"STAINLESS STEEL FOR
THE MUNICIPAL COMPANIES"
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WASTE WATER STAINLESS STEEL EQUIPMENT IN ITALY AND ABROAD; APPLICATIONS, GUIDELINES AND LIFE CYCLE COST ANALYSIS

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By Dr. Ing. L. Fassina and C. Powell
Consultants to the Nickel Development Institute

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1. SUMMARY

Internationally, there has been increased growth and interest in the use of stainless steels in waste water treatment. Stainless steels have the attributes of being able to handle a wide range of effluent streams experienced by plants in various locations and also the treated waters, gases and sludges within each plant as they progress through the treatment processes. Extremely low corrosion rates even at high turbulence combined with good fabricability allow comparatively lightweight systems and fabrications to be used. Overall ease of handling and installation enhance versatility and cost effectiveness.

Type 304 and 316 grades of stainless steel are the standard materials of construction, with duplex and super austenitic alloys considered for more arduous service. Alloy selection and optimum performance is achieved by due consideration of chloride levels. Good fabrication is essential, particularly the removal of heat tint in more critical areas. The paper provides guidance for the effective use of stainless steels and describes applications where they are used internationally. Particular attention is given to the selection of stainless steel for the Pero plant in Milan, its service experience since 1999 and how performance, lifecycle costing and legislative change in Italy can combine to influence material selection for the future.

1.2 Introduction

Stainless steels have found increasing application in waste water treatment plants in many countries worldwide. Good performance has led to confidence in their suitability together with an appreciation of how design, fabrication and operational practices can achieve the best service from the materials.

With greater importance in material selection being given to ease of installation, reduced maintenance, durability and recyclability, the properties of stainless steels can be used to advantage and produce significant benefits in life cycle costs compared to galvanized steel or coated steel and other traditional materials.

This paper provides information about the grades of stainless steel suitable for waste water treatment plants, the applications they are used for internationally and guidelines on how they should be used to achieve their full potential in terms of good fabrication, installation and operational practices. Examples of applications are given together with a more detailed examination of stainless steel used in the Pero plant in Milan since 1999 and how life cycle costs can be used together with service experience to aid their selection.

For simplicity, the popular names of stainless steels (e. g. types 304 and 316) are referred to in the text without quoting directly their EN designations. The relevant EN designations can be found in Table 2, Section 2.

1.3 Environments In The Waste Water Treatment Industry

By the time sewage has arrived at a waste water treatment plant, it is in the form of a thin liquid which contains food materials, human waste, detergents, fats, oils and greases, sand clay, paper fibres as well as other waste chemicals and debris. Within the plant, it undergoes a process of screening, settlement and oxidation of polluting matter until it is sufficiently clean to be discharged back into the natural environment.

Processes can vary from plant to plant (1,2) but typically involve: -

Table 1-Typical Waste Water Treatment Processes

Preliminary Treatment	Coarse and Fine Screening	To remove large debris e.g. Sticks, rags, bricks which can damage equipment and cause blockages
	Grit removal	Grit sinks to bottom of chambers or channels as effluent flows through
	Chemical treatment (Facilitates precipitation of unwanted pollutants such as phosphorus)	E.g. addition of ferrous sulphate, aluminium sulphate, ferric chloride, poly-aluminium chlorides and sulphates.
Primary Treatment	Primary Settlement	In large circular or rectangular tanks where the fine particles sink to form a removable sludge.
Secondary Treatment	Biological filtration (The biological activity converts organic matter to carbon dioxide, water and nitrogen compounds)	Micro-organisms form colonies in circular or rectangular beds filled with irregular stones which air can circulate around. Sewage is sprayed over the beds by moving distributors. Humus sludge is formed which is further settled out in final settlement tanks.
	Activated Sludge (Settled sewage is mixed with activated sludge containing appropriate bacteria until the organic matter is oxidized.)	Air is provided by agitating the surface of the tank by paddles or bubbling air through the tank.
	Membrane Technology	
Tertiary treatment	Sand filtration	A final "polishing"
	Pebble bed clarifiers	
	Microstraining	
Sludge Treatment	Digestion (Tanks at a temperature of about 35° C)	Anaerobic bacteria in the sludge convert most of the organic matter to mainly methane and carbon dioxide and less harmful stable solids.
	De-watering (Raw or digested sludge)	On air drying beds with under drainage or can be conditioned with chemicals and dried mechanically.

Hydrogen sulphide gas is often generated in the digesters and throughout much of the plant.

1.4 Pipe work systems conditions

The conditions, which the main pipe work systems can operate in, are: -

1.4.1 AERATION PIPEWORK

Above the aeration basins, piping is exposed to general atmospheric conditions and to humid atmosphere containing hydrogen sulphide. Within the basins, piping is exposed to aerated sludge containing sulphates, chlorides and carbonates from local waters; naturally present bacteria and biological additives to treat sludge; hydrogen sulphide and treatment chemicals such as chlorine, ferric chloride, ferrous sulphate and other compounds. Internal surfaces of the stainless steel aeration pipes are also exposed to warm moist air.

1.4.2 SLUDGE TRANSFER PIPING

Sludge piping is exposed externally to general atmospheric conditions. Internally to dewatered sludge, hydrogen sulphide, bacteria and chemicals found in local waters and treatment chemicals.

1.4.3 DIGESTER GAS PIPEWORK.

This piping is exposed externally to the atmosphere. Internally it is exposed to moist hydrogen sulphide and other gaseous products from the digester tanks.

2. ADVANTAGES OF STAINLESS STEELS

Alloys used in the construction of waste water treatment plants tend to be ferrous based materials such as carbon steel, galvanised steel and concrete lined ductile iron. These metal systems corrode and corrosion allowances must be incorporated into the design.

Stainless steel, by contrast, provides a material with extremely low corrosion rates in the handling of a very wide range of effluents and moist gases. Unlike steels, high levels of aeration in activated sludge processes are beneficial to the performance of stainless steels in maintaining their protective surface film and keeping the surface of the metal clean.

With excellent corrosion-erosion characteristics in high flow rates (up to 30m/s), stainless steel can handle changes of cross-section, pumping turbulence, and high velocities. The tight, adherent oxide that naturally forms on stainless steel provides it with excellent resistance, unlike steels which are limited to 1m/s before their protective films become removed by erosion or mechanical action of the effluent stream.

With no corrosion allowance, stainless steel systems can be designed using thinner walls and a light-weight design (**Figure 1**).

Figure 1. England -Screening and Grit Removal.
Screenings are collected, compacted and passed up shute to be carried in removable containers.

Also, if high flow rates are permissible, smaller cross-sectional piping sizes allow movement of equivalent quantities of sewage or sludge in the same time period. Reduced sizes and low weights can also be a significant advantage in installations where space and handling capabilities are restricted, which may be the case in upgrading a plant or in packaged water treatment units. An instance in New Zealand (3) is a spirally welded aerial sewer in type 316 stainless that was light enough for a helicopter to lift into place, **Figure 2**.

Figure 2.
New Zealand.
A 316L stainless spirally welde pipe, 60 m long. The central span is a 20 metres long truss that utilises the sewer pipe as the chord.

Of growing importance, now that the durability of stainless steel has become recognized is the life cycle cost advantage of stainless steels for reduced maintenance where coating systems do not have to be maintained. One example is the selection of a 316 ducting to vent hydrogen sulphide from treatment works in the North West of England, **Figures 3 and 4** (4).

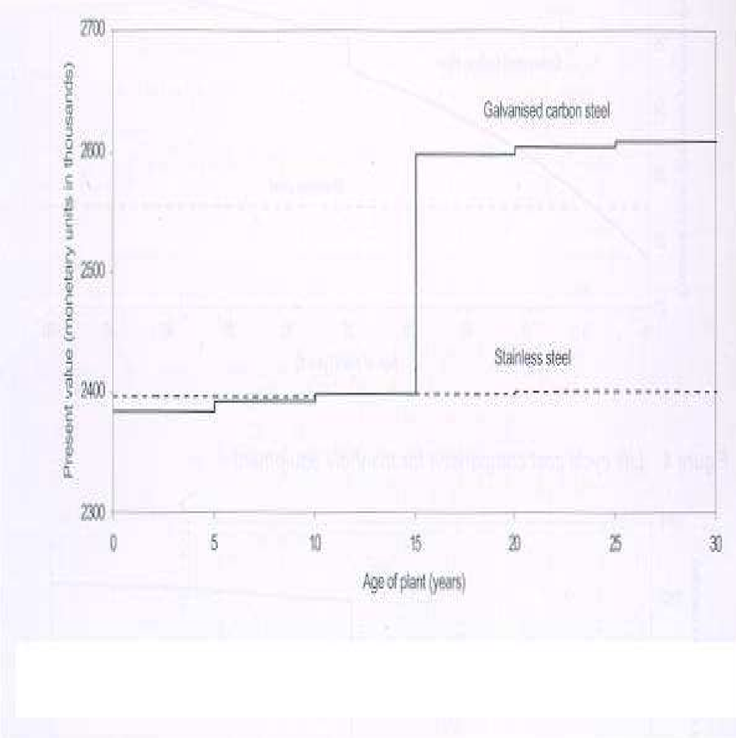

Figure 3 –UK – Life Cycle Cost comparisons for duct-work to remove odorous fumes in a sewage inlet works.

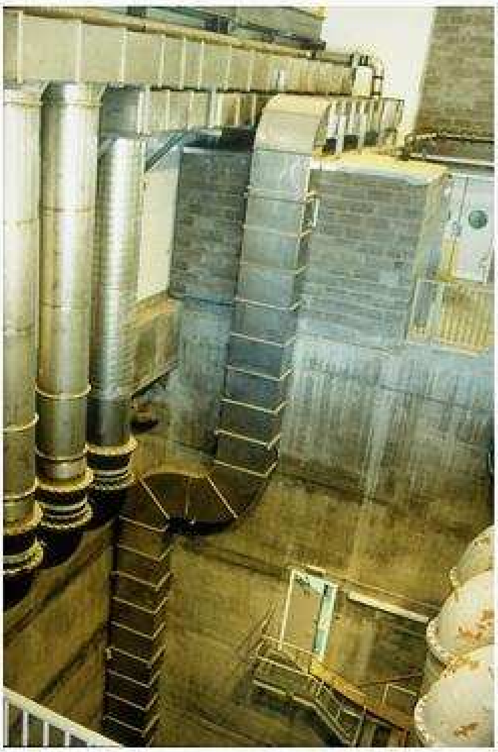

Fig 4 – Fleetwoood, UK – Type 316 stainless steel odour extraction ducting.

Thin sections and lack of coatings meant that the initial cost difference between stainless and coated steel was not as great as first expected. Overall costs were similar after about 5 years when the first main maintenance schedule was planned because coating *in situ* was not needed and there was a sizeable cost advantage after 15 years when replacement of the steel would be planned.

Figure 5. Heaton Lodge, UK. Coated steel distributors in the foreground have been replaced with new a pyramid shaped design made from type 304 and 316 stainless steel as shown in the background.

Similarly, stainless steel was chosen in the replacement and redesign of distributors (5,6) in a biological treatment process in a plant owned by Yorkshire Water, UK, shown in **Figure 5.**

The new pyramid design, using type 304 for the main frame and 316 for the chassis, was predicted to have a process availability of 97% and a cost saving of 50% over a 20 year life compared to the coated steel units they replaced. After 2 years service, the stainless steel is exceeding expectations as the maintenance has so far been cut by over 90%.

2.2 Grades Of Stainless Steel Used In The Waste Water Industry

The standard austenitic grades that are used for waste water applications involve type 304 and 316 stainless steels. Grade 304 is generally considered acceptable for chloride levels up to 200 ppm chloride and 316 for levels up to 1000 ppm or where a greater level of confidence is required. Localised corrosion has been found to be rare below these levels. Type 316 stainless steels offer the greater resistance, due to 2-3% molybdenum content. For aggressive waters and exposures to coastal environments, duplex stainless steel (austenitic-ferritic) grades and the 6% molybdenum austenitic stainless materials have been considered. Duplex alloys have higher strengths than austenitic materials and this can be utilised to further decrease wall thickness and weight, if necessary. Typical compositions and mechanical properties are shown in **Tables 2 and 3**.

Table 2. Typical Chemical Composition (%) of Commonly Used Stainless Steels

Alloy	Euronorm EN 10088	Carbon max	Nickel	Chromium	Molybdenum	Others
Type 304	1.4301	0.08	10.0	18.0	-	Rem Fe
Type 304L	1.4307	0.03	10.0	18.0	-	Rem Fe
Type 316	1.4401	0.08	12.0	17.0	2.0 – 3.0	Rem Fe
Type 316L	1.4404	0.03	12.0	17.0	2.0 – 3.0	Rem Fe
Type 316Ti	1.4571	0.08	12.0	17.0	2.0 – 2.5	Ti, Rem Fe
22% Cr Duplex	1.4462	0.02	5.5	22.0	2.5 - 3.5	N, Rem Fe
25% Cr Duplex	Various*	0.03	7.0	25.0	3.0 – 4.0	Cu, W, N* Rem Fe
6% Mo	1.4547 1.4529	0.02 0.02	18.0 19 - 21	20.0 24 - 26	6.0 –7.0 6.0 –7.0	Cu, N, Rem Fe Cu, N, Rem Fe

* Composition and Euronorm designation depends on proprietary grade used

Table 3. Mechanical Properties
(Taken from EN 10088-2 for cold rolled strip)

Alloy	0.2% Proof Stress (min) N/mm^2	Tensile Strength N/ mm^2	Elongation (min)%
304	230	540 -750	45
304L	220	520 -670	45
316	240	530 - 680	40
316L	240	530 - 680	40
22% Cr Duplex	480	660 - 950	20

The low carbon grades of materials or grades stabilised with titanium or niobium should be considered for welded fabrication of sections above 3 mm.

2.3 Applications

2.3.1 GENERAL APPLICATIONS

Table 4 provides a list of applications where stainless steels have been successfully used within waste water treatment plants internationally.

Table 4. Stainless Steel Applications in Waste Water Treatment Plants

Hand Rails	Walkways
Screens	Travelling Bridges
Grit Removers	Scrapers
Slide gates	Bolts
Aeration Piping	Pumps and Valves
Sludge transfer piping	Tanks
Digester gas Piping	Weirs
Ozone Generators and Piping	Ultraviolet Equipment
Chemical treatment Lines	Ladders
Manhole covers	Ducting
Backwash systems	

2.3.2 RESULTS OF NORTH AMERICAN EXPERIENCE

Since the late 1960's over 1600 waste water treatment plants have been built in the USA using stainless steel aeration, digester gas and sludge transfer piping (7,8) as well as slide gates, valves, tanks, screens, handrails and other equipment.

A review of the experience (8) rates the material as showing good to excellent performance. 304L is the standard material there for digester gas piping and for piping used to handle treated flowing sludge and has performed well. For the most part, plants are in inland locations where chlorides are less than 200 ppm. A few plants in coastal locations use the more resistant alloy 316L.

Reports of corrosion have been very few considering the age of the first plants. The most common problem has been staining of pipe exteriors caused by embedded iron. This is caused by poor handling and fabrication practices such as using steel slings for handling, cleaning welds with steel rather than stainless steel brushes, grinding steel near to the stainless fabrication. Embedded iron can be removed by pickling and this is a common requirement after fabrication. There have also been a few instances of crevice corrosion under tightly adherent sludge deposits, which were not removed during normal cleaning operations.

In general this reflects the feedback from other countries like Germany, Italy, Switzerland, UK, Sweden, New Zealand, and Australia, that given good fabrication and installation practices, high performance can be achieved from stainless steels in a wide range of applications in waste water treatment plants.

3.1 Design And Operation Considerations For Optimum Corrosion Resistance

3.1.1 ATMOSPHERIC CORROSION RESISTANCE.

When fabricated and finished to suitable standards, the type 304 and 316 grades can retain their bright appearance in atmospheric exposure for many years particularly when any surface deposits which build up are removed by a periodic wash down. In marine or chloride bearing atmospheres the 316 grades are recommended where maximum life and good appearance are required.

3.1.2 CREVICES.

It is true that stainless steels do not suffer uniform corrosion when exposed to effluent environments. However, they can be susceptible to localised corrosion under certain sets of circumstances, which designers and end users need to be aware of and take actions to avoid. Attack, if it occurs, is usually localised in creviced areas, which can be man-made and originating from design or construction, or naturally occurring in crevices formed by deposits or microbial growth, resulting in under deposit corrosion.

Susceptible man-made crevices have occurred at the roots of welds due to incomplete through wall penetration, as a result of poor welding practice. These crevices can entrap sediment and allow chlorides to concentrate to several times the concentration in the bulk water. Attention to detail during welding, ensuring complete through-wall weld penetration and the use of appropriate welding and inspection procedures can help address these issues. The circumferential welds in those areas exposed to the handling of sludge-the outside of the aeration piping and the inside of the digester and sludge piping should be free of crevices and fully penetrated.

Other man-made crevices, such as flange faces under suitable gaskets materials and mechanical_joints have posed few problems in low chloride effluent.

Naturally occurring deposits, can be reduced by maintaining flow rates. For stainless steel, flow rates of greater than 0.6m/s are preferred in sludge service. It is under stagnant conditions that bacteria can colonise and form biomounds and tubercles. While both aerobic and anaerobic bacteria have been reported to initiate microbiologically influenced corrosion (MIC) under conducive conditions, it is usually in anaerobic conditions under soft biomounds and tubercles, that MIC occurs. Although MIC will occasionally occur in base metal away from welds, the normal location is in the area of welds that have not been cleaned of heat tint scale. Removal of heat tint scale restores base metal corrosion resistance and greatly improves resistance to MIC. Microbiologically influenced corrosion has been surprisingly rare in waste water treatment processes. Reasons for such good performance are thought to be due to good welding procedures and removal of heat tint and the low chloride content of most waters. The agitation of the sewage caused during activated sludge process helps keep the surface of the pipes clean together with cleaning of the basins when out of service. It is during hydrotesting at the commissioning stages of pipelines and tanks using raw waters when there is the greatest risk of this type of corrosion.

3.1.3 HYDROTESTING.

Hydrostatic testing of pipelines lines and vessels represents a very important approach in checking the integrity of systems after construction. However, it is very important to drain and dry stainless steel systems after testing, if the equipment is not going into service directly. This is particularly important when raw waters are used for testing where bacteria and water stream sediments can settle out when left stagnant and initiate under-deposit corrosion attack in the area of welds. Potable water or filtered waters are therefore preferred for testing and where draining is not possible the maintenance of a regular flushing of the system on a daily basis until it goes into service should limit potential problems.

3.1.4 CHEMICAL TREATMENTS

Care must be taken when adding chlorine compounds to various process streams. Serious consideration needs to be given to ensuring that chlorine and aggressive chemicals, such as ferric chloride (added for flocculation purposes), are added centrally into the stream for good dispersion. Concentrated forms of these chemicals directed at or down the side of stainless steel piping or equipment can result in localised attack

Ozonation has increased in popularity. Ozone is a powerful oxidant with limited retention life; it does not create ions or compounds, which are as aggressive to stainless steel. Type 316 stainless steel is a standard material used in ozone generation and for the handling of the ozonated water streams.

3.1.5 HYDROGEN SULPHIDE

Hydrogen sulphide gas is generated in digesters and throughout much of a waste water treatment plant. It can contribute to general corrosion which occurs on copper alloys, aluminium alloys and hot dipped galvanized steel, painted/unpainted steel. The general corrosion rates of 304 and 316 stainless steels in the atmosphere and in closed systems (e.g.

pipework), where moist hydrogen sulphide is present, are negligible at near ambient temperatures. Experience in the USA has found minimal corrosion problems due to hydrogen sulphide gas being present in these environments.

However in closed systems there may be a propensity for localized corrosion attack (pitting and crevice corrosion) to occur in 304 and 316 alloys if moist hydrogen sulphide and chlorides are present together, at elevated temperatures. The acidity of the waste waters may also be raised and therefore become more corrosive if condensates containing dissolved sulphur dioxide are generated forming sulphurous acid.

High acidity, moist hydrogen sulphide and chlorides present in waste waters at elevated temperature can provide an environment where localized corrosion of the stainless steel 304 and 316 may occur. These more corrosive environments may require higher molybdenum austenitic stainless steels (e.g. 904L) or duplex stainless steels (e.g. 2205) to be considered as materials of construction.

4. WASTE WATER TREATMENT PLANT EVOLUTION IN ITALY

4.1 Canegrate and Pero plants

4.1.1 INTRODUCTION

After the worldwide view of increasing stainless steel application in waste water treatment plants, here is a look at the Italian experience. The evolution in this field can be well summarised by two plants, both located in the Milan Province: Canegrate with a capacity of 270,000 "equivalent "population and Pero with 360,000. The Canegrate metal equipment, which has been working since 1988, is made only of carbon steel protected by paint or zinc coating. At Pero, which began operation in June 1999, a large part of the equipment is made of stainless steel. Selection was influenced by the time span required to complete the plant such that the first equipment installed had to be resistant to extended atmospheric attack.

4.2 Stainless steel equipment in Pero

4.2.1 HISTORY

Pero construction started at the beginning of the '90s and was completed at the end of the decade. The long construction time was not due to environmental or technical reasons, but to extended financial allocations. However, as the Pero plant construction followed that of Canegrate, the designers took advantage of their former experience.

The owner of both plants is a municipal company created by the association of 39 little towns in Northern Milan with the Milan Province Administration. In 1996 the company name was changed in "Consorzio idrico di tutela delle acque del Nord Milano" or "Water Association to safeguard water in the Northern Milan"; the new name was a consequence of an Italian legislation change that implied different responsibilities and operations of municipal companies or associations.

In 1993, in agreement with the "Consorzio", NiDI chose Canegrate as a WWTP for a Life Cycle Costing study case. The LCC findings emphasise how cost effective stainless steel can be as a structural material for most metal equipment. Once the study was concluded, the Consorzio designers found that their stainless steel choices for the Pero plant were in line with the LCC analysis independently carried out by NiDI.

4.2.2 MAIN STAINLESS STEEL APPLICATIONS

Most of the equipment is made in 304 stainless steel except for that in contact with biogas containing hydrogen sulphide (H_2S) where the grade selected is 316.

Examinations were made in 1994 and in 2001, while the plant began operation in June 1999. All pictures confirm the good performance of stainless steel even for equipment, which, after installation, remained inactive for more than 5 years.

A plant innovation regarded treatments that produce odours such as *coarse and fine screenings* as well as *oil and grit removal* in **Figure 6**. To prevent odour diffusion both sections are inside buildings just for this purpose. The same result was reached in the *biological oxidation* section where air blows into the effluent and the process is carried out inside closed equipment, as shown in **Figure 7**.

Figure 6 (March 2001). Air blowing along a tank longitudinal side in the *Oil and Grit Removal section.*

Figure 7 (March 2001). Pipe work to convey air for the *Biological Oxidation.* In the foreground a pair of stainless steel collectors, 700 mm diameter.

In each circular tank of the *primary and secondary sedimentation* section there is a rotating stainless steel bridge like that in **Figure 8**. The periphery of the circular tanks is equipped with a scum baffle and two effluent weirs, as in **Figure 9**, fabricated from stainless steel strip.

Figure 8 (March 1994) - *Primary and secondary sedimentation.* The rotating stainless steel bridge installed in each circular tank

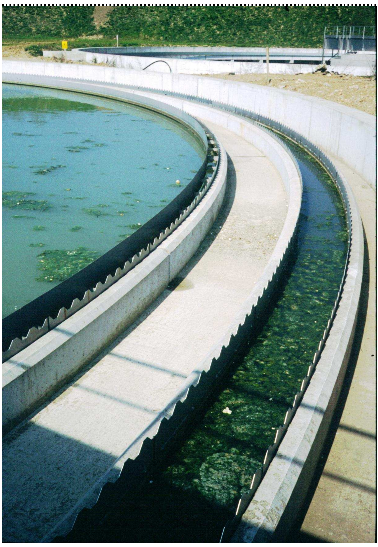

Figure 9 (March 1994) Type 304 inner scum baffle and effluent weirs.

From the *activated sludge* section the 316 tubes containing biogas travel to the digester domes (**Figure 10** and **11)**.

Figure 10. (March 2001) – Type 316 work pipe at the digester domes.

Figure 11. (March 2001) –Type 316 tube cross the dome collar to penetrate the digester

Stainless steel was used at Pero not only for the process equipment but also for other applications around the plant as **Figure 12** shows.

Figure 12. (March 2001). On the driveway connecting plant with the building office in the background, stainless steel arches and chains are installed to prevent car parking.

Table 5 summarises all the stainless steel equipment installed in Pero.

Table 5. Stainless steel applications in Pero

Plant Section	**Equipment**
Coarse and Fine Screenings	• Mechanical bar screens • Housings of the mechanical cleaning racks. • Slide gates.
Oil and Grit Removal	• Four travelling bridges, equipped with a skimmer blade at the water surface and a scraper close to the tank bottom. • Piping to convey air in the four removal tanks. • Equipment to compact grit and floating matter.
Primary Sedimentation	• Three rotating bridges installed in the sedimentation circular tanks. • The scum baffles and effluent weirs installed at the periphery of the circular tanks.
Biological Oxidation	• Collectors, 700 mm diameter, and pipe work to convey air for the effluent biological oxidation.
Secondary Sedimentation	• Three rotating bridges installed in the sedimentation circular tanks. • The scum baffles and effluent weirs installed at the periphery of the circular tanks.

Activated sludge	• 316 stainless steel pipe work connecting compressor room, digesters, and gas tank.
Other features	• Arches and chains to prevent car parking on the driveway to the office building.

4.2.3 EXPANDING CAPACITY

It is planned to double the Pero plant to produce a capacity equivalent to servicing a population of 720,000. This implies an equivalent increase in the use of stainless steel. The executive programme of the plant extension, made by the "Consorzio" designers, is almost finished and the tender has been predicted for the end of 2001.

5. THE LIFE CYCLE COST ANALYSIS AT THE PLANNING STAGE

5.1 The Canegrate case

5.1.1 THE LCC APPROACH

In 1993 NiDI selected the Canegrate plant, which has been operating since 1988, as an up to date source for all relevant details of a WWTP. The LCC approach considered the following main equipment: mechanical bar screens, travelling and rotating bridges, hand- and foot-rails installed all over the plant. Only piping was excluded although it represents a relevant part of the material selection; this was due to the decision to pay more attention to equipment traditionally made of mild steel and protected by paint or zinc coatings. Using the “Euro Inox computer-programme” (9)**,** Life Cycle Costs were calculated for the following three material options: carbon steel, 304 type and 316 type stainless steel. According to Canegrate experience, the maintenance was based on a 5 year cycle and scheduled the maintenance operations for each material option. Moreover the analysis was very conservative as the following two figures were introduced: zero production loss and only 10% weight reduction of the stainless steel components, as **Tables 6 and 7** show.

Table 6. Equipment Weight

Plant section	Equipment Type	No. (m)	Carbon Steel Weight	Stainless Steel Weight
Screening	Mechanical bar screens	4	4 x 1.2 t = 4.8 t	4 x 1.08 = 4.32 t
Oil and grit removal	Travelling bridges	3	3 x 3 t = 9.0 t	3 x 2.70 = 8.10 t
Primary treatment	Travelling bridges	3	3 x 7,7 t = 23.1 t	3 x 6.93 = 20.79 t
Secondary treatment	Travelling bridges	3	3 x 21 t = 63.0 t	3 x 18.9 = 56.70 t
Sludge thickening	Rotating bridge	1	1 x 10 t = 10.0 t	1 x 9.0 = 9.00 t
Hand- & Foot-rails (In all the sections)	Hand- & Foot-rails	(2,000)	2000 x 20 kg/m = 40.0 t	2000 x 18 kg/m = 36.00 t
PLANT	Metal equipment	---	149.90 t	134.91 t

Table 7. Rates and Duration

Monetary Unit	1,000 Italian Lire
Year Zero	1993
Cost of capital	10.00 %
Inflation rate	5.00 %
Real interest rate	4.76 %
Desired life cycle duration	30 years

'St. St./ C St.' weight ratio	0.90
Maintenance cycle	5 years
Total maintenance events	5
Maintenance cost per event:	(1993 Million Lire)
C steel	*260.64*
Type 304	*16.66*
Type 316	*16.66*
Downtime per Maintenance event	0
Value of lost production	0

Using the computer-programme, the maintenance costs and the LCC of each unit were calculated; the result for the single unit was then multiplied by the number of units in each section. **Table 8** gives the LCC findings of each section as well as that of the whole plant. All costs are given in year zero value that is 1993 Million Italian Lire.

Table 8 - Life Cycle Costs (1993 Million Italian Lire)

Equipment Type	Initial costs (Year 0)			Final costs (Year 30)		
	C steel	304	316	C steel	304	316
1 Mechanical bar screens	32	36	40	64	48	52
3 Travelling bridges	54	69	75	102	78	84
3 Travelling bridges	132	168	177	243	174	183
3 Travelling bridges	339	453	486	606	462	495
1 Rotating bridge	61	78	81	108	80	83
2,000 m of Hand- & foot-rails	220	300	340	391	296	335
PLANT	838	1104	1199	1514	1138	1232

5.1.2 LCC MATERIAL COMPARISONS

Figure 13 shows LCC graphs referring to three material options. It is seen that all the graphs have the same trend but the step rise depends on the maintenance costs; thus the steps are very high for carbon steel due to high levels of labour required to maintain surface protection, and the steps are low for both 304 and 316 stainless steel which basically require only a visual check.

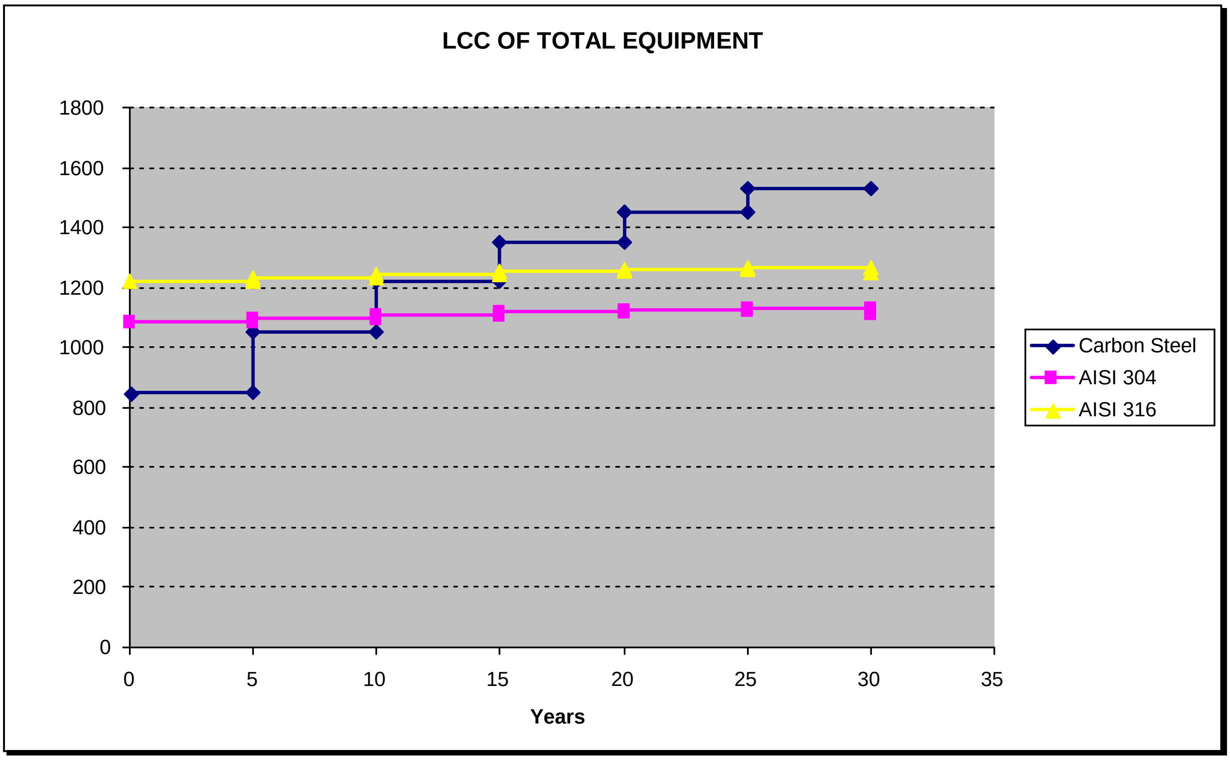

Fig. 13 - LCC material comparison

Figure 13 helps to make an easy comparison between the findings. In particular, the changeover point at which stainless steel becomes more economical than carbon steel is 10 years for 304 and 15 years for 316, even with the conservative figures used for the production loss and the weight reduction.

5.2 Legislation changes in Italy

5.2.1 "LCC" AT THE PLANNING STAGE

During the 1990s there were relevant changes in Italy in regard to regulations involving both public works and the responsibilities of the municipal companies. The changes were introduced by the so-called Merloni law (9) issued in 1994 and its subsequent regulations (10) of 1999.

As a consequence, the legal constraints at the time of the Canegrate plant construction were different from those that will regulate the expansion of the Pero plant. For Canegrate, the lowest bid was considered more important than taking into account the consequent effects in maintenance and downtime costs. This favoured structural materials such as carbon steel, which are more convenient in terms of initial costs.

However, the new legislation influenced, among other things, (Article 16), the following three levels of planning: preliminary, definite and executive design. As far as the definite design is involved, it must include "... a report which specifies the criterion adopted for the design as well as the properties of the materials selected ...". Furthermore the subsequent executive design must include a maintenance plan of the complete works and the main components

"... paying attention to operation and maintenance needs ...".

The new legal perspective in which the municipal companies have to operate means that the LCC analysis still is an even more effective tool for material selection because indirect costs like maintenance, replacement, downtime and production loss must now be considered and these have an important influence on the outcome of a life cycle cost analysis. LCC analysis will be most effective only if it contributes to the plant specifications before the tender for contract.

These changes are more favourable towards the selection of stainless steel.

5.2.2 PLANT COMPARISON RESULTS

Italy is one of the countries where stainless steel applications in WWTP are increasing. The NiDI study of 1993 measured how cost effective both 304 and 316 stainless steel types are when compared to painted or galvanised carbon steel.

The comparison between Pero plant, built in the '90s, and Canegrate built in the '80s, shows the progress already made in terms of the use of stainless steel equipment, and this will continued with the Pero extension.

The conditions created by recent legislative changes in Italy influence material selection for the future.

6. CONCLUSIONS

6.1 Characteristics

- Stainless steel alloys are strong, ductile and readily fabricated materials.
- They have extremely low corrosion rates when exposed to a wide variety of waste waters.
- They can be used for welded or mechanically joined construction and are 100% recyclable.

6.2 Benefits

- Stainless steels can be used as light-walled constructions (no corrosion allowance) and are ideally suited for modular and replacement components.
- They can handle turbulent or high flow velocities and with minimal flow friction loss over time.
- They provide long service life with the proper operational care, which based on life cycle cost analyses (initial capital investment, maintenance, replacement for the life period of

the equipment) makes stainless steel a very cost effective material of construction when compared with the more traditional construction materials.

6.3 Good Practices

- Choose an appropriate grade and design to keep crevices to a minimum.
- For optimum performance, consideration needs to be given to good fabrication practices, particularly making full through-wall welds, removal or minimising heat tint, and cleanliness.
- Systems which are not put into service directly after hydrotesting should be drained and dried in order to avoid potential problems especially if raw waters are used. If this is not possible, the waters should be circulated regularly.
- Flowing conditions should be maintained where possible. Preferred flow rates in sludge are greater than 0.6m/s.
- Oxidising chemicals injected directly at or along the walls of stainless steel and excessive dosing should be avoided.

7. REFERENCES

1. Sewage Treatment and Disposal. Severn Trent Water
2. Modern Sewage treatment. Brian Chambers. Wet News, UK. Oct. 1999
3. Stainless New Zealand. 2001
4. Applications of Stainless Steel in the Water Industry. Water Industry Information Guidance note IGN 4-25-02 January 1999. UK. WRc Publication.
5. Nickel Development Institute, Nickel Vol. 15, No 2, Dec. 1999.
6. The Water Industry’s Balancing Act: maximizing Process Availability at Minimum Cost. Stainless Steel World March 2001
7. Stainless Steels In Municipal Waste water Treatment Plants A. H. Tuthill and S. Lamb NiDI Technical Series 10 076.
8. Survey of Stainless Steel Performance in Low Chloride Waters. A. Tuthill and RE Avery Public Works Magazine USA November 1994
9. “Life Cycle Costing – LCC”, Euro Inox computer-programme.
10. Italian reference law, regarding the public works, No. 109 of 11 February 1994.
11. Italian DPR, No. 554 of 21 December 1999.