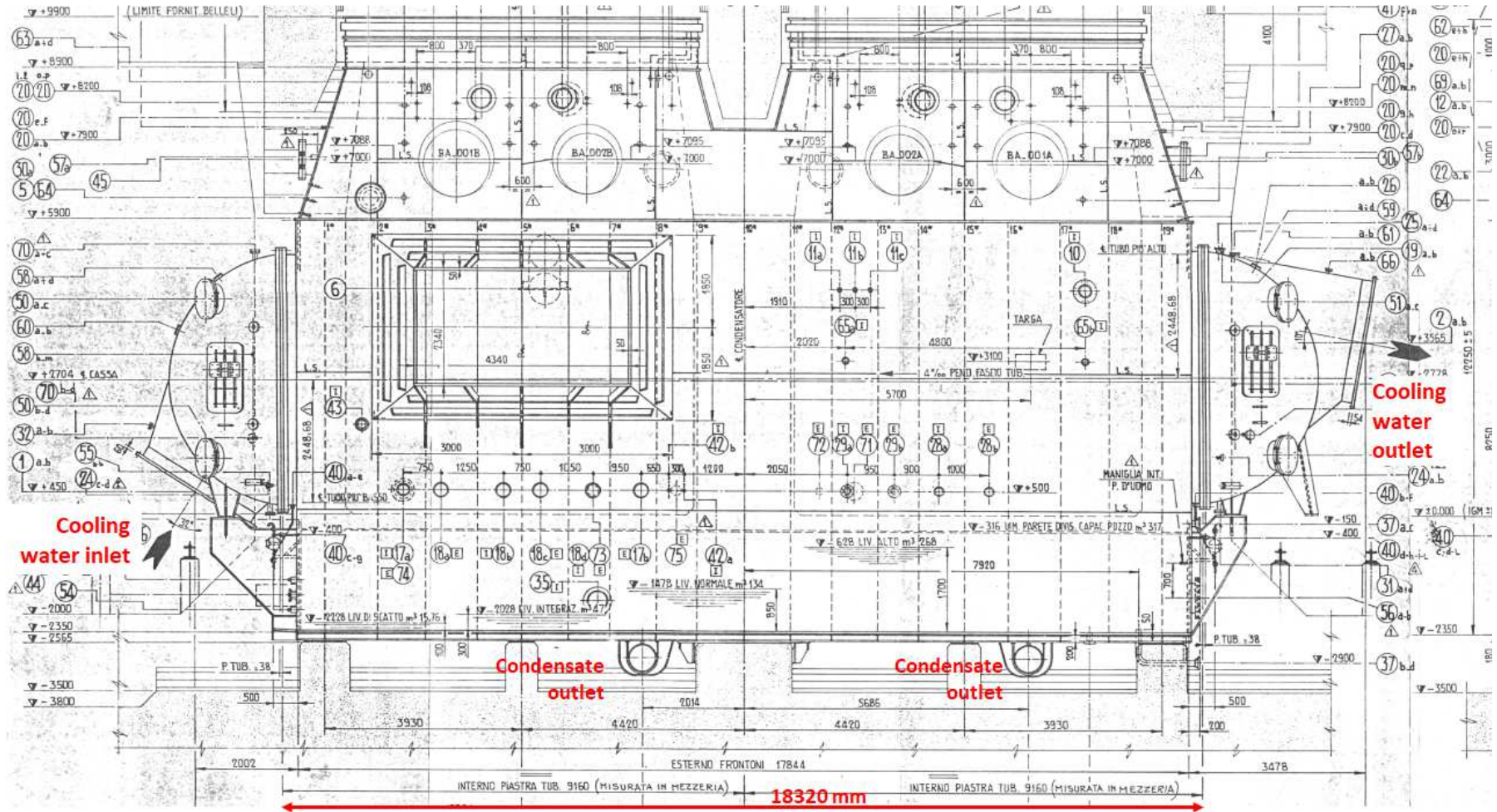



Figure 5 – Condenser 1 and 2 lateral view

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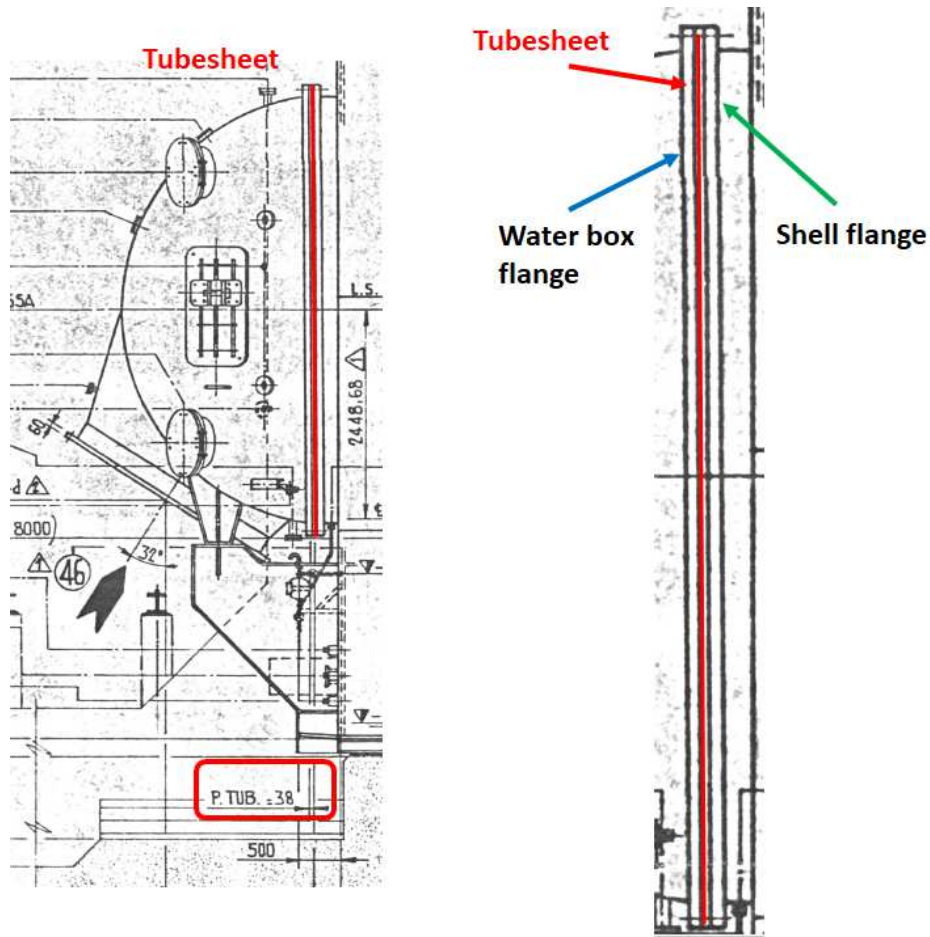




Figure 6 – Condenser 1 and 2 tubesheet fixing detail

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1.1.2 Unit 3 & 4

Condenser Unit 3 and 4		
SUPPLIER		TOSI
COOLING WATER		sea water
Cooling water flow rate	m3/s	22,50
Total exchange surface	m2	30.600
water passage	#	1
Hotwell volume	m3	268
Tubesheet number		2
Tubesheet material		ASTM B 171 ALLOY C 63000
Tubesheet thickness	mm	38
Tubesheet coating		/
Tubesheet type		rectangular
Tubesheet sizes	m	
total number of tubes		16.752
tube length	m	18,4
tube material		Titanium
Tube diameter	mm	31,75
Tube thickness	mm	0,7
Water boxes material		ASTM A 285 Gr. C
Water boxes coating material		epoxy
number of manholes		11
number of sacrificial anodes		112
sacrificial anodes material		zinc

Table 2 – Condenser 3 and 4 main design figures

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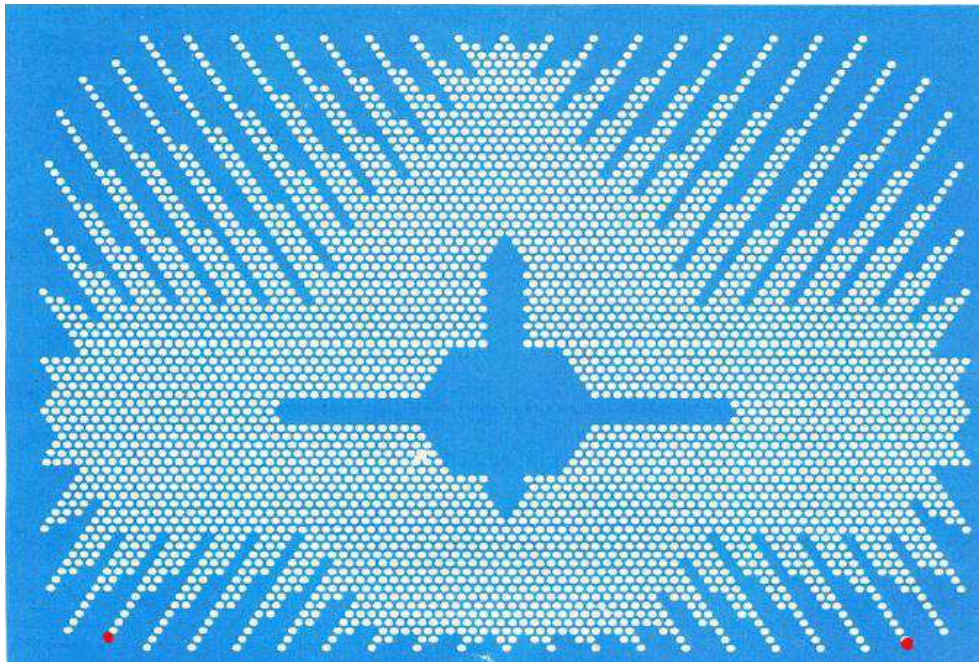



Figure 7 - Condenser 3 and 4 tubesheet layout

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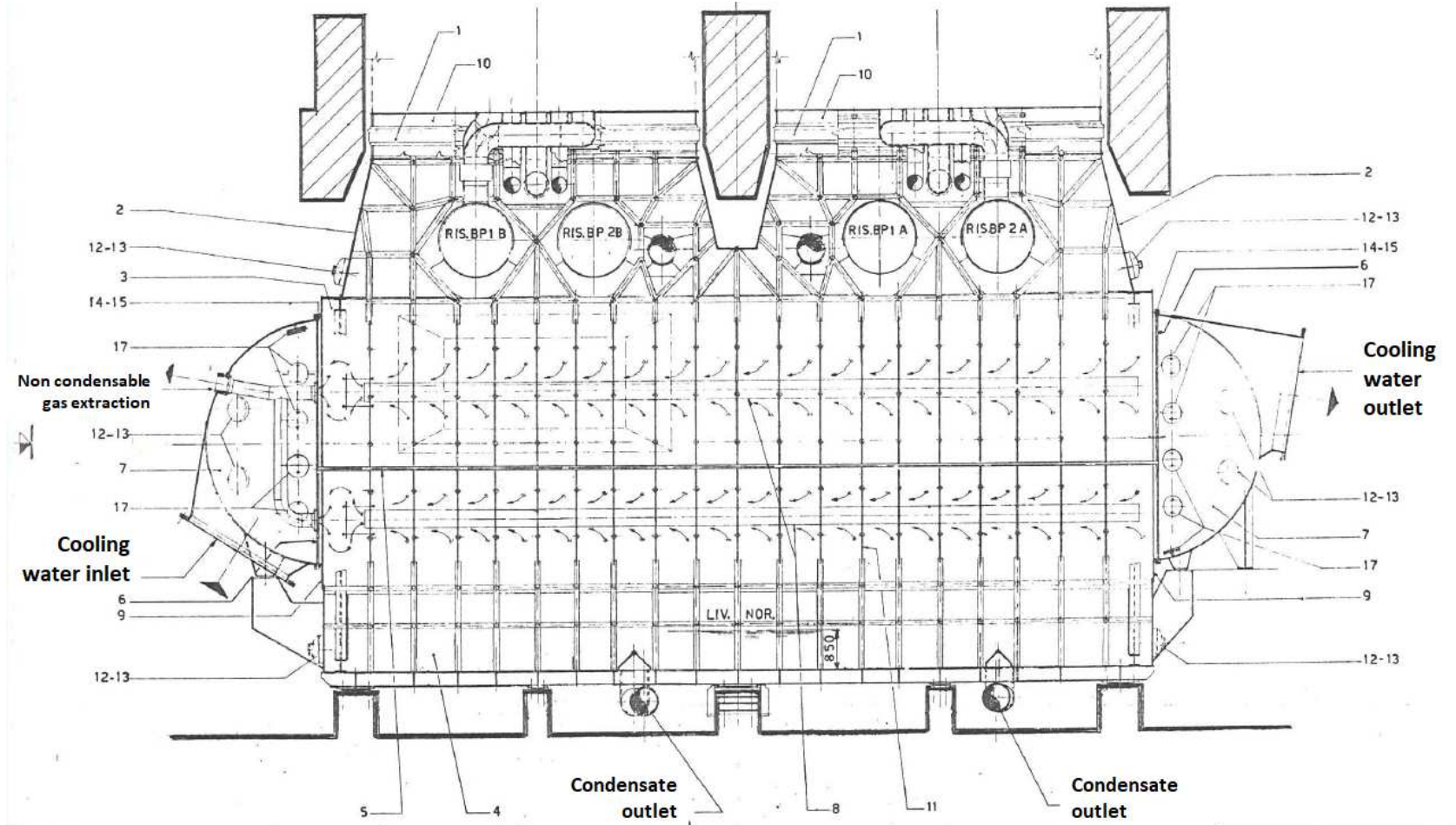



Figure 8 - Unit 3 and 4 condenser mechanical drawing

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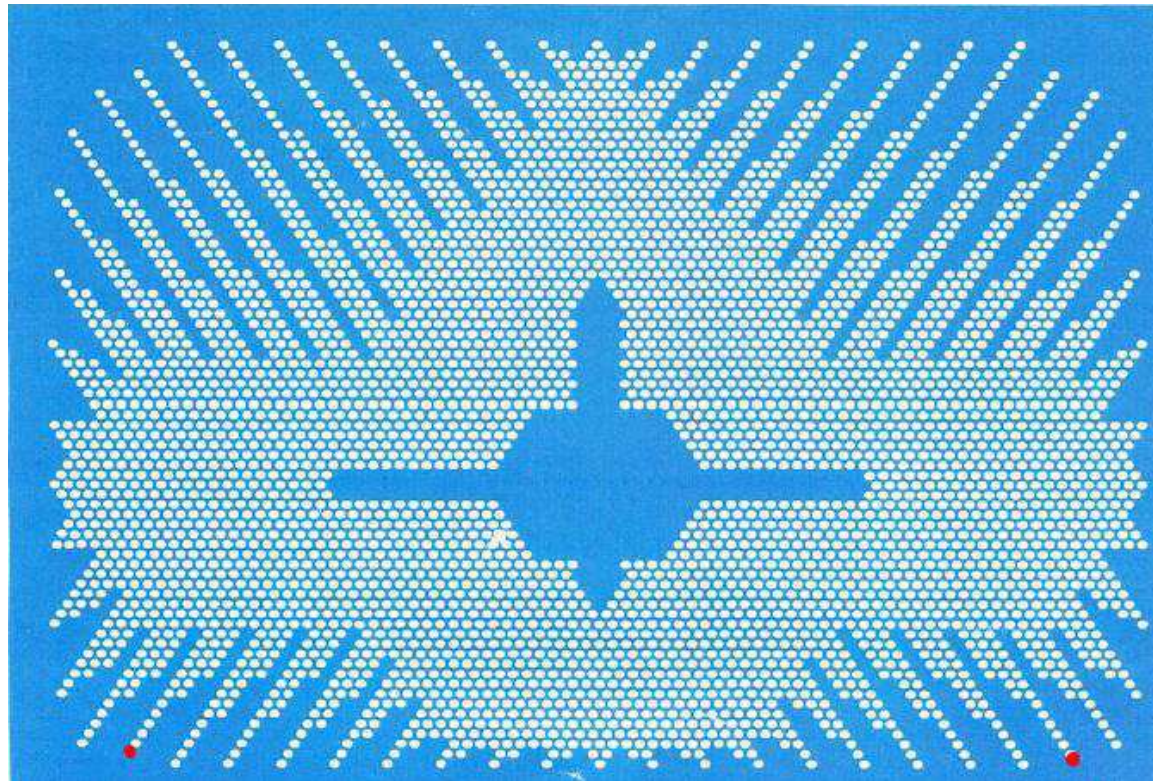



Figure 9 - Unit 3 and 4 tubesheet layout

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1.2 Cooling water treatment

As anticipated in once through system we generally apply the dosing a biocide, sodium hypochlorite, to mitigate the issues related to biofouling. In sea water application biofouling is generally the most evident cause of condenser performance degradation.

In the proposed use case biocide is dosed in the four channels

Dosing of the biocide is primarily limited by the discharge limit of 0,2 mg/l. in order to avoid to exceed the limit the actual dosing is generally far below the authorized one. So it can happen that in some condition the dosing is not effective.

In addition considering the very large flow rate used in the cooling system, biocide consumption is quite large and require an adequate storage to avoid shortage of products during the operation. Storage on site is not so easy because of authorizations and preservation of the products.

For all these reasons we would like to evaluate the application of ultra sound technology in order to reduce or even eliminate the need of biocide dosing. This would allow to improve plant sustainability, reduce the need of storage and simplify the day by day operation.

1.3 Operating conditions

The four unit of the power plant are in operation since early 1990 (Gr. 1 in 1991 and Gr.4 in 1993).

Up to 2015 the units have been operated in base load conditions. In the last year the operation of the units was more variable to follow the market demand and the renewable generation profile.

Water temperature at the inlet of the cooling circuit has a seasonal variation and a daily variation. The temperature range varies from around 10°C in winter up to 30°C in summer.

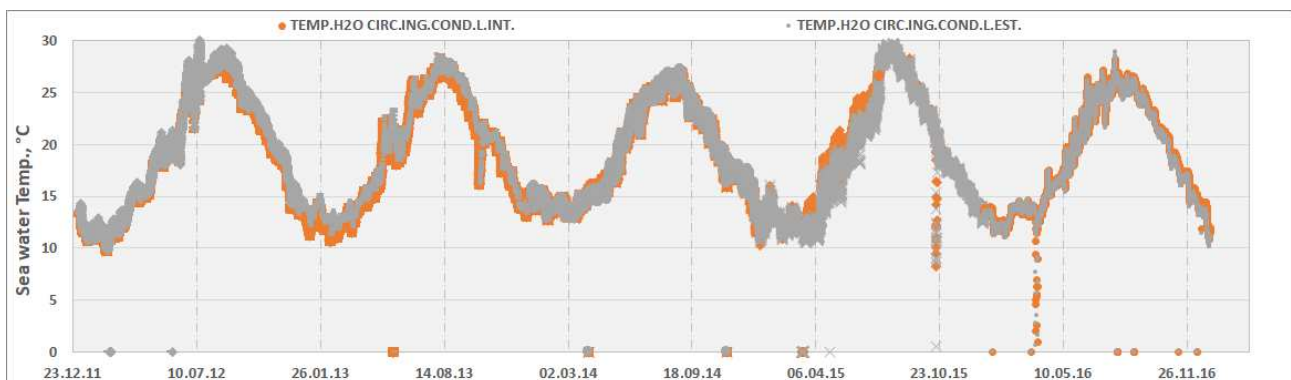



Figure 10 - Unit 3 and 4 tubesheet layout

Temperature at the condenser outlet depends on the unit load and of course from the cooling water inlet temperature. As a general indication the condenser outlet temperature is 5-10°C higher than the cooling water inlet temperature

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2. Heat exchanger in geothermal application

In Chile we have a binary geothermal plant which has some heat exchangers to transfer the heat of the geothermal fluid to an organic fluid which feeds the turbines. Because of the geothermal fluid composition some scaling issues have been experienced.

In detail the plant is equipped with 2 generating units, each one constituted of 2 turbines. Each turbine is then fed by an organic fluid steam, generated in a pre-heater (which use the latent heat of the geothermal brine at 162°C to pre-heat the organic fluid from around 48°C up to 126°C) and a vaporizer (which use the geothermal steam to evaporate the pre-heated organic fluid up to 153°C).

In Figure 11 a scheme of one unit is reported.

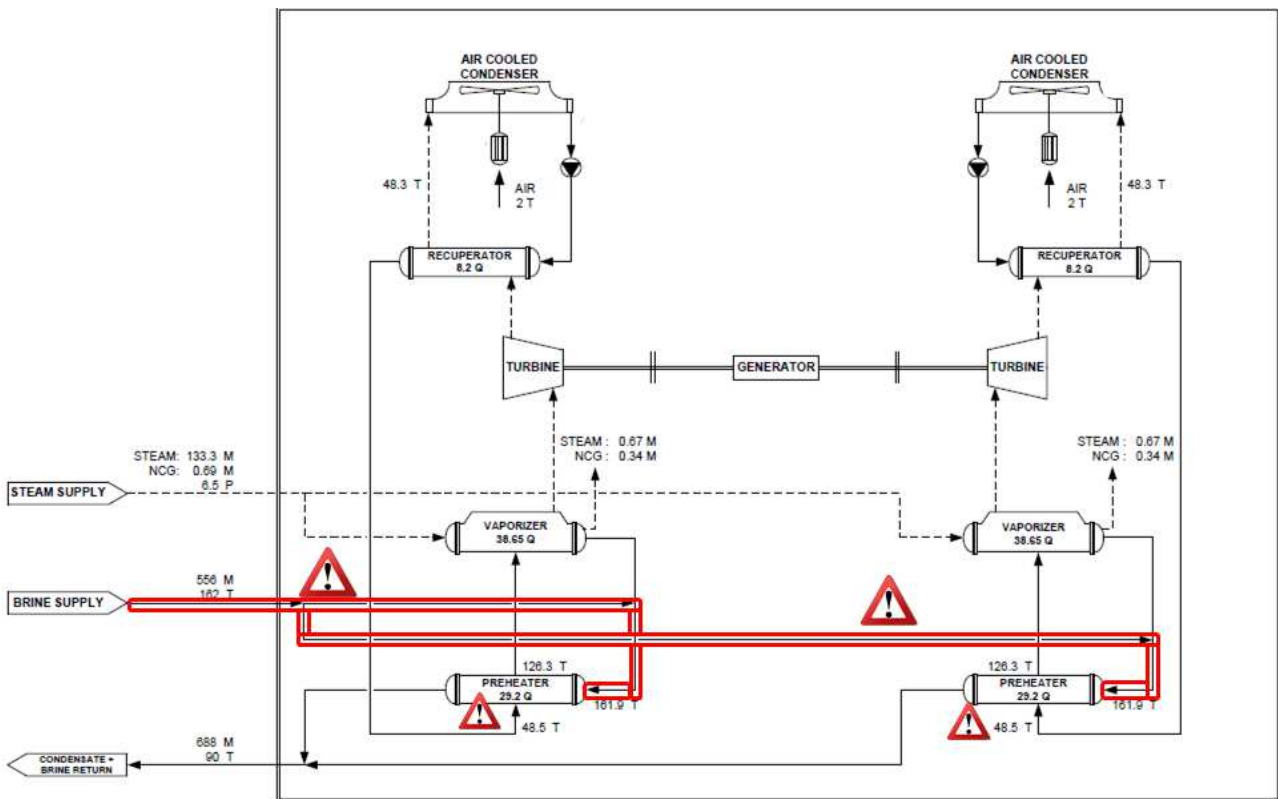



Figure 11 – Simplified layout of a generation unit highlighting the section with scaling issues (pre-heaters and their feeding lines)

Scaling issues have been met in the pre-heaters where salts contained in the brine precipitate on the tube internal surface and in the water boxes. Other scaling issues have been met in the pre-heaters feeding pipes. Scale is accumulated in the internal surface of the pipes during the normal operation and during outages, when the decrease of temperature promote the deposition rate. During the restart this deposits looks to be crushed by thermal shocks and removed from the pipes by the brine flow, which pushes the debris into the heat exchanger generating plugging issues.

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These phenomena lead to an increase of the pressure drops which limit the brine flow and then the performance of the pre-heater and force the operators to perform frequent cleaning of the heat exchangers.

The cleaning consists in switching off the unit to mechanically and in some case chemically clean the heat exchangers.

We are then looking for a solution which can protect the heat exchanger bundles from scale depositions and a solution which can help in reducing the scale formation in the inlet pipes too to avoid plugging issues at the restart of the unit.

More details about the operating conditions and the system figures are reported in the following paragraphs.

2.1 Operating conditions:

The heat exchangers which suffer from scaling are fed by the geothermal brine which flow inside the tubes.

Heat exchangers design data are the following

- Flow rate MAX (Brine + condensate from vaporizer) 344,5 t/h
- Temperature IN 162°C
- Temperature OUT 90°C
- Brine velocity 1,4 m/s
- Feed Pressure 6,5 bar

Depending on the wells in operation and specific constraints the heat exchanger are working with a lower brine flow rate and in some cases Brine velocity inside the pre-heaters can drop down to 0,5 m/s. As an average velocity we can consider that the pre-heaters are working at around 1 m/s.

Because of site specific constraints no chemicals can be used to treat the brine.

2.2 Pre-heaters details


Pre-heaters are horizontal heat exchangers with 4 passages for the brine (hot fluid) which flows inside the tubes and 2 passages for the organic fluid (cold fluid) which flows in the shell. The HX is equipped with straight tubes and two tube sheets

Main heat exchanger figures:

Number of Brine passages	4
Number of Organic fluid passage	2

Tubes:

Type	straight tubes
Number of tubes	740
Number of tubes per pass	185
Tube length	18288 mm
Tube external diameter	1" – 25,4 mm

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Tube thickness 0,035" – 0,889 mm
 Tube internal diameter 23,62 mm
 Tube material SA-789/S31803

Tubesheets:

Quantity 2 (inlet/outlet and return)
 Diameter 1380 mm
 Thickness 120 mm
 Material SA 266/2 coated with SA 240/531803

Tube sheets are exposed respect to the shell but are covered by thermal insulation

For more details see Figure 13 and Figure 14.

Baffles:

Types of baffles 4
 Quantity 16 for each type
 Thickness 14 mm
 Materials S235JR

For baffles installation details see

Shell:

Internal diameter 1178 mm
 External diameter 1226 mm
 Material SA 516/GR70

Brine piping:

Inlet pipe diameter 12" sch80S ; 12,7 mm ; I= 320
 Inlet pipe material SA 312/TP316L
 Inlet flange type 12" * 300 S.O.R.F
 Inlet flange material SA 182/F316L
 Brine velocity 1,5-2 m/s
 Brine Temperature 160°C

Outlet pipe diameter 12" sch80S ; 12,7 mm ; I= 320
 Outlet pipe material SA 312/TP316L
 Outlet flange type 12" * 300 S.O.R.F
 Outlet flange material SA 182/F316L
 Brine velocity 1,5-2 m/s
 Brine Temperature 90°C



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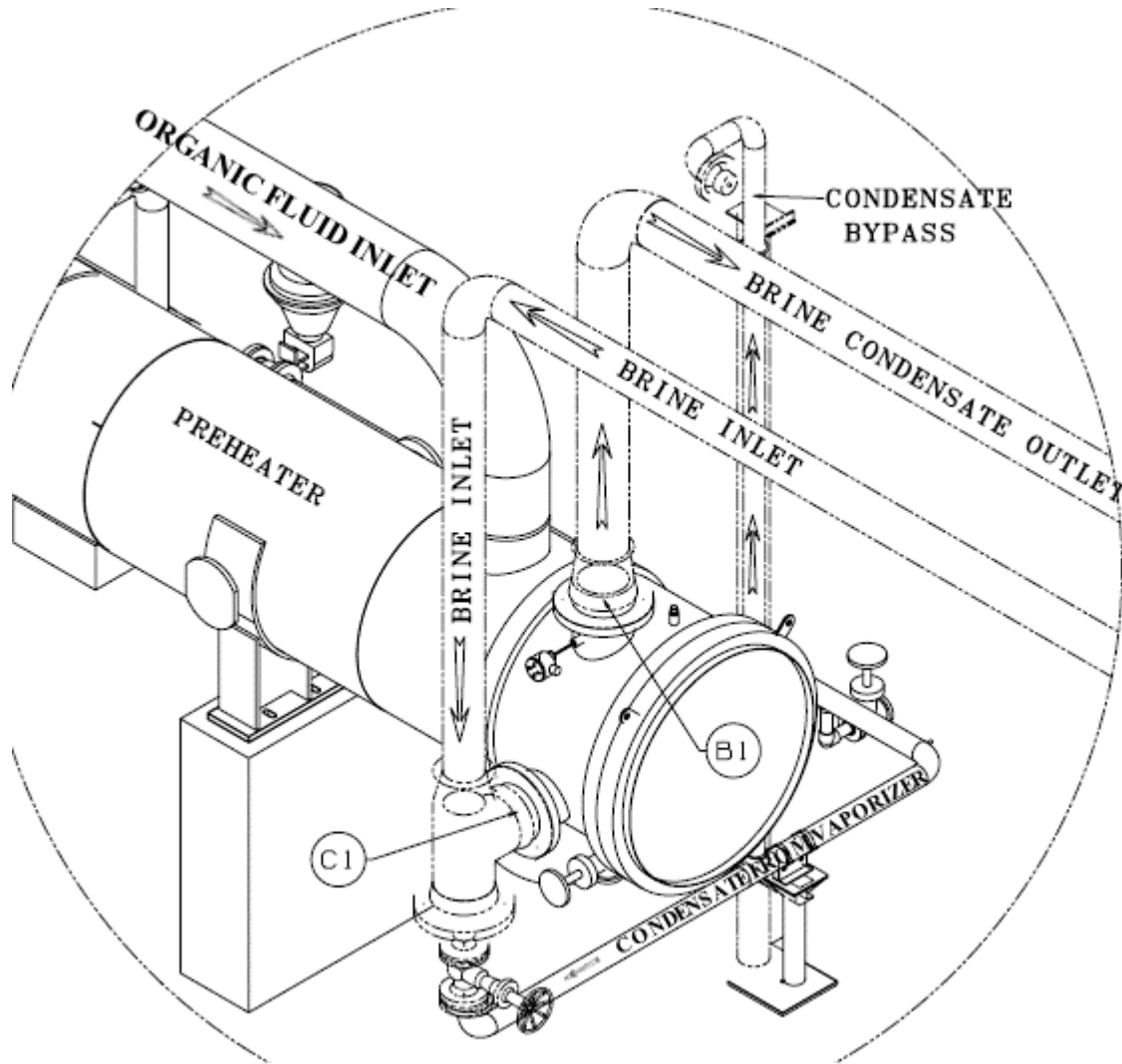



Figure 12 - Heat exchanger piping layout

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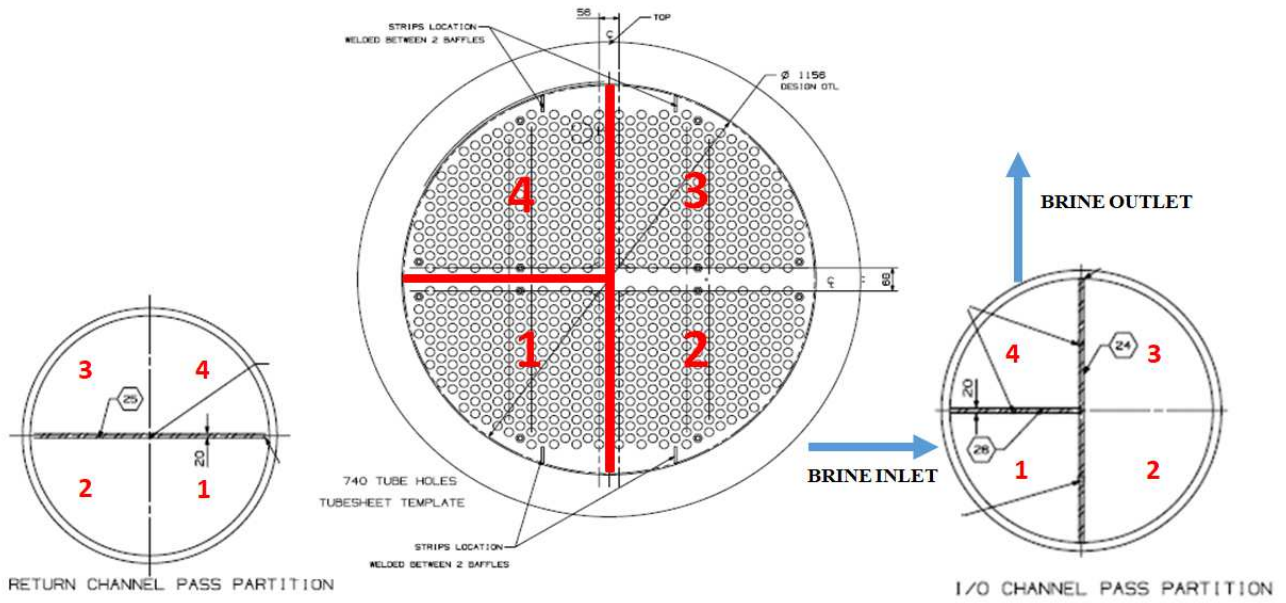


Figure 13 – Tube sheets configuration

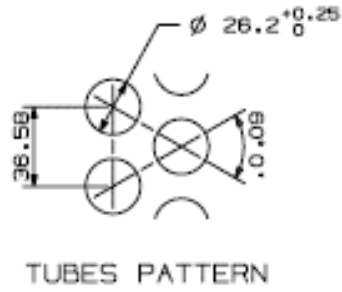


Figure 14 – Tube layout



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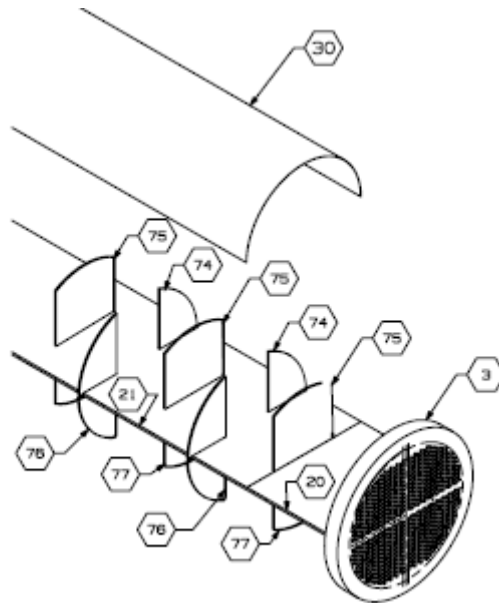
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SET BAFFLES
0.859.57.452.0
14 mm thick.

TUBES PATTERN

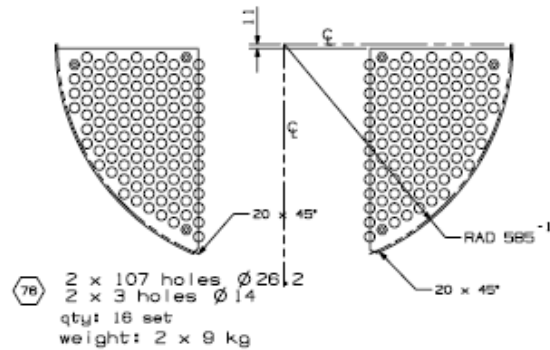
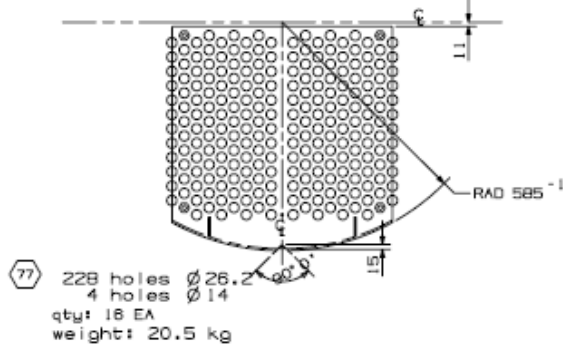
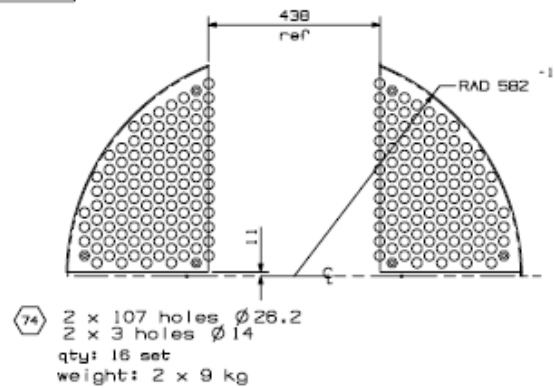
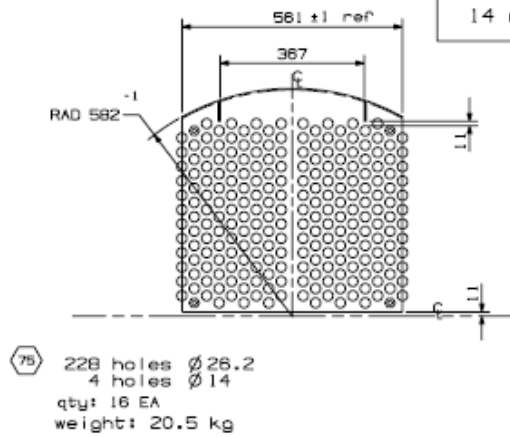


Figure 15 – bundle baffles layout



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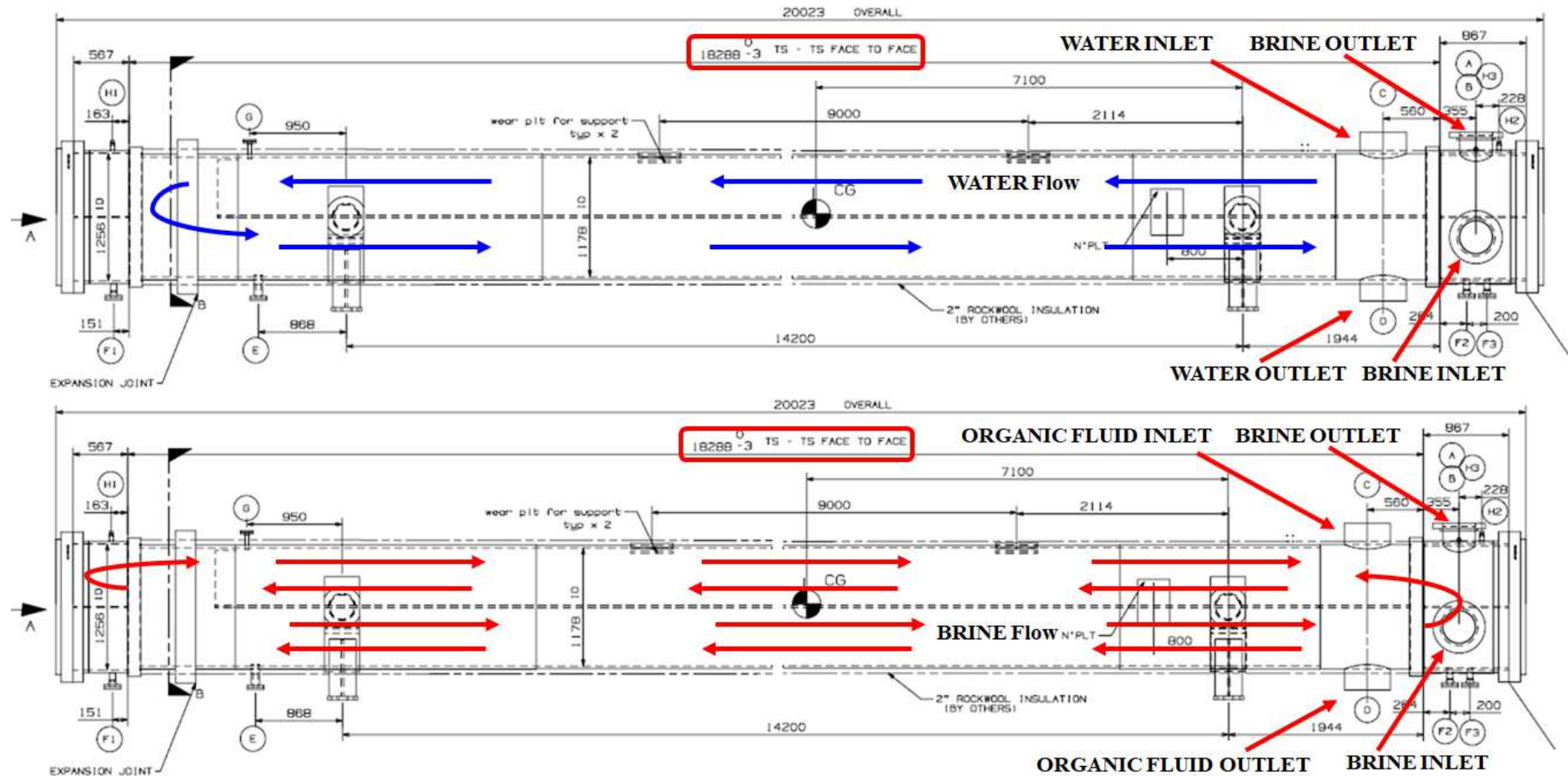



Figure 17 – bundle baffles layout

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2.3 Brine composition

In Table 3, composition of the brine is reported. In the first column is reported the brine analysis before to be mixed with the condensate of the vaporizer, while the second column show the composition of the blended stream.

Because of some operational constraints the mixing of the condensate is not always possible so the pre-heaters are working directly with the raw brine. This configuration reduce the velocity inside the tubes and increase the average salinity of the fluid increasing the risk of scaling.

BRINE		BRINE	BRINE + Condensate
pH		6,81	5,65
Cond.	μS/cm	32320	24426
Na	mg/l	6388	4615
K	mg/l	1021	649
Ca	mg/l	775	539
Mg	mg/l	0,29	0,17
F ⁻	mg/l	3,34	1,38
Cl ⁻	mg/l	12037	8488
SO ₄ ⁻	mg/l	43	26
Br ⁻	mg/l	14	11
I ⁻	mg/L	3,44	2,47
Li	mg/l	63	49
Al	mg/l	0,27	0,15
Fe	mg/l	0,42	1,40
Rb	mg/l	8,69	6,61
Sr	mg/l	16	13
Cs	mg/l	36	27
Mn	μg/L	304	320
Ni	μg/L	15	17
As	mg/l	91	69
Sb	mg/l	3,30	0,64
B	mg/l	349	303
H ₃ BO ₃	mg/l	2377	1733
NH ₄ ⁺	mg/l	4,52	5,81
H ₂ S	mg/l	47	35
SiO ₂ tot	mg/l	593	449
TDS	mg/l	21462	17073

Table 3 – Brine analysis

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2.4 Deposits analysis

In the following paragraph some analysis of the scale encountered in the heat exchanger and in the inlet pipes are reported. The scaling is mainly related to silica, sulphides (orpiment and stibnite) and (Al)-silicates but is not homogeneous indicating the prevalence of different salts precipitation along the circuit.

2.4.1 From the heat exchangers

To check the scale composition inside the pre-heaters some samples have been removed from the heat exchanger and have been analysed with an electronic microscope.

In Figure 18 are shown the four samples of scale deposits collected from one of the pre-heaters. It's clearly visible from the visual investigation that different salts were precipitated in the four samples

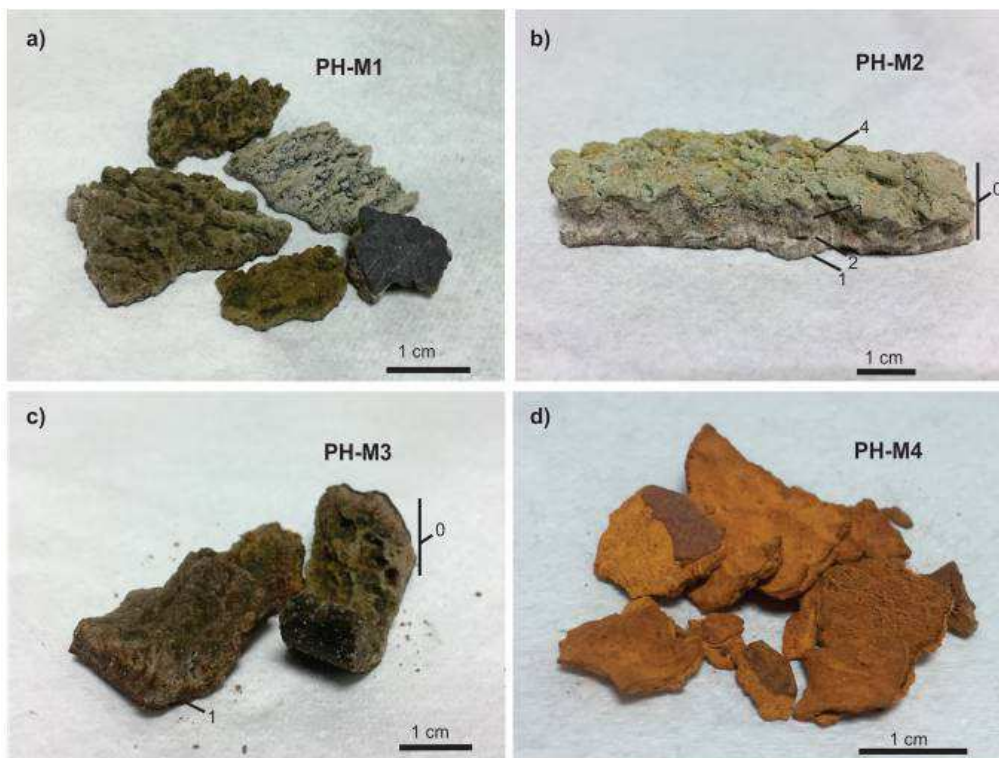


Figure 18 – Scale samples taken in the pre-heaters

In Table 4 and Table 5 are reported respectively the elementary analysis of the four samples and the mineral analysis.

From the elementary analysis is possible to see that "**Silicon (Si)**" is the most abundant element in all the samples. The second element which is present in all the samples is the "**Antimony (Sb)**" followed by "**Sulfur (S)**". in the fourth sample a relevant amount of "**Arsenic (As)**" is also present.


Elementary composition (%)	PH-M1	PH-M2	PH-M3	PH-M4
Sb	5,07	2,17	6,1	7,67
S	1,74	0,93	2,32	7,27
O	51,61	54,81	49,76	45,12
As				7,34
Fe	0,59	0,83	0,51	
Cl	1,6	0,41	3,9	0,44
Al	0,77	1,24	0,63	0,35
Si	37,13	38,09	33,61	31,41
Na	1,07	0,67	2,74	0,47
Br				
Ca	0,56	0,44	0,62	
K	0,39	0,52	0,51	0,27
Mg		0,29		
Total	101	100	101	100

Table 4 - Elementary analysis of the samples

Form the mineral analysis the scale samples are mainly constituted by Opale and Quarz, as precipitation product of the SiO₂ followed by Stibnite and Orpiment.

				PH-M1	PH-M2	PH-M3	PH-M4
Minerales Identificados	Opalo	Opal	SiO ₂	61	42	56	26
	Cuarzo	Q	SiO ₂	11	26	7	16
	Halita	H	ClNa	10	1	8	3
	Estibina	S	Sb ₃ S ₂	18	10	29	18
	Oropimente	O	As ₃ S ₂				38
	Albita	A	(Ca,Na)AlSiO		20		
	Piroxeno	P	(Ca,Mg,Fe)AlSi		+		
	Zeolita (Mordenita)	Zeo	K-Ca-Na,Al ₄ Si ₈ O ₂₄		+	+	
	Esmeclita	Sm	Ca-Na-Fe-Mg,Al ₄ Si ₈ O ₂₄ -OH		+		
	Fluorite	F	CaF		+		

Table 5 – Mineral analysis of the four samples

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2.4.2 From the piping

SEM's mineralogical and compositional analyses were performed with the FEI Quanta 250 SEM. The samples were treated without polishing due to the fragility of the material, covered with carbon and analyzed in high vacuum mode to obtain images of backscattered electrons (BSE). Semi-quantitative analysis of chemical composition were performed by means of X-rays Energy Dispersion Spectrometry (EDS) in selected regions for each mineral phase by means of punctual analysis. Both for BSE and EDS were performed under 20-15 keV voltage acceleration conditions, with a spot of 5 μm , at a distance of 10 mm and with a measuring time of 60 s. For the comparison and determination of the mineral composition were used references from the Mineralogy Database page (www.webmineral) and Mindat (www.Mindat.org/).

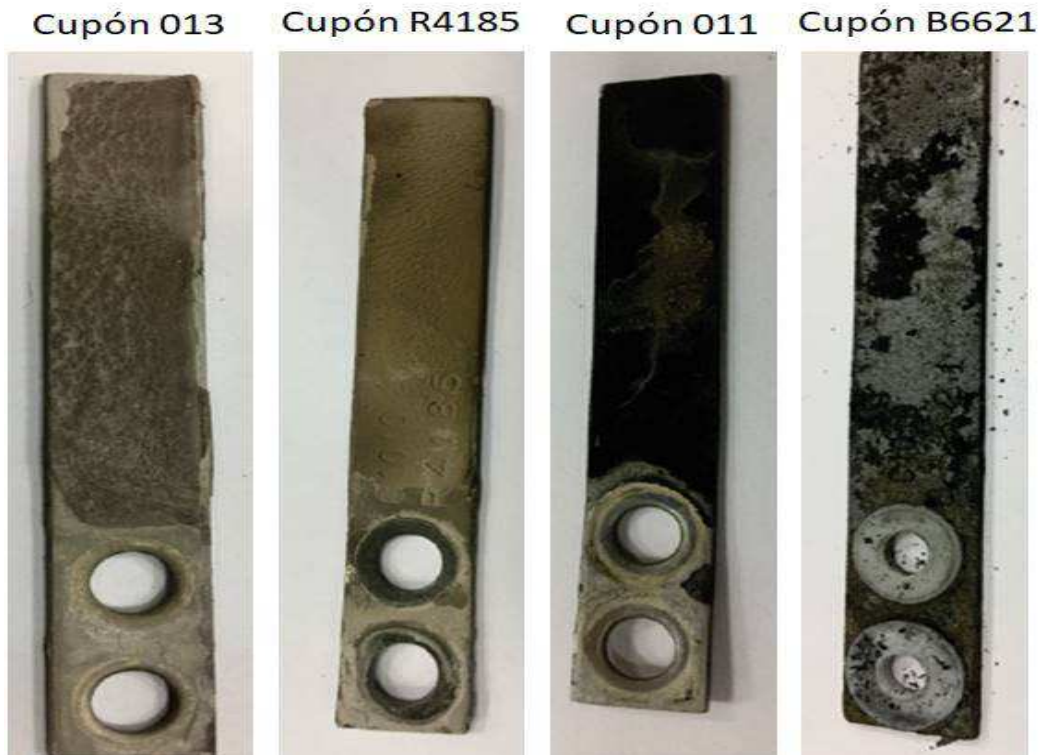



Figure 19 – Coupons with scale samples from pre-heater inlet pipe

In Table 6 and Table 7 are reported respectively the elementary analysis of the four samples and the mineral analysis.

From the elementary analysis, of Table 6, is possible to see that for Coupon B6621 and Coupon 011 the most abundant element is "**Antimony (Sb)**" followed by "**Sulfur (S)**". For Coupon 013 the most abundant element are **Oxygen(O)**, "**Silicon (Si)**" and "**Antimony (Sb)**". For coupon R4185 the most abundant element are **Oxygen(O)**, "**Silicon (Si)**" and "**Aluminum (Al)**".

According to elementary analysis the mineral analysis highlight that the deposits of Coupon B6621 and Coupon 011 are mainly constituted by Stibnite and Getchellite while Coupon 013 and Coupon R4185 are mainly constituted by Mordenite , Halite and Stibnite.

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Elementary composition (%)	Cupón B6621	Cupón 011	Cupón 013	Cupón R4185
Sb	64	68,04	4,89	1,42
S	25	26,21	1,67	0,57
O	4	2,01	52,13	61,04
As	3	1,32		
Fe	2	0,43	0,58	0,47
Cl	1	0,83	1,62	0,86
Al	1	0,5	0,73	5,16
Si		0,46	36,66	26,86
Na		0,56	1,21	2,4
Br		1,11		
Ca			0,56	1,19
K			0,39	1,61

Table 6 - Elementary analysis of the samples

		Cupón B6621	Cupón 011	Cupón 013	Cupón R4185
Estilbina	Sb ₂ S ₃	85%	85%	8%	8%
Getchelita (o oropimente + estilbina)	AsSbS ₃ (o As ₂ S ₃ + Sb ₂ S ₃)	10%	10%		
Halita	NaCl	4%	4%	20%	20%
Silvina	KCl	1%	1%	1%	1%
Mordenita	(Ca, Na ₂ ,K ₂) Al ₂ Si ₁₀ O ₂₄ .7(H ₂ O)			70%	70%
Hematita	FeO			1%	1%
tot		100%	100%	100%	100%

Table 7 – Mineral analysis of the four samples