POLYAMIDE 11 COATINGS: AN ALTERNATIVE TO STAINLESS STEEL TO DECREASE OPERATING AND CAPITAL EXPENDITURE IN WATER TREATMENT PLANTS USING MEMBRANE TECHNOLOGIES.

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Introduction

The ever-increasing consumption of water throughout the world for both domestic and industrial use combined with its scarcity due to the climate change requires new innovative solutions for water and wastewater treatment. Membrane filtration technologies have permitted to address those issues. We can mention reverse osmosis membranes decreasing the cost of desalination as well as the ultra-filtration membranes allowing the removal of pesticides in river and underground water. Membrane technologies play also a major role in regards to the challenges raised by the strengthening of wastewater regulations. Whereas the development of those technologies appears as a real breakthrough, some innovations are still required to make them more affordable. This paper introduces the polyamide 11 coatings and describes its benefits throughout 40 years of relevant usage references within the water industry. We will show how it can give the opportunity to engineering companies and subcontractors to decrease both OPEX and CAPEX in water treatment plants using membrane technologies.

Polyamide 11 coatings

Material presentation

Polyamide 11 is a high performance thermoplastic material with excellent functional properties. It is marketed under the brand name of Rilsan®. It is obtained by the polycondensation of 11-amino undecanoic acid, which is coming from a vegetable origin: castor oil. It contributes to sustainable development in that:

- It is bio-based high performance bioplastics-100% of carbons in polyamide 11 are organic and coming from plant based renewable resources (ASTM 6866)
- Its production from primary energy sources and primary raw materials requires less fossil energy than most performance polymers.
- Its production from primary energy sources and primary raw materials generates much less CO_2 and other greenhouse gases emissions than other performance polymers.

The excellent properties of polyamides and in particular polyamide 11 are a result of the amide linkages in the chain, which allow a strong interaction between the chains by hydrogen bonds. Polyamide 11 compares advantageously to standard nylons such as 6 and 66 because of its lower water absorption resulting in better ageing resistance, lower density, higher chemical resistance, very good dimensional stability with time and limited changes in the electrical properties and mechanical properties. Comparative data are given in **Table 1.**

It is manufactured both in granules and powder form. Granules are transformed by conventional process (extrusion, injection…) to be used in industries including oil and gas, transportation and sports.

This paper will deal with polyamide 11 powders, which are used for metal coating applications for years in a great variety sectors:

- For dishwasher basket due to its resistance to dishwashing detergents and thermal cycles.
- In the transportation industry as a durable protection for components exposed to high mechanical and chemical strains (spline shaft, sliding door rail, fuel line coating…) or for noise reduction purposes (seat components, sun roof cables…).
- For roller for litho offset printing machine because of its machining ability, its wear resistance as well as its inertia to ink and cleaning solutions.
- For the steel protection in fluid transfer industry including water treatment and transportation, oil extraction and gas transportation

Table 1: Comparison of different polyamides.

	PA 66	PA 6	PA 11
Melting point (°C)	255	215	188
Density	1,14	1,13	1,03
Flexural modulus (MPa) 50 % Relative Humidity/23°C	2800 (1200)	2200	1300
Water absorption at 23°C 50 % Relative Humidity In water immersion	2,5 8,5	2,7 9,5	1,1 1,9
Charpy notched impact ISO 180/1A 23°C - kJ/m^2 - 40°C – Kj/m^2	5,3 (24) ×	8 (30) ×	23 13
ISO 527 Tensile stress (MPa) Tensile elongation (%) Elongation at rupture (%)	87 (77) 5 (25) 60 (300)	85 (70) 15 - 200	36 22 360

Application process

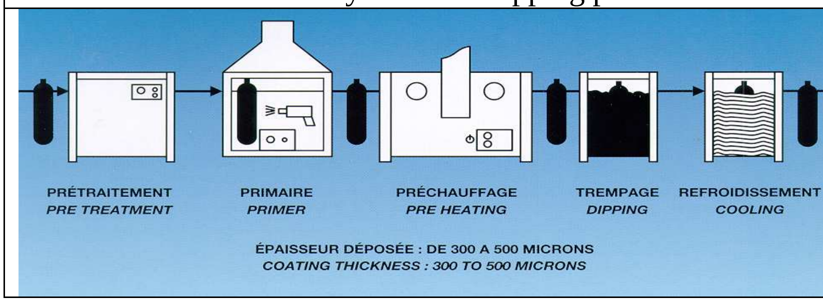
Comparing to conventional thermosetting materials, polyamide 11 is a thermoplastic, which means that no chemical reaction and thus optimised control of application conditions are required to obtain the designed mechanical properties. The application thereof brings no pollution in the application workshop and both the powder and coating release no volatiles, organic substances or odour.

Various processing technologies are available, which allow its application on different types of substrates in order to obtain an optimum protection. The main application processes include dipping in fluidised bed, electrostatic spraying on cold substrates or spraying on preheated substrates. When requiring optimal anticorrosion properties, as it is typically for water treatment industry, a water-based primer should be applied prior to polyamide 11 to form what we will call later in this paper “the polyamide 11 system”.

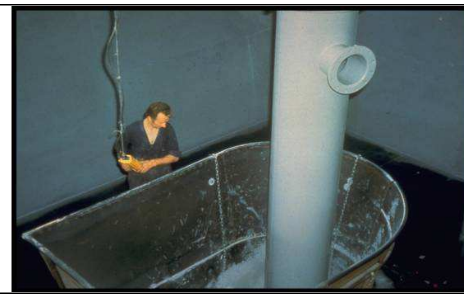
The most suitable process to coat components for a water treatment plant remains the dipping process, which is described in **scheme 2**. Using vertical fluid bed of powder (often as deep as 7 meters- see **picture 3**), both internal and external coatings could be achieved in one step on tubes and elbows up to 6 m length and having diameters larger than 1 m. A uniform overall thickness is obtained due to the sharp melting peak of polyamide 11, typically a nominal thickness of 350µm ± 50 µm. In order to ensure the performances of the coated parts and to provide relevant tools to engineers for risk management, standards from all over the world (Holland—KIWA K-759, USA—AWWA C-224, Japan—JWWA WSP-067, Australia—AS/NZS 4158, Europe—EN 10310) covers the following points:

- Effect of coating materials on water quality according standards in force (NSF 61, WRAS…)
- Coating material performances (resistance to impact, water immersion, corrosion…)
- Application procedure (surface preparation, primer application, coating)
- Quality control on coated parts (Appearance, thickness, holiday detection, adhesion…)

Scheme 2: Polyamide 11 dipping process



Pictures 3: Vertical bed of PA 11



Polyamide 11 in water industry

Polyamide 11 has been used in water industry for coating pipes, pumps, valves and fittings since 1967. It is international acknowledged as a coating material that can be used with confidence by the engineer and designer to combat corrosion, without sacrificing the economy and strength of basic metal substrates. Its unique properties allow providing to water companies, municipalities and industry the following benefits:

Water quality preservation:

Polyamide 11 coating does not release any hazardous compound. It has been evaluated and found to comply to various regulatory requirements, for example, WRAS and DWI in UK, DVGW-KTW and DVGW-W270 in Germany, ACS according to Circular DGS/VS4/N°99.217 in France, KIWA-ATA in Holland, JWWA WSP 067-2001 in Japan, NSF61 in US and AS4020 in Australia.

Easier handling of coated pieces

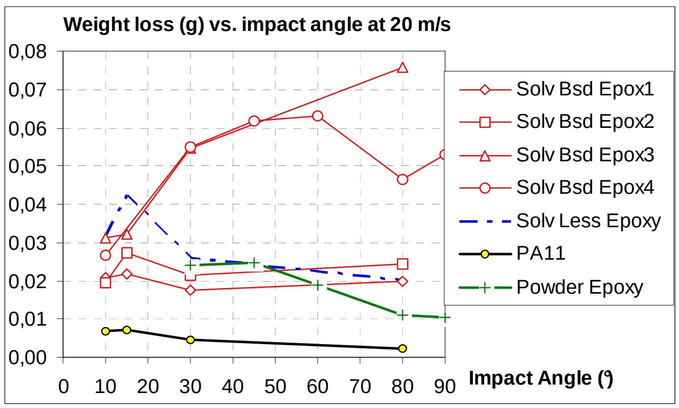
Polyamide 11’s semi crystalline structure brings to the material both the hardness of thermosetting materials and the flexibility of thermoplastics. As a ductile material, it won’t chip or crack like epoxy does but its hardness will allow compressions that would damage all polyolefin’s based coatings. It results in a high resistance to impact, even at low temperature, that allows pipe transportation and handling before its installation under harsh field conditions as well as a quite remarkable elasticity (>20% elongation at break), which makes possible pipe bending on site up to 30 times its diameter without cracking allowing the coating to follow the deformation of the steel. More over, its weathering resistance prevent the coating to chalk as it is observed with epoxy coating.

Free maintenance coating through an excellent durability

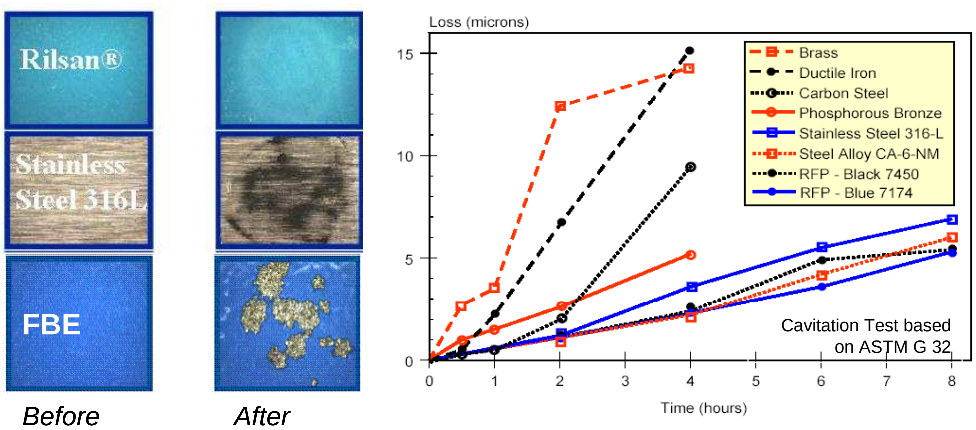
Polyamide 11 coatings systems used for water treatment applications are designed to withstand water and saltwater continuous exposure at temperature up to 50°C, pH from 3 to 10 without limitation considering the pressure (tested with success at 150 bars). In those conditions, it maintains the original designed quality of the piping system thanks to its excellent resistance to wear, chemicals and corrosion as discussed below:

- Wear resistance: As shown in **graphic 4**, polyamide 11 presents a much superior resistance to erosion [1] than other type of coating. Cavitation erosion tests [3], carried according to ASTM G32: *Standard method for determination of cavitation erosion using vibratory apparatus*, have demonstrated without surprise that polyamide 11 offers better resistance than FBE coatings, which are eroded to the metal surface. The same experimental work proved that polyamide 11 performs better than the metals used in water industry (see **graphics 5**).

Graphic 4: Comparison of erosion resistance of several coatings



Graphic 5: Loss in microns and optical comparison of cavitation erosion resistance of several materials



- Chemical resistance: Polyamide 11 coatings resist to most of the chemicals used in water treatment including some that corrode most of stainless steel grades. We can mention disinfectants (chlorine, chlorinated chemicals, ozone…), oxidizing agents (oxygen, potassium permanganate…), flocculants and softening agents (Ferric chloride, aluminium chloride, sulphates) as well as membrane cleaning agents (sodium bisulphite, hydrochloric acid, sodium hydroxide…).

- Corrosion resistance: The corrosion resistance of the polyamide 11 coating system has been proven throughout laboratory evaluations, on field trials and confirmed by 40 years track records (**table 6**). This outstanding behaviour is due to the low gas and vapour permeability combined with the excellent adhesion retention of the system avoiding the creation microscopic gaps or lack of intimate contact, which favours the condensation or the enrichment of corrosive agents on the metal. More over the primer limit the propagation of the rust in case of coating damage due to inappropriate manipulation giving to the plant operators or constructors the chance to repair the damage on site with a touch up.

Table 6: Information regarding the corrosion resistance polyamide 11 system

<table>
<tr><th>Laboratory results</th><th colspan="2">On site trials</th></tr>
<tr><td>No loss of adhesion or corrosion propagation after 2000 hours salt spray</td><td rowspan="3">
External and internal coating of a water pipeline used for the water injection assisted extraction of crude oil (Algeria)</td><td rowspan="3">Temperature: -6→45°C
Pressure: 15bars
Water quality:
- 41g/l of NaCl,
- 6ppm of H_2S
- 150ppm of CO_2
Conclusion [3]: No coating degradation, no loss of adhesion or blistering after five years and a half.</td></tr>
<tr><td>No loss of adhesion or corrosion propagation after ten years immersion in seawater</td></tr>
<tr><td>Resist to cathodic disbondment
(WIS 4- 52-01/EN 10310)</td></tr>
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Energy saving

Polyamide 11 coating has a very smooth and low friction surface. This benefits to keep the pressure loss of the piping system and the pumps low and thus optimise the energy consumption. Measurements have demonstrated a reduction of pipe pressure loss by 50% compared to cement coated pipes and a lower friction parameter of PA 11 coatings compared to epoxy based ones [1]. This low factor of friction lasts, as the coating does not support bio-film formation, scaling and resists to erosion

References throughout the whole water cycle since 1967

The French company Les Eaux du Nord, uses Polyamide-11 coated drilling pipes to pump abrasive underground water. Many pumping stations in Europe are also using this coating.

In 1967, Polyamide-11 coated mild steel piping system was first used in a potable water production plant at Looksbroek. Kersten B.V. at Brummen in Holland was the coating applicator. This plant is still in operation after 40 years and the piping system hasn't required any renovation yet. Now, around 70% of the Dutch potable water treatment plants and more than 50% of the German one are using PA 11.

Since 1980, the Japanese water utility has adopted polyamide 11 coating for the water storage tank panel and the pipes along bridges to transport water from mainland to the nearby islands. The coated pipes resists to earthquakes due to its flexibility. Its usage in Europe in the domain of drinking water transport started in 1986. In turin, as in several other localities in Italy, several hundred of kilometres of pipeline (with a diameter ranging from 10" to 50") have been laid.

The first wastewater treatment plants using polyamide-11 appeared in 1980. Since that, we have referenced more than 16 wastewater plants using this coating for the piping system. The **picture 7** shows a wastewater treatment plant using flanged pipes and fittings coated with polyamide 11.

Picture 7: Wastewater treatment plant built in 1990 at Bocholt in Germany

PA 11 coatings: A cost effective alternative in membrane treatment plants

Membrane filtration market has been growing very fast last years as membranes provide unique solutions to current water industry challenges. Actually, Salt Water Reverse Osmosis (SWRO) gives new possibilities to combat the lack of water caused by the climate change. Nano-filtration, ultra-filtration and micro-filtration provide responses to the problem of the pollution of river and underground water and play also major roles in regards to the challenges raised by the strengthening of wastewater regulations. This makes this sector very dynamic and highly innovative. But even if many problems have already been solved, water companies have to produce water at competitive cost so they are still looking for innovations that make the use of membranes in water treatment plant more affordable. Actually the use of this technology induces indirect costs that impact both capital expenditure and operating expenditure. The major ones are listed below:

- The materials cost because of the sharp increase in price of stainless steel and the expensiveness of complex Glass Reinforced Plastics (GRP) parts
- The energy cost because of the pressure required by those processes
- The maintenance costs due to the replacement of the membranes and the aggressive environment

We will discuss why among the piping systems currently available for water treatment plant, polyamide-11 coated piping systems appears to be one of the best solution to fulfil the objective to deliver high quality treated water at optimum CAPEX and OPEX.

Material costs

The piping system represents nowadays a 15% of the capital cost of a water treatment plant [(4)]. So the choice of the material for the piping system appears to be key in order to save CAPEX. This is more and more the case since the sharp rise of stainless steel prices due to the combination of the exponential rise in consumption for the last 10 years (+14% in 2006) and the strong increase of alloy surcharges. Stainless steel prices rose by a factor 2.5 between January 2006 and May 2006 mainly due to the skyrocketing nickel price. We are going toward a stabilisation but at high prices because of the demand that should remain high.

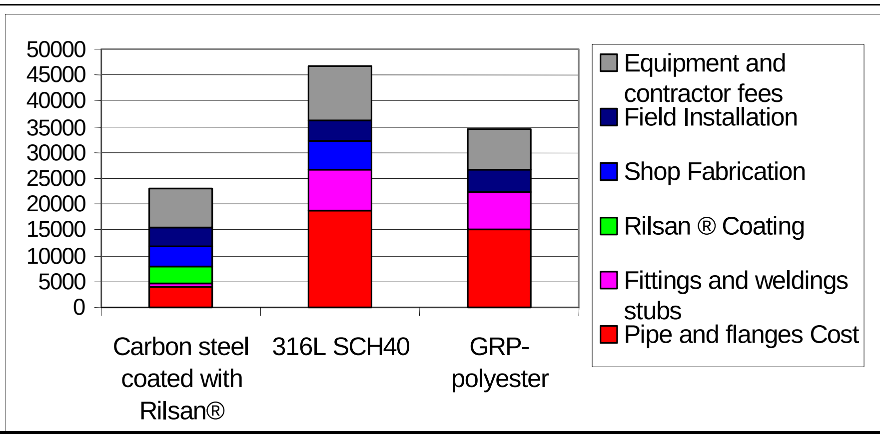
Obviously, the cost of the full installed piping system in a water treatment plant depends not only on the material costs (pipes and fittings) but also on the shop fabrication, the field installation costs as well as the equipment and contractor fees. To get an accurate estimation of the cost comparison between different piping, we need to consider each cost segments as they vary materials from materials. For instance:

- Welding stainless steel will be more expensive than welding steel, increasing the costs for shop fabrication and field installation.
- GRP parts cannot be shop fabricated like steel. So the price from the spool manufacturer will be more expensive especially for complex parts but there is no cost for shop fabrication.
- Coated pipes cannot be welded on site. So more prefabrication work is required but this is balanced by a quicker assembly time of flanged pipes versus to welded pipe reducing contractor fees.

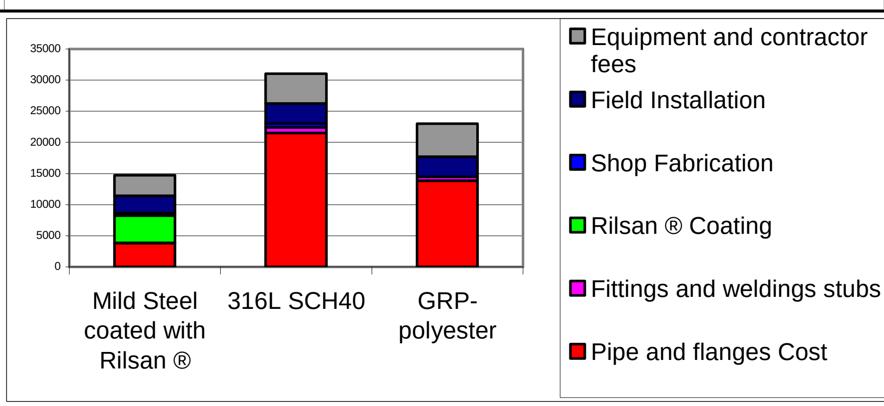
Finally, depending on piping system design (straight run piping or complex piping system), the importance of each cost segment will be different. The cost of pipes and fittings will have a greater share in a straight run piping whereas shop fabrication costs will be higher for complex piping systems.

Taking into account the above considerations, we have tried to compare the full installed cost of piping systems using carbon steel coated with polyamide 11, stainless steel 316L and GRP. We did this exercise for both a straight run piping and a complex piping system (see **graphics 8 and 9)**. We based our work on a study published by Lindley & Floyd [(5)] and we updated the 1993 results to get to an estimation of what could be achieved in 2007. We proceeded as explained below:

- We updated the pipes and fittings costs with the French construction price evolution index (provided by INSEE), which consider 65% for raw materials costs and 35% for manpower.
- Field installation costs were updated at 110% of the French inflation rate to take into account the price increase of oil when other costs were updated at 90% of the French inflation rate taking into account the evolution of the technology



Graphic 8: Cost comparison for a 4” Diameter, 400 ft Complex Piping System



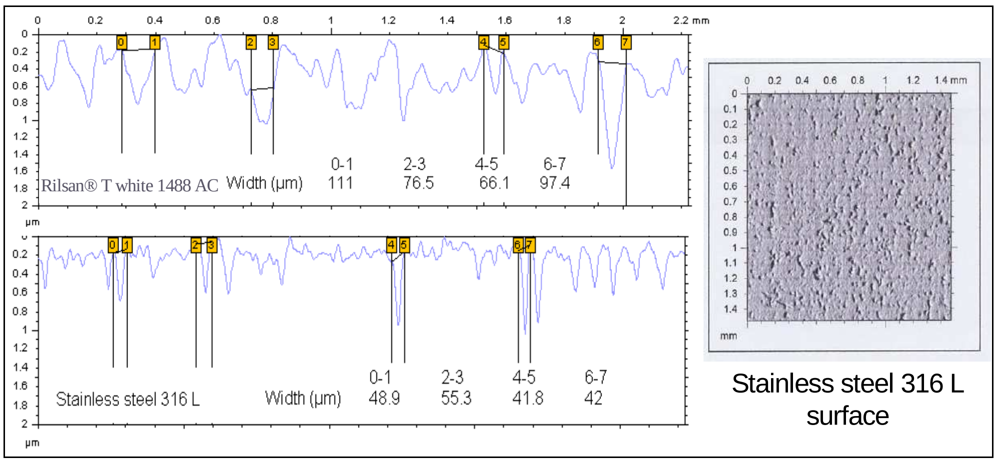
Graphic 9: Cost comparison for a 4” Diameter 500 feet Straight Run Piping System

Energy costs

Energy represents one the largest expenditure for SWRO desalination plants with a typical 30% share. Actually, standard energy consumptions are around 3.8 KWh/m3 of produced water considering energy recovery. So here again, there are possibilities for major savings. Most of the work done to reduce the energy costs has been focused on developing technologies for energy recovery (Pelton wheel, Pressure exchanger…), or to optimise pumps efficiencies through new designs. Materials through their friction factor have also an impact on energy consumption. Optimising the pressure looses of the piping system in using materials having smooth surfaces may lead to OPEX savings. Those needs to be calculated for each piping system as they are highly design dependent.

We can observe on the **figure 10** that the density of peak of polyamide 11 coating is 3.5 times lower than stainless steel 316L, which benefits to lower the pressure losses.

Figure 10: roughness profile comparison between Polyamide 11 coating and stainless steel 316L



Maintenance costs

Membrane filtration technologies still require high maintenance cost primarily to take care of the membranes itself. Actually the membranes are prone to bio fouling, scaling and accidental damage. In order to limit the maintenance, companies have set up cleaning procedures that consist in backwashing the membrane with specific solutions. But those chemicals lead to pitting corrosion for most of stainless steel grades, especially when they consist in chlorinated chemicals in acidic medium, and thus cause further maintenance problems on the piping and the pumps.

Besides the problems related to the maintenance of the membrane, SWRO desalination plants face major corrosion challenges for their piping. Actually, only very expensive grades of stainless steel like super duplex can resist to seawater and even more to brines. Even using those very specific grades, problems occur because of the difficulty to weld the pipes onsite without creating potential corrosion sites.

Polyamide-11 coated piping systems do not face this corrosion issue, as the coating system is inert to seawater and membrane cleaning agents. More over, plants using coatings are engineered for flanges pipes. The simple design adjustments required are greatly balanced by avoiding the risks of corrosion during the onsite welding.

Reference in water membrane technology

Keeping in mind their objective of delivering good quality water without interruption at competitive cost, some companies already use polyamide 11 coated piping system to replace 316L and super duplex to decrease operating and capital expenditure in some of their water treatment plants using membrane technologies. We can mention the following references:

- The coating of the piping system and vessels in membrane filtration skids (see **picture 11**). Those are in operation in several water and wastewater treatment plants in France, Russia, China and on-board ships.

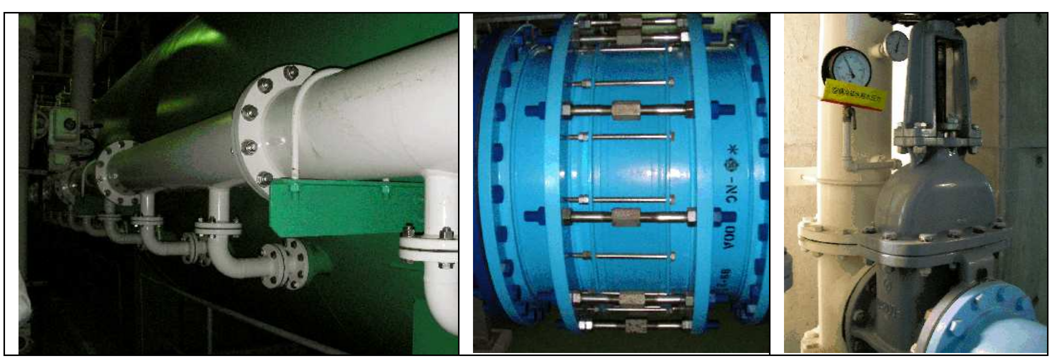
Picture 11: Membrane filtration skids using polyamide 11 coatings

 Vertical ultra filtration skid (internal and external coating of the piping)	 Horizontal ultra filtration skid (internal and external coating of the piping)	 SWRO skid (internal and external coating of the vessel)

- The coating of the piping system (joining the skids) of the ultra filtration water treatment plant of Roetgen in Germany (144 000 m3/day)

- The coating of piping systems, valves and fittings in the Chatan reverse osmosis seawater desalination plant of 40 000 m3/day at Okinawa in Japan (see **picture 12**) There was no maintenance with the polyamide 11 coating since its installation in 1997.

Picture 12: Polyamide coated parts in the SWRO Chatan desalination plant



- The coating of split case pumps and impellers up to 7 tons for salt water injection or brackish water pumping

Conclusion

Polyamide 11 has been used in water industry for coating pipes, pumps, valves and fittings since 1967. Its unique properties bring to the water companies, the municipalities and the industries numerous benefits including the preservation of the water quality, the protection of the parts during handling and storage, the decrease of maintenance cost as well as the saving of energy. Those benefits have been proven through relevant usage references in the water industry.

Besides, polyamide 11 coating appears to be an alternative to stainless steel to decrease operating and capital expenditure in water treatment plants using membrane technologies. Actually we showed that it may bring savings up to 50% on the high alloy piping system, may save maintenance costs due its better corrosion resistance to membrane cleaning agents, seawater and brines and could allow to save energy decreasing pressure losses. Those benefits are already used by companies involved in membrane filtration technology, which have specified polyamide 11 coated piping system to replace 316L and super duplex.

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