Stainless Solutions for a Sustainable Future Conference

Title: Stainless Steel in Reprocessing & Effluent Treatment Plant

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CONTENTS

Introduction

For many industrial and domestic applications, the choice for stainless steel is obvious: it will not rust under normal conditions, it is tough and strong and requires little or no maintenance. It is when special circumstances in extreme operating conditions call for a reliable and sustainable material, that stainless steel outshines many other metallic and non-metallic materials. The phrase ‘little or no maintenance’ is high on the Process Plant Managers mind, which in turn influences the design and procurement authorities. For long-term storage of high-level nuclear waste, deep underground in stainless steel-lined vaults, the phrase has a very literal meaning and there is very little choice for alternative materials.

The main theme of this presentation is the remarkable Deep Tunnel Sewer System and Changi Water Reprocessing Plant, currently under construction in Singapore. Stainless steels are used extensively throughout the plant that will provide a long-term sustainable future for the citizens of Singapore throughout this century. The role of stainless steels in Nuclear Reprocessing Plant, Desalination Plant and other water treatment projects is also touched on briefly.

1. THE SINGAPORE DEEP TUNNEL SEWERAGE SYSTEM

The Government of Singapore is in the process of replacing the existing sewerage system, which dates back to 1910, with a Deep Tunnel Sewerage System (DTSS). The purpose is to provide sewerage infrastructure that will serve Singapore through the 21^{st} Century. This long- term project, which will be implemented over the next two decades, consists of two large, deep tunnels crisscrossing the island, two water reclamation plants and two deep-sea effluent pipelines right into the Straights of Singapore. The cost of the project is estimated at S$7billion and a considerable proportion of this will be spent on a large range of stainless steels, several thousands of tonnes being required. Some of the many Knife-gate valves, fabricated and engineered entirely from 316L, weigh over 50 tonnes each.

Approximately 250 km of tunnels, with diameters up to 6.5m, will be built at between 20m and 50m below ground. These tunnels will be used to convey sewage flows by gravity, to the two new water reclamation plants at Changi and Teas in the southeastern and southwestern corners of Singapore. The existing 6 sewage treatment works and 139 pumping stations will be gradually phased out over the next 25 years as the new facilities come on-line.

The benefits to Singapore are many and include: maximizing the re-use of water; the release of land for higher value developments; better water quality in the Straights of Johor; an enhanced operational reliability of the sewage system; new business development opportunities and significant savings in operational costs. Since the existing sewer systems would be in need of phased reconstruction and upgrading to cope with the expected population increase, the total savings from these factors has been estimated at over S$5billion.

The new Water Reclamation facilities also form part of the ambitious Singapore Green Plan 2012. The target is that by 2012, non-traditional sources will constitute 25% of Singapore's water supply – 15% from NEWater, 5% from seawater desalination and the remaining 5% from treated industrial water. NEWater is obtained from sewage water through the use of advanced membrane technology utilising reverse osmosis and requires considerably less space than conventional sand filtration.

Singapore is famous for its Singapore Sling, which some know as the Gin/Grenadine/Cherry Brandy cocktail, and others as the sewage which is currently discharged into local shallow waters. A new phrase 'Singapore Sludge' will come to represent the economic benefits derived from high-tech reprocessing of human and industrial waste.

2. The Changi Water Reprocessing Plant (CWRP)

The site for the CWRP is immediately adjacent to Changi Airport on land that has only recently been reclaimed from the sea using landfill to a height of 3m, formed largely from digested sludge from the existing sewage plants. Site development is constrained by CAA requirements, which limit the height of buildings to 45m because of radar interference. The treatment facilities are generally below ground level, with the buildings above ground being used for ventilation and process control equipment. Some of the liquid process rooftops are used for offices, light industry, warehousing and maintenance equipment. Other areas are grassed over to meet the requests of the CAA.

The CWRP will receive raw sewage flow as well as treated effluent flows from the existing outdated sewage treatment plants at Kranji, Seletar and Kim Chuan. A wide range of sewage characteristics will be processed from industrial, commercial and residential areas. High quality effluent is inherent in the process design and the proportion that is discharged into the sea, will have no visual evidence of sewage.

The plant is designed to handle 2.4 million cubic metres per day and will convert this waste into useable or recycled water, wastewater for deep-sea discharge, and the solids for fertilisers and agricultural use. Provision is made to add a biological phosphorous removal plant if future legislation requires this additional control.

Description of Plant Facilities

The design concept was computer modelled in 3D, which allowed for a fully integrated considered design throughout. The Influent Pumping Station, part of which intersects the DTSS, comprises 3 vertical shafts 10m in diameter and 60m deep. The first stage is the **screening shaft,** which filters out large objects and then splits the flow between the two pumping shafts. Remotely controlled clam bucket and hoist systems remove the rubbish from the screening plant to the surface for storage and disposal off-site. The two **pumping shafts** raise the remaining influent to the surface levels for Preliminary Treatment. Gravity then takes over for moving the influent between all subsequent stages. The pumping shafts also house the Odour Control equipment, which provides high airflow rates (340 m^3/hr) and maintains H_2S to low levels.

Preliminary Treatment

Primary Treatment consists of 8 sedimentation tanks 50m long x 12m wide x 8m deep and is a primary source of odour and also corrosion of materials and equipment. The stainless steel lined tanks are completely decked over with concrete and ventilation air is introduced at a rate of 20 changes per hour. This completely removes offending odorous air and greatly reduces the potential for corrosion.

Secondary Treatment

Secondary Treatment provides the biological function of the Reprocessing Plant where the bulk of biochemical oxygen demand and nutrient removal is accomplished. Two major elements comprise this stage: **Bioreactors** - a complex system of weirs, sluices and air agitation leading to the **Secondary Sedimentation Tanks** – these remove the sludge and scum by chain and flight mechanisms and send it to the to centrifuges via stainless steel control valves.

Disinfection and Pumping
The Plant is designed primarily to deliver treated effluent to the Straights of Singapore without disinfection but provisions are made to allow this should it become necessary. The Discharge Pump rate is dependant on the conditions in the Straights of Singapore. Pumps are designed to lift the effluent to the required hydraulic grade line to pass through the outfall to the Straights of Singapore. Some of the discharge is further processed to become part of NEWater for human consumption.

Dewatering Centrifuges and Sludge Drying
The centrifuge is capable of processing 40 tonnes/hour of digested sludge. Located on floor 6 of the solids building, the dewatered sludge cake drops directly onto conveyors for further drying. The high temperature Rotary Drying System, located on lower floors, is capable of drying 450 tonnes/day. The final product is a granulate particle in the range of 96% dry solids, with a uniform size distribution from 1 to 4mm.

Product Transport and Storage
Stored in concrete silos then gravity fed to truck mounted containers for final disposal.

Product Uses
The product is sold as fertiliser or soil conditioner, as additives for newly reclaimed land; golf courses, landscaped areas and landfill sites around Singapore.

3. Welding of Austenitic Stainless Steels and the Changi Valves

The science and practice of welding Stainless Steels is well established, researched and documented by a number of distinguished metallurgists and leading steel manufacturers, although not Harry Brearley. Austenitic stainless steels are relatively straightforward to weld and are usually left in the as-welded condition, without preheat or post weld heat treatment. However, depending on the thickness and the structural design of the component, significant residual tensile stresses, up to yield point magnitude, can remain in the weld on completion. The designers of the knife gate valves for Changi were very concerned about this aspect and insisted that a post weld stress-relief heat treatment (PWHT) be carried out on completion of fabrication and welding. The reason being that the potential residual stresses, which will be additive to the

operational stresses imposed on the valves, would reduce the design safety factors to an unacceptable level.
TWI (The Welding Institute) were involved and they provided a considered opinion, supported by several references, to show that in order to reduce the residual welding stresses to minimum levels (about 80% reduction), a PWHT at 900^0C was required. The usual PWHT at temperatures around 550^0C, would only reduce the residual stress by 40% at best. The welding and materials technologists at AvestaPolarit, who supplied the plate material, were concerned when told of the intentions to carry out stress relief at 900^0C. They pointed out the possibility of impaired Intergranular corrosion resistance, and that of reduced toughness, both due to carbide precipitation, Sigma and Chi formation (and other exotic inter-metallic compounds with Greek names). TWI also drew attention to these potential deleterious effects.

In addition to the standard welding procedure qualification tests required by the ASME code, additional tests were carried out on the welded test plates after the 900^0C PWHT. Intergranular corrosion tests were carried out on the parent material, weld metal and heat-affected zones. This involves immersing the samples in boiling acids for a period of 24hrs, bending them through 180^0 around a former and then examining the surfaces for cracks at low magnification. A test failure is indicated by the presence of cracks or tears around the grain boundaries. Fortunately no such cracks were observed on a total of eight welded samples.

Impact tests at 20^0C however, revealed significant reductions in the parent material, the heat affected zone (HAZ) and the weld metal after PWHT at 900^0C. The weld metal suffered the greatest, followed by the HAZ then the parent material.
The parent material dropped from an 'anvil-stopping' 299J to 140J, which whilst a significant drop, still represents a material with extremely good toughness properties. The HAZ fell from 150J to 90J average, again a significant reduction but still high toughness. The weld metal average fell from 110J to 60J and is due in part, to the presence of delta-ferrite – most austenitic welding consumables are formulated to produce approximately 5% delta-ferrite to avoid hot cracking during cooling.

The main cause of reduced impact strength however, is due to the precipitation of inter-metallics around the grain boundaries which, form films of weakness. Were it not for the fact that the 316L plate material supplied by Avesta was indeed very low carbon (0.018%), the reduction in impact strength by this PWHT, and possibly the corrosion test as well, could have been more significantly impaired.

Another significant consequence of the high temperature stress relief, is the formation of an adherent black oxide film on the surface of the components. This has to be removed by either mechanical methods or by pickling. Pickling by acid immersion was chosen for the Changi Valves because of the additional requirement to passivate the welds – this is a further chemical treatment that optimises the material's corrosion resistance. As one might expect, the acids used during these processes are extremely hazardous and environmental controls have to be rigorously enforced.

4. Health & Safety in Manufacture

The Health and Safety of people also has to be carefully managed and especially so for welders. Stainless steel welding fume contains many different complex and potentially harmful compounds. Hexa valent Chrome is one of these, which in the short-term can induce flu-like symptoms in the welder (welder's fever). Longer-term affects of this and other particulates with possible carcinogenic properties, are somewhat uncertain. The welder has to be protected from the welding fume.

Best fabrication workshop practices tackle this in three main ways: fume extraction at the source of welding; good general shop ventilation; Personal Protection Equipment (PPE). Electrostatic suction machines best achieve extraction at source, which removes all particulates to a bag for safe disposal. The best PPE is a fully sealed face unit with airflow to the helmet provided by a fan/filter pack attached to the welders back. The use of modern materials in these units has made them more streamlined and efficient and more comfortable for the welder to wear. These three methods of dealing with welding fume were all employed during the welding of the Changi Valves. However, despite these measures, there have been a few remarks by welders of feeling nauseous after a long shift welding, and that they can 'taste chrome on their lips'.

5. Nuclear Fuel Reprocessing Plant

A vast range of materials is used in the construction and the operation of a fuel reprocessing plant. Stainless steel figures prominently in many critical applications where it is relied on for its outstanding corrosion resistance and other properties such as high sub-zero toughness. It is readily available in many forms, easy to fabricate and weld. It is also easy to decontaminate the surfaces of equipment, which have radioactive debris on them – certain parts of robotic handling equipment and vessels are periodically washed down using nitric acid.

The workhorse grade for pipe-work and process vessels for the first 30 years was 18Cr-13Ni-1Nb. This was superseded in the 1980's with NAG 18/10L (nitric acid grade), which was jointly developed by BNFL and steel companies. NAG 18/10L is basically a 304L type with reduced carbon and close control of residuals to give enhanced corrosion properties. It is used on all high integrity nitric acid applications but only a limited number of steel manufacturers are able to supply this material due to stringent QA requirements.

316L stainless steel is also used extensively throughout the plant, for lining the waste containers destined for long-term storage and for transport between sites. The philosophy of the materials engineer in the nuclear industry, has to be cautious in approach to new materials; evolution rather than revolution is the modus operandi. This probably explains the relatively slow take up of some of the newer, more highly alloyed stainless steels such as the duplex range. Some new materials have been developed and are in use. One of special interest to the metallurgist, and to the public, is the neutron-absorbing stainless steel that is used to line Transport Flasks, which move around the globe. This material is basically an 18Cr-10Ni (304) grade, but is loaded with Boron, which adjusts the crystal lattice so as to reduce the passage of high-energy radioactive particles. It could be described as a 'force field', which helps contain radiation.

Research into the effects of irradiation on stainless steels (and other materials) is receiving much attention in several organisations. The Los Alamos National Laboratory is investigation the possible embrittlement and corrosion effects of Gallium on stainless steel. Gallium is present in the order of 1% in weapons grade plutonium and stainless steel lined flasks are used to hold these high level wastes for temporary storage (50 years). Long-term storage (10,000+ years) in deep geologic repositories currently under construction in several parts of the world, will require thousands of tonnes of stainless steel to help safely contain radioactive materials.

The Yucca Mountain Project in the US is one such project that will provide long-term deep storage of spent nuclear fuel, all of which is currently in temporary storage at 130 sites throughout the US. More than 160 million people live within 75 miles of temporarily stored nuclear waste.

In Russia, the Mining Chemical Association (MCA) plant near Krasnoyarsk, was built in 1950's to produce energy as well as weapons grade plutonium and reprocessing of nuclear fuels from other Russian Plants. It is another stainless steel clad cavern, set deep in a mountain. Since the end of the Cold War, various Defence Conversion Programmes have evolved, such as R&D into silicon semiconductors, solar batteries, alarm systems, colour TV assemblies and the production of ultra pure materials such as Gallium and Tellurium.

6. Desalination Plants and other examples

The expansion of the world's deserts, global warming, the increase of droughts particularly in Africa and the devastation that War brings, will all secure the continual growth in demand for Desalination Plants and for stainless steels. The process of extracting salt from seawater has been around for millennia, but the process of extracting drinking water from seawater on a mass production scale is relatively new. Desalination Plant technology has been around for decades, but the demands for improved efficiency, improved life and reduced maintenance costs, are increasingly leading to the use of highly alloyed stainless steels. Traditional materials such as copper and nickel-based alloys and 316L stainless steel, are now gradually being replaced with higher alloyed steels, such as Duplex and Super Duplex stainless steels. The superior corrosion resistance and higher strength of these advanced materials enables considerable reductions in wall thickness for many components including piping and heat exchangers.

Closer to home, the Yorkshire Water project called **HumberCare**, is another modern water and sewage treatment plant that utilizes stainless steel on a large scale. At a cost of over 200million pounds, the plant will process 38 million gallons a day – significantly more than the existing Victorian system can handle. This new system will end the outdated and unsatisfactory practice of discharging

raw sewage into the Humber Estuary, after only preliminary treatment to remove solids.
RiverCare is another Yorkshire Water project designed to address some of the infrastructure and environmental problems we have, those due largely to the Industrial Revolution. During this period, the region's rivers and streams were used to carry human and industrial waste and little regard was given to the environment. The Victorians did a tremendous job of building state-of-the-art sewage systems in many major UK cities, out of glazed brick and cast iron. Many of these are worn out and cannot cope with current needs and environmental requirements. They are also very expensive to maintain. Today's modern sewage and water systems, in contrast, are built out of concrete, plastics and stainless steels and are designed to be of low maintenance with high environmental care.

Harry Brearley, a product of the Victorian Era and one of our great (metallurgical) engineers, was recognized for his contribution to industry when he was awarded the Iron & Steel Institute's Bessemer Gold Medal in 1920. Bessemer is another name famous in the region for his 'Converter', which heralded the start of steel-making. The last remaining example of which can be seen at Kelham Island Industrial Museum here in Sheffield.

Harry, who died in Torquay in 1948, would be delighted to know that his initial discovery in 1912 whilst researching rifle barrel problems, has had such a profound effect on mankind. Stainless steels are about to leave our solar system; the Voyager, Mariner and other deep-space probes contain many stainless steel parts, as do ordinary commercial satellites. Although corrosion as such does not exist beyond earth's atmosphere, other physical attributes of stainless steel make them ideal for the extreme conditions of radiation and temperature found in space. Stainless Steels are increasingly being used in architecture, civil and mechanical engineering, space and sea exploration, chemical process plants and also countless numbers of new sewage and water plants. Fully recyclable itself, stainless steel will continue to play a major role in recycling mankind's unwanted rubbish.