Failure Analysis of the HCL Column InterCooler
Cause, Effect, Results and
Economical Solution for Severe Media
Case Study

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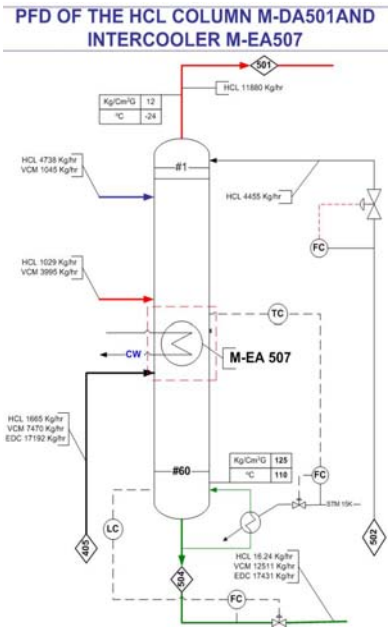
Introduction:

The **Egyptian Petrochemicals Co. (EPC)** is located at **Alexandria - Egypt**, it is considered as one of the most important plants in the middle east, it consists of the following plants:

PVC plant with possible expansions, **VCM** Plant, **CL_2** Chlorine & **NaOH Caustic Soda** Plant, **PVC Compounding** plant, **Power** Plant, and **Utility** plant. **(EPC)** had been established since 1987 for the production of the products (PVC Resin, PVC Compounding, Chlorine Liquid, Caustic Soda Flaks, 50% Liquid Concentration, **HCL Acid** 30% Concentration, and sodium hypochlorite 12%) these materials are supplied to the local market, and Exported to the European and Arabic Countries.

Process Description

The **VCM** Plant is one of most important and critical plants for petrochemical industries, it is susceptible in operation for many technical reasons mainly dealing with the aggressive media, maximum moisture contents which is limited by (10 PPM) and the stability of the electrical power supply.



M-DA 501 HCL Column

The main problem has correlation with section 500 of the **VCM** plant (purification section), it is limited by the **HCL** column **M-DA 501**, the intercooler **M-EA 507** and the interconnected circuits as shown in the **PFD** (**P**rocess **F**low **D**iagram).

The intercooler **M-EA507** is embedded in the **HCL** column at it's mid of Elevation, The intercooler **M-EA507** helps to maintain, Control and keep the thermal balancing of the operating condition; obviously it plays an important role to control the performance of **M-DA 501**.

The **HCL** Column **M-DA 501** carries a group of dry gases, liquids **HCL**, **VCM**, and **EDC** which are surrounding the outside surface of **M-EA507, while** The tube side of **M-EA 507** carries the cooling water. Both of **M-DA501** and **M-DA 507** are made of carbon steel**.**

Due to frequent failures of the intercooler M-EA507 it had been replaced With new carbon steel intercoolers many times (No.9 New Intercoolers Replaced Within 7 years) without positive result.

<u>Description of the Problem and Cause of Failure</u>:

The feeding of M-DA501 contains a blending of dry **" GASES and LIQIDS"** such as **HCL ,** Chlorinated Hydrocarbons **(VCM , EDC)** at normal operating condition (moisture 10~30 ppm in system) there is no corrosion.**M-DA 501** (HCL Column) has certain process features in design criteria which is obviously limited by the Operating / Design temperature at the Top is – 24 ^{o}C while at the Bottom is 110^{o}C,so there is any chance for the presence of the moisture neither at the Top nor at the bottom.

Although chloride is a strong oxidizer and will combine directly with metals. Since the intercooler **M-EA507** is located at the mid of the HCL Column at operating temperature approximately **50^{o}C~ambiant** ,so the operating temperature is suitable to retain a percentage of the moisture which is very harmful to the material of construction at the middle section of the HCL Column , intercooler **M-EA507**, and Trays of **M-DA501** (all made of Carbon Steel).

At **Low** temperatures this reaction is so Sluggish than Dry Chlorine can be shipped in CarbonSteel.
At Ordinary temperature ,if Chlorine Gas is dissolved in water ,it will react with it to form Hydrochlorous and Hydrochloric Acid.
Hydrochlorous and Hydrochloric Acid is an Oxidizing Acid and Bleaching Agent which is reduced to Hydrochloric Acid in the Bleaching reaction .

This combination of an Oxidizing and NON Oxidizing Acid is responsible for the Corrosion effect of moist Chlorine on metals .Wet Hydrogen Chlorde at Normal temperatures as Concentrated Hydrochloric Acid.
At **High** Temperatures Hydrogen Chloride and Chlorine are similar in their behavior.

Due to successive shut down , power failure , incomplete drying of the system during the EDC ,VCM circulation operation “pre-operation” as stand-by in this case the moisture content shall be increased around the intercooler (the process side), the circuits which contains **HCL “ GAS “ & VCM “ DRY “** shall be affected with the moisture and transformed into **HCL ACID** (Typical reducing acid ,Entire strongly acidic character ,Harmful effect of the chlorides) with low concentration which is very aggressive to attack the Carbon Steel tubes (WITH THK. 2.1 mm) PITTING Corrosion takes place . consequently after the failure of any tube , the cooling water passes through the **HCL Column** and the process circuits shall carry aggresive

meddia . Now the process circuits are contaminated with **HCL ACID** ,wet **VCM, EDC** hence the failure of other tubes are forecast NOT only to M-EA507 but also for other equipment which are linked with the process circuits and **M-DA501** it self,due to the contamination of the **COOLING WATER** system with **WET HCL .** So it is clear that the intercooler **M-EA507** is very critical equipment and a vital solution must be taken in consideration .

Maintenance:

Traditional maintenance to restart up the plant is not the practical solution (such as plugging the failed tube from both sides) , in case of failure of any tube that means contamination of the whole system with diluted HCL which is very aggressive to attack the carbon steel tubes (which have small thickness of material) and pitting corrosion takes place,so to plug the failed tubes means expected failure within few days.

Acidic areas on a metal surface remains stationary rather than shift about .When this occurs corrosion takes the form of pits rather than general thinning (uniform Corrosion).Although pitting can arise from various causes , chlorides are well known as pit producers.

The chloride IONS accumulate at ANODIC areas and either penetrate or dissolve the passive film.Since the chloride corrosion product is **HYDROLYZED to HYROCHLORIC Acid** ,The acidity at the ANODE increases as more Chloride migrates to the ANODE and the corrosion rate increases with time .Self accelerating reactions of this kind are described **AUTOCATALYTIC** reaction.

The most practical decision is cleaning & neutralizing the system circulation then drying the circuits by purging the system with nitrogen then replace the

InterCooler with new one up till the moisture content shall be decreased to 10 ppm as maximum,and continue the drying by dry **EDC**.

As expected the failed InterCooler had been exposed to **PITTING CORROSION** which has the property of unexpected failure. From our practical experience (for a long time) the failed heat exchanger could not withstand the operating condition after plugging the failed tubes.

DESIGN BASES:

M-EA 507 HCL Column InterCooler is designed according to :

ASME II parts A,C,D.

ASME VIII DIV 1.1995

ASME IX.

TEMA Class "C"

ASTM

MATERIAL OF CONSTRUCTION:

ASTM A-516 GR70(for the shell of the HCL Column),from the Top and 13200.0mm down the material of construction is **KILLED CABON STEEL** since the operating temperature is $-24^{o}C$ and suject to impact test (supplementary **S5), A179** (for the intercooler tubes)**, A-283 GR C** (for the nonpressurised parts) **, A-105** (for standard Flanges) **, A-106 GRB**(for the Nozzles) , **A-193 GR B7**(For Bolts),**A-194 2H** (For Nuts) **.**

ASME II Parts A,C,D

ASTM

TEMA CLASS " C "

SIZE : 700 / 1050 .

TYPE : AEU.

SURFACE : 32.7 m^2 .

OD OF TUBES = 19.05 mm.

No OF TUBE = 225

THICKNESS OF TUBES 2.1 mm.

DESIGN DATA	SHELL SIDE	TUBE SIDE
DESIGN PRESSURE	16.0 Kg / Cm^2	7.6 Kg / Cm^2
WORKING PRESSURE	12.3 Kg / Cm^2	5.6 Kg / Cm^2
DESIGN TEMPERATURE	180 ^oC	60 ^oC
OPERATING TEMP. IN/OUT	52 / 52 ^oC	31 / 40 ^oC
CAPACITY	34000 LIT.	308 LIT
CORROSION ALLOWANCE	3.0 mm	2.0 mm
JOINT EFFICIENCY	1	0.7
NUMBER OF BASSES	1	10
FLUID CIRCULATED	HCL VCM HCL	*COOLING WATER

- **COOLING WATER ANALYSIS :**

Ca++	**174 PPM AS Ca CO_3**
Mg++	**160 PPM AS Ca CO_3**
Na+K+	**500 PPM AS Ca CO_3**
HCO3	**90 PPM AS Ca CO_3**
SO4	**435 PPM AS Ca CO_3**
CL	**315 PPM AS Ca CO_3**
TDS	**800-2400 (AT UPSET CONDITION)**
PH	**8.5**

WATER IS STABLE SCALING TO DEFINITELY SCALING.(there is no corrosion from the cooling water side).

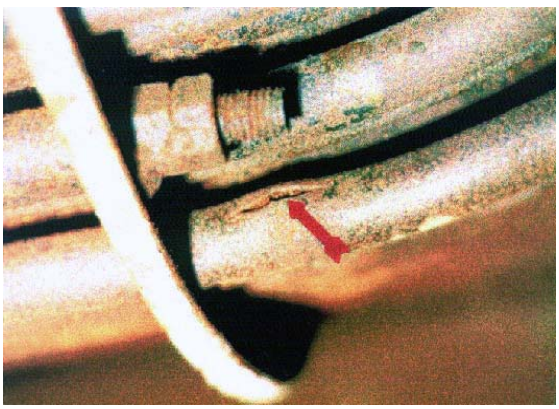
Visual Inspection and Corrosion Shapes:

The visual inspection for **some failed tube bundles** shows the following:

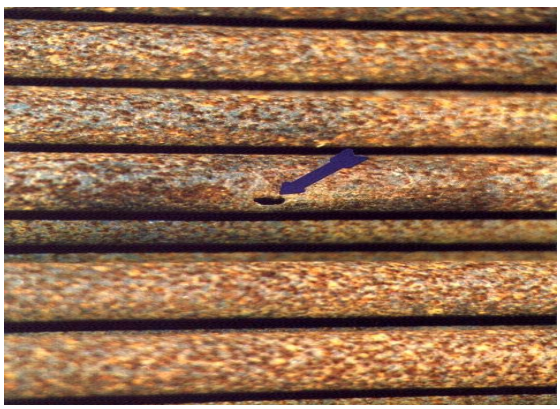
1-Pitting at different locations on the tube surface.

2-Failure of the seal welding of the tube to tubesheet.

3-Longitudinal crack at the tube bend.



M-EA507Longitudinal Cracking at one of the tubes



Localized Corrosion and pitting

Failure for the seal welding of the tube to tubesheet

M-EA507 Tubesheet Layout – shows the location of the failed tube to tube sheet.

Results of the Failure of M-EA507

a- Shutdown the Plant.

b- High cost for purging and drying the circuits with NITROGEN.

c- High cost for Inspection & Maintenance.

d- Long procedure and great effort to restart the plant.

e-15000.0mm length of the HCL column (at the middle section) had been replaced after few years.

f- Replacement of some trays at the middle section.

g-Contamination the cooling water system with HCL Consequently (the other equipments are affected with the attack of HCL) Expected failure of other equipment.

h- Environmental Pollution.

i- Decrease the annual production Plan.

j- Purchasing No.9 **NEW** M-EA507 Intercoolers.

Recommended Solutions

For safe operation and high performance, it recommended the following:

a) To use a higher grade of material to overcome the corrosion problems at the upset conditions.

The selected NEW material to fulfill both technical and economical requirements is Super Duplex Stainless Steel

ZERON 100.

Equivalent to standard (UNS S 32760 ASTM A789).

DIN X 2CrNIMOCWN 25-7-4.

Nominal Chemical Composition of ZERON 100

C%	Si%	Mn%	Ni%	Cr%	Mo%	N2%	Cu%	W%	PREN
0.02	0.40	0.70	7.00	25.00	3.60	0.22	0.70	0.70	40 min

Applied Chemical Composition of ZERON 100

0.018	0.36	0.55	7.04	25.46	3.67	0.254	0.73	0.62	41.635

PREN = Cr + (3.3XMo+16XN) = 41,635 $\geq$ 40

- The material is produced by Electric Furnace.
- The material has been SOLUTION ANNEALED at 1140 ^{o}C, Holding Time 5.3 minute, rapid water quenching cooling.
- The material has been full length tested by ULTRASONIC acc. to **ASTM A450 – D 587.**

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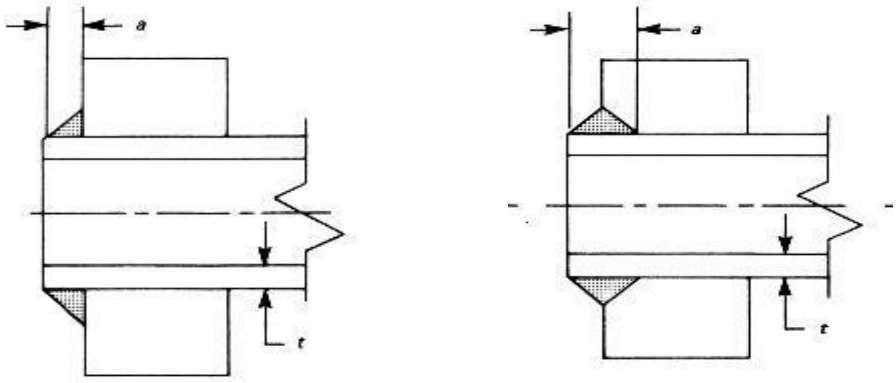
b) To change the welding technique of the tube-to-tube sheet .

It has been observed in some cases that the problem is coming from the failure of the joining of the tube-to-tube sheet.

To overcome this problem we have changed the technique of joining the tube-to-tube sheet.

The old technique was based on seal welding of the tube-to-tube sheet (one pass) and light expansion as per Sketch (1).

Since the Intercooler is operating at high pressure (at shell side) and it has been exposed to aggressive fluid ,we changed the Joining Technique to be Strength Welding instead of one pass seal welding as per Sketch(2).



Sketch(1) Sketch(2)

(B-1)Welding Technique:

As well known that Duplex Stainless Steels consists of two structural components **ferrite (α)** and **austenite (γ)** .The ferrite gives the material high mechanical strength and high **SCC** Stress Corrosion Cracking resistance and the austenite works beneficially on the ductility and impact strength.

The thermal cycle during welding has a large influence on the ferrite content , which normally should be in the range **25–70 %** . The heat sink caused by the tubesheet is very large , meaning that the correct structure of the weld metal and the heat affected zone **(HAZ)** shall be difficult to obtain, unless the correct welding technique is done.

T/Ts – welding means that relatively small weld is done to seal the Crevice between the Tube and the Tube sheet.

The weld metal of the Duplexes solidifies (primarily) ferritically and the austenite is then formed successively as the temperature decreases .Under very rapid cooling as in the case of tube – to – tube sheet.

Welding, The structure “FREEZES” at very high ferrite level .Nitrogen in the ferrite can not be completely dissolved and chromium nitrides can be precipitated .This intermetallic phase may have a detrimental effect on the corrosion properties.

(B-2)For the improvement of the weld microstructure it has recommended the following solutions:

(1) Use of filler metal with a higher Nitrogen content.

(2) Use of **3% N_2** in shielding gas **TIG , MIG** to overcome to compensate the defused Nitrogen Gas.

C) To perform Some Experimental tests.

THE Material had been requested with some lab tests to guarantee the performance:

-Guaranteed against corrosion (see **ISO** Corrosion Curve)

-The material shall be tight and Phase balanced as much close to **50 Ferrite & 50%Austenite** (requested Micro graphical examination acc. to **ASTM E112** for each heat No.).

The sample reveals a regular Austenitic Ferritic structure **(500 X)** FREE from Carbide precipitates and Phases like **SIGMA, CHI, LAVES.**

Micrographic test 500 magnification transverse direction Ferrite determination according to **ASTM E 562 = 49.06%**

-High resistance to pitting corrosion (requested acc.to **ASTM G48** method “**A**”).

Pitting Corrosion test

The pitting corrosion test applied to a sample according to **ASTM G-48**. For Chloride Stress Corrosion Cracking in a solution **45% $MgCl_2$,aerated , 150^{o}C .For duration 500 hours.**

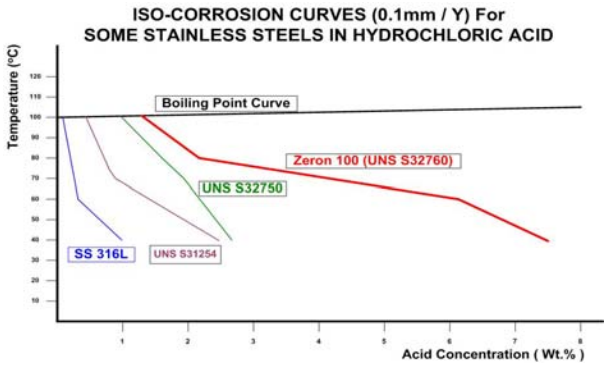
The test at 40 ^{o}C of temperature for 24 HRS **.There is no weight loss**

The sample passed the test **successfully.**

-Good weldability.

-Excellent mechanical properties tensile, hardness, eddy Current, and Flaring,…etc.(acc. to **ASTM A370**).

-Excellent resistance to **SCC S**tress **C**orrosion **C**racking (requested acc.to **ASTM G36**).



ISO-Corrosion Curve for Stainless Steel and Super Duplex with Hydrochloric Acid

(Micrographic test 500 Magnification) Super Duplex Structure 50 Ferrite and 50 Austenite

D)To perform periodical analysis for the Cooling Water (every 2 hrs) for measuring the HCL content in water, and measurement the moisture content in Process side to early predict of the failure before propagation.

<u>Conclusion</u>:

1. The higher grade of the selected material has excellent performance.
2. The selected material is the most economical solution comparing with the other NON Ferrous Alloys.
3. The selected material has been in operation without any failure since 8 years.
4. The material had been applied to other similar applications which are carrying CHLORINATED HYDROCARBONS with positive results.
5. The plant has never stopped due to failure of the new material.

Key Words:

-VCM Vinyle Chloride monomer.

-EDC Ethylene Di Chloride.

-PVC Poly Vinyle Chloride.

-HCL Hydrogen chloride (in Gas or dry Liquid Phase).

Hydrochloric Acid (in Liquid Phase).

-NaOH Sodium Hydroxide (Caustic Soda).

References:

-WEIR Materials & Foundries Catalogues.

-Corrosion in the Petrochemical Industry.

-ASME II.

-ASME VIII Div.1 2002.

-EPC Construction Drawings.

-WEIR Materials & Foundries inspection reports of the supplied material.

-ASTM.