Nickel based alloys in power production units

Nickel alloys and Nickel based super alloys are widely popular for their outstanding resistance properties to corrosion and heat in addition of small thermal expansion features. These features are significant in industries that need components to retain stability and potential to prevent corrosion in the various temperature ranges.

Heanjia Super-Metals produces a vast range of nickel based alloys for use in the power production units that rely on equipments like nuclear reactors, gas turbines, steam generators and compressors, these are subjected to the large levels of heat and extremely corrosive steam conditions. The Nickel alloy components are used in the power industry for their characteristics to prevent corrosion, deformation, fracturing and metal fatigue at the elevated temperatures. We have a range of Nickel alloys available for fully implementing their attractive features in the most severe conditions. The austenitic heat resistant alloys are suitable for use in the harsh environments for their immense strength and excellent resistance to carburization and oxidation at the increasing temperatures up to 2100of. The alloys have been developed with suitable workability, ductility and weldability to offer excellent cyclic oxidation resistance at the elevated temperatures. As these are made for service in the high temperature applications, it is not wondering that these are the most suitable material for use in the heat processing furnace components, afterburner parts and gas turbine combustion chambers.

<u>Nickel Alloys in Power houses</u>

Nickel based alloys have a significant role in the power houses. Their key application in Ontario Hydro plants is in form of heat exchanger tubes in nuclear reactors, for discarding heat from the moderator and reactor and for the steam production.

The heat exchangers quenching by lake water have been done inadequately, several tubes have been failed from pitting on the cooling water side. Steam generator functionality, although has been great and slight tube corrosion is noticed.

In this study, examples of damages and comparison of the functionality of the variety of alloys has been done. Variety of research programs will be described to state ameliorative assessment of lake water quenched heat exchangers and to confirm regular consistency of the steam generators. The nuclear plant heat exchangers distribute heat from one unit or part to another. Most of the heat exchangers in operation in Ontario Hydro service units include several tubes, straight or U-bent connected to a common tubesheet, with the supporting plates lengthwise, and installed in a shell of steel. Considering their mechanical and thermal characteristics and their corrosion resistance capacity, Nickel based alloys have been utilized widely as tubing materials in the heat exchangers.

It is easy to classify heat exchangers in two classes, those functioning mainly at temperatures lower than 100oC for example moderator heat exchangers and shut down coolers and condensers, another are those functioning at the elevated temperatures specifically the steam generators. The most of the heat exchangers functioning in the smaller temperatures involve lake water however the steam generator conditions include distribution of demineralized water.

The functionality of steam generator tubes has been found outstanding however the lake water quenched heat exchangers have shown moderate to bad functionality. Hence it is easy to differentiate these two classes of heat exchangers in the various titles.

This post will analyze the materials , service and research programs conducted to enhance or maintain the functionality of heat exchangers for both kinds.

<u>Raw materials for Lake water quenched heat exchanger tubing</u>

The materials utilized should be-

1. Robust at the high temperatures

2. Resistant to corrosion and erosion attack
3. Efficient in heat distribution
4. Cost - effective

One alloy cannot meet the entire of above criteria. Traditionally, copper based alloys were widely utilized in the lake water quenched condensers in coal fired producing stations. Considering the nuclear power stations made, it was already evident that copper base alloys were normally prone to under-accumulated pitting attack.

The nickel based alloys soon became popular as an alternative option to copper base alloys in the several applications in nuclear stations. This post focuses on two such applications for lake water quenched heat exchangers – shutdown coolers and moderator heat exchangers.

Materials for Steam generator tubing

The chief factors in choosing materials for nuclear steam generator tubing were corrosion resistance, role to primary side activity, transport and price. the recommended alloys – Monel 400, Inconel 600 and Incoloy 800 have been utilized as a chief material for steam producer tubes at the different units.

Considering the suitable service in the beginning with the configuration in United States nuclear submarines, it was confirmed to utilize Inconel 600 in tubing for the steam generator at Canadian power unit – Nuclear Power Demonstration (NPD) located at Ontario. The presence of high concentration of nickel, Inconel 600 offers suitable resistance to chloride stress corrosion cracking, an issue occurred with the traditional stainless steel tubing.

Monel 400 was chosen for tubing at Douglas Point and Pickering A nuclear units on the base of suitable functionality of this alloy at the fossil fuel based units and economical material. It offers suitable resistance to chloride and caustic corrosion.

However extreme ^{60}CO activation troubles were found in the beginning use of alloy 400, a low cobalt alloy 400 was used in Pickering B.

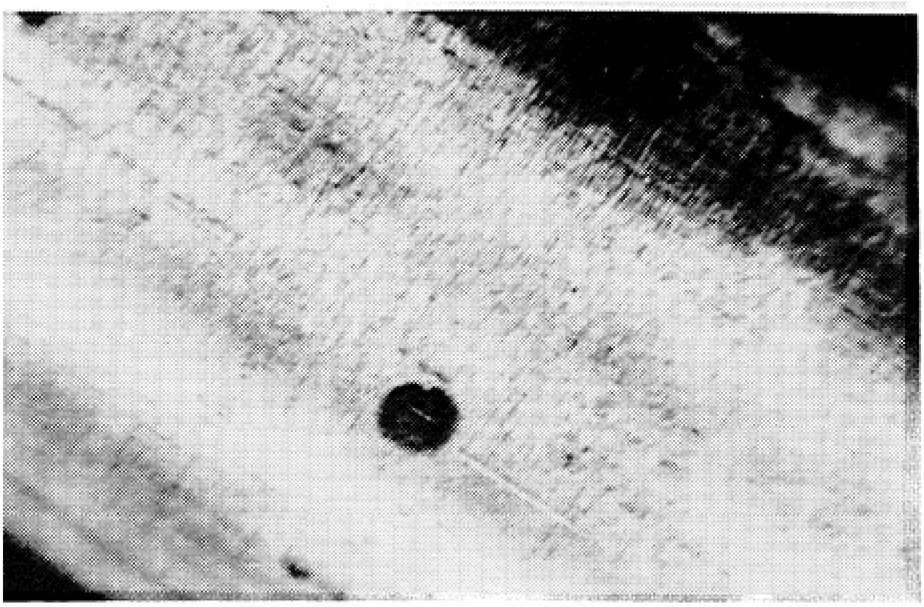
Due to the feasibility of higher oxygen contents in Bruce A heat supply water, and also as an outcome of good performance at NPD, alloy 600 was chosen as steam generator tubing for Bruce A and then for Bruce B.

For the latest Candu unit at Darlington, although alloy 800 was selected on the base of its excellent resistance to intergranular corrosion and stress corrosion cracking in pure water. Its protection from the caustic corrosion is found almost identical as for Inconel 600 and its role to basic radiation areas should be kept small.

Lake water quenched heat exchanger tubing service record

Moderator heat exchangers are needed to discard 90 HW of heat energy from the moderator while normal reactor function. The moderator heat exchangers installed in the units of Douglas Point and Pickering A were made of **Copper-Nickel alloy 70/30** that provided suitable performance and no corrosion occurred after metallurgical damage of tubes discarded from the Pickering A in 1979 and then in 1983. The fretting damaged took place although caused the final replacement of the damaged tubing with another tubing material of Incoloy 800. This substitution damaged after around 2 years of operation due to pitting corrosion due to lake water on the outer dia of tube.

Following figure shows the pitting corrosion of alloy 800.



The pit is visible as tiny black round enclosed by red-brown rings of iron-based accumulations. The metallographic segments across pitted region has shown a large susceptibility to pits to weaken the tube wall. The corrosion seems uniform following the microstructure with annealing two boundaries getting some preference. Certain ions causing the corrosion have not been recognized and the feasible role of microbiological performance has been neither validated nor refused.

The shutdown coolers are needed for discarding heat from the heat supply unit to the lake water while reactor closing and to treat as backup heat sink on the loss of boiler feedwater. Generally these are in a sluggish form with low temperature lake water on the shell.

The closing or shutdown coolers in the entire functional Ontario Hydro nuclear units were made with **Monel 400 tubing**. This material offered suitable performance in Douglas Point, Pickering A and Bruce A without tube failures or considerable corrosion on the discarded tubes.

The tubing surface got pitting attack, although was found 6 months after use to Lake water at the Pickering station B. Wide perforation in the wall noticed within 3 years. Again the corrosion type was localized corrosion in the lake water accumulations.

Some matching were found among pitting corrosion of alloy 800 moderator heat exchanger tubes and alloy 400 shutdown cooler tubing. The pitting attack occurred in the conditions in the mineral accumulations with pits enclosed by rings of red-brown, iron enriched materials. The elemental evaluation of corrosion materials in the pits of alloy 400, although identified one weight % of chlorine and sulfur that was not discovered on alloy 800 pits. Additionally the pit morphology is distinguished considerably among these two alloy grades. The conical pits with big dia to depth ratio were observed in alloy 400.

Through larger magnification, the intergranular corrosion is evident. As stated earlier, alloy 800 pits were weaken and the intergranular corrosion was not noticed.

Alloy 400 shutdown tubing, at the near and virtually same Pickering A unit, offers merely superficial localized corrosion after operation for 13 years. The sole variation in the tubes found at units A and B were the presence of extremely adherent security layer of thickness 6 to 13 microm from the tube mill annealed. The Pickering B station tubing were surface grounded subsequent to annealing to improve ultrasonic check-ability.

Service record of steam generator

The service of Ontario Hydro nuclear steam generators has been found outstanding. Pickering A has experienced one tube damage in around 50 years of service in the reactor that took place in second unit in 1974 and was almost an outcome of production or material imperfection. At Bruce A 14 tubes have needed plugging in around 30 reactor years of service, the damage mechanisms were not completely evident however were doubted to occur because of low cycle fatigue.

Despite of providing outstanding service record, the steam generators were regularly evaluated, often by harmless methods and the outlines are shown as following:

<u>NPD reactor:</u>

In 1979 the power yield of NPD plant rapidly reduced from 25 MWe to 18MWe. A test described the wide accumulations on the steam generator tubing. The steam generator was cleaned chemically and around 900 kg of the material, primarily iron oxide and copper was discarded. The condition of tubing after cleaning was checked and expected to return to operations, heat supply efficiency had become equal to its actual vale and the power supply was again 25 MWe.

The iron and copper oxides were formed because of attack on feedwater system, allows and enter the steam generator at small concentration (below 10 micro-gram per liter) while the standard service. Due to very high feedwater speed, there are considerable magnitudes of this material entering the steam generator annually.

<u>Douglas Point GS</u>

Two parts of steam generator at Douglas Point GS were eliminated throughout the service due to tube damages. After checking around 30% wall thinning was noticed in the highest temperature region of each part.

<u>Pickering GS A</u>

The eddy current testing of steam generators in the Pickering A station showed accumulation around of depth 350mm on the tubesheet in 1979 & 1981. After one year, the samples were evaluated again. The availability of accumulated pile was verified however the accumulations were very hard and merely small samples could be eliminated.

These specimens were observed to be primarily the corrosion materials of feedwater systems. The eddy current testing of tubes in the accumulated area has been unable to find the problem however the susceptibility of the device is not totally good in this zone.

<u>Heat exchanger corrosion evaluation</u>

In the entire heat exchanger tubing damages, the accumulations on the tube surfaces was noticed as a cause of pitting corrosion. The irrelevant accumulations clearly conducted the production of locally severe conditions in the merely benevolent freshwater media.

A vast study has been conducted to retrieve the corrosion data with respect to the particular application environments and to create relationships between immediate lab testing and prolong functionalities. The study factors include electrochemical evaluations, immersion analysis, microbiological analysis, deposit featuring and replication, parametric analysis of alloy chemistry influence and the heat exchanger test rig analyses.

In the basic cyclic potentiodynamic polarization CPP and immersion analyses, Incoloy 800 and Monel 400 described extensive sensitivity to pitting corrosion. The corrosion rate of alloy 400 was found remarkably based on layer stability on its formation mechanical and chemistry. The factors are essential in evaluating the difference between the functional Monel 400 at Pickering stations A and B.

First tests offer a basic lab material study for lake water performance. More work will be conducted basically for field analysis of materials in the heat exchanger simulated rig conditions at the different areas. The rig will be used to receive in-site electrochemical potentials in the tubes and type of variations in the potential due to accumulation.

The lab analyses will be conducted to get a basic understanding of the electrochemistry of layer production and the main polarization of the nature of material in bad conductive electrolyte for example lake water. This study will enable for enhanced trust in extrapolating information received in the lab test to the sites and will create a pit beginning chances and transmission rates for eligible heat exchanger tubing raw materials.

<u>Steam generator corrosion analysis</u>

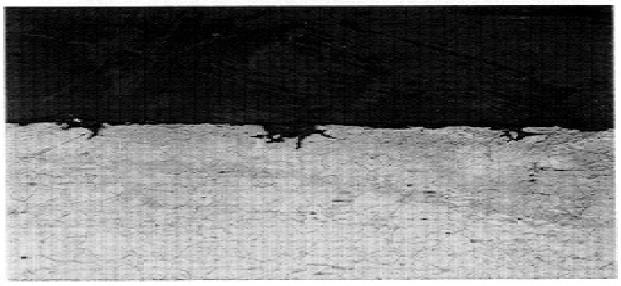
However the functionality of Ontario Hydro's steam generators has been great, corrosion issues in these steam generators are found to be resulting in the vast outages in pressure water reactors in US and Europe. Definitely, some values included in the generator replacement at the price of around hundred million dollars.

The attack on the generator materials is resulted by the availability of chlorine and oxygen in the water steam unit. The main source of ionic contaminants is because of leakage of condenser quenching water in the feedwater unit.

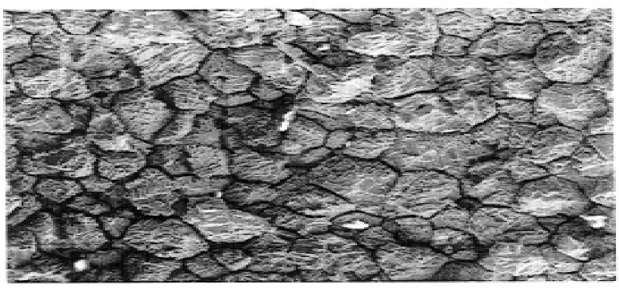
The quenching water utilized by Ontario Hydro is comparatively innocuous, completely dissolved solids below to 200 mg/L and hence extensive steam generator water contaminant contents are normally lower than service limits. Testing, although has described that the vast magnitudes of deposits exist in steam generators at Ontario Hydro stations. Content of ions below deposits is responsible to increase contaminant content by 10(4) over the bulk content, developing severely harmful conditions for steam generator tubing. Hence a steam generator corrosion study was conducted to know the following factors:

Destructive magnitude of corrosion materials of feedwater line entering the steam generator, types of destructive corrosion materials, areas of mostly affected steam generators, tolerable level of condenser leakage, which severe chemicals should be prevented to use and which methods can be used to discard deposits from steam generators and the possibility of harmful effects of these methods.

The study on the content of contaminants and their resulting attacking effects was performed in the lab. The short term testing with very high content of water contaminants was conducted in the static autoclaves whilst the prolong services, refreshed units that offered suitable control of water composition were utilized with low contaminant content. The contaminants have been found to accumulate under the deposits and sludge mass to extents that are severe to steam generators. Pitting attack damage of Inconel 600 tubing and intergranular corrosion of alloy 400 are evident as shown in the following diagrams



Pitting corrosion damage of Inconel 600



Intergranular attack of Monel 400 :

The accumulation procedure was discovered to be a physical process, the chemical behavior of sludge is the second factor. The condenser leakage, although is significantly destructive because ions can accumulate under the deposits by four times of magnitude. The tubesheet, where the parts of tubes are submerged in the sludge, are the portions that are extremely sensitive to corrosion.

Chlorides are the most severe ion found in this study specifically in combination of oxygen, on carbon steel parts as the tubesheet itself. There have been reports from US that sulfur species have caused intergranular corrosion and resulted in SCC of alloy 600. Work is regularized to determine the possibility of this incident in the steam generators of Ontario.

The prevented aqueous EDTA with citric acid and hydrazine, pH maintained with ammonia was found to be an appropriate solvent for cleaning of steam generators. Copper is taken in an individual stage using ammonia solution sparging with oxygen. The choice for generator cleaning is necessarily cost-effective.

The lab tests described that contaminants can accumulate under the sludge stack in a nominal depth of 5cm and they have not influenced the performance of generator till now. The solvent didn't create any damaging effect on alloy 600 generator at NPD, however it is comparatively small and suitable washing was able to be conducted. The analyses conducted to find the influence of solvent residues on the alloys when a system to brought back to operate and hence started working.

The high pressure water streams have also been evaluated in the lab tests as a suitable source to discard sludge piles. The precautions must be followed to work with the tubes directly. Overall the entire concerning factors that generated while the study are answered.

Outline

The consistent heat exchangers are important for the required service of any power unit. A major aspect in their functionality is the integrity of tubing because leakage can cause expensive system outages. The functionality of nickel base alloys in the tubing form for lake water quenching heat exchangers is variable, suitable in specific conditions however bad in others. A reactive study is conducted to receive a better evaluation of the corrosion procedures involved for ameliorative measures to be performed. Similarly the functionality of the nickel based alloys in the form of tubing for steam generators has been outstanding. On the base of experience of other uses, although another study that is anticipatory in nature is conducted to determine potential issue areas and hence to assure regular consistent service.

Heanjia Super-Metals produce the following Nickel species:

Alloy 36	Nilo 36/ Invar 36			
Alloy 42	Nilo 42, low expansion and glass sealing, AMS5683			
Alloy 48	Nilo 48			
Alloy 52	Glass Sealing			
Alloy 80A	Nimonic 80A			
Alloy 90	Nimonic 90			
Nickel 200, Nickel 201		AMS5553		
Alloy C276/Inco C276	Hastelloy C276			
Alloy A286	Inco A-286			
Alloy 400	Monel 400			
Alloy K-500	Monel K – 500			
Alloy 600	Inconel 600	AMS5540	AMS5580	AMS5687
Alloy 601	Inconel 601	AMS5870	AMS5715	
Alloy 617	Inconel 617	AMS5887	AMS5888	
Alloy 625	Inconel 625	AMS5581, AMS5599, AMS5666, AMS5869, AMS5837		
Alloy 718	Inconel 718	AMS5589, AMS5662, AMS5663, 64, AMS5590,, AMS5596, AMS5597, AMS5832		
Alloy X750	Inconel X750	AMS5582, AMS5583, AMS5747, AMS5598, AMS5667, AMS5668,		

		AMS5669, AMS5671
Alloy 800	Incoloy 800	AMS5871
Alloy 800Ht	Incoloy 800HT	
Alloy 825	Incoloy 825	
Alloy B-2	Hastelloy B-2	
Alloy X	Hastelloy X, AMS5587, AMS5588, AMS5755, AMS5754	

Contact us to know more about the corrosion resistant nickel based super alloys.