STAINLESS STEEL IN SUGAR INDUSTRY

A lifecycle perspective

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Corrosion of sugar manufacturing equipment has been among the most important concern of the plant operation in the sugar industry. Stainless steel has emerged as the most suitable material for overcoming most of the problems associated with the sugar industry. This paper is an attempt to explore the various application in the industry with a view to minimizing the life cycle costs for the industry.

What are Stainless Steels

Stainless steels grades are essentially alloys of iron with more than 11% of Chromium These grades may contain additional elements like nickel, manganese, carbon, nitrogen, silicon, etc. They can further be modified for special purposes by addition of molybdenum, titanium, niobium, silicon, sulphur, etc. A wide range of these grades have been developed based on specific requirements. These are classified into following categories based on their microstructure:

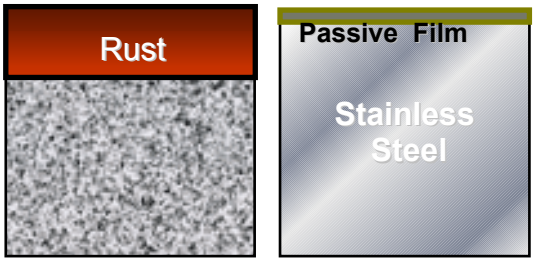

Figure 1: **How stainless Steel works** –Carbon steel, Stainless steel with > 10% chromium forms a passive layer of Chromium oxide

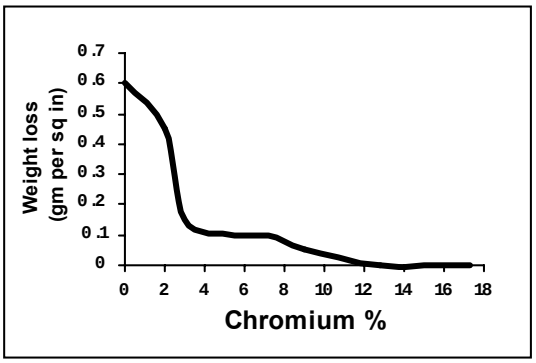

Figure 2 : Effect of Chromium on corrosion resistance, Ref: A J Sedriks "Corrosion of Stainless Steel"

Ferritic Stainless Steel: These are non-hardenable plain chromium grades with chromium content varying from 11% to 28% and with low carbon content. These are magnetic and exhibit better resistance to corrosion than martenstic grades. These grades are employed in applications where the desired formability, weldability and corrosion resistance is between those of martensitic and austenitic types.

Martensitic Stainless Steel are plain chromium grades containing 12% to 18% of chromium with relatively high carbon content (0.1%-1.2%). Initially developed for cutlery, these are well suited for applications requiring high hardness and resistance to abrasion and erosion. These grades are magnetic and display fair cold forming characteristics. Although these can be hardened by air-cooling, oil quenching is sometimes used to assure uniform hardness. These grades can be welded but require stress relieving after welding. They exhibit their best corrosion resistance in hardened condition and perform well in mildly corrosive environments. Martensitic Stainless Grades are commonly used for knife blades, turbine blades, surgical instruments, fastners, shafts, spindles, valves and pins.

COMMON GRADES OFSTAINLESS STEELS
Ferritic : 405, 409, 409M, 410, 430, 436, 439
Martensitic : 410, 415, 420
Austenitic Cr-Ni : 301, 304, 309, 316, 317, 321, 347
Austnitic Cr-Mn : 201, 202, JSLAUS(J1) J204Cu, J4, JSLTube
Duplex : 2205, 2304

Austenitic Stainless Steel These grades are characterized by superior corrosion and oxidation resistance, weldability, ductility and toughness compared to ferritic and martensitic Stainless Steel grades for similar Chromium levels. Austenitic Stainless Steel grades exhibit excellent resistance to atmospheric corrosion, can withstand attacks of most acids. There are two broad categories of Austenitic Stainless Steel – Chrome Nickel (300 Series) and Chorme-manganese (200 Series). Cr-Ni are the largest produced Stainless Steel category globally. Typical applications include food processing, chemical plants, pharmaceutical equipments, Sugar industry evaporator/ pan tubes, architectural, building construction, etc.

Cr-Mn Austenitic Stainless Steel are the fastest growing category in the world because of its high performance to cost ratio. Major grades are : J201, J202, JSLAUS(J1), J204Cu and J4. All these grades have austenitic structure in annealed condition at ambient temperature similar to 18/8 (304). Stainless Steel have higher strength, excellent formability, weldability and good corrosion resistance than mild steel. Due to lower nickel content, these grades are highly cost effective in most applications where 304 is used. Jindal Stainless is the largest producer of chrome manganese Stainless Steel in the world.

Duplex Stainless Steel grades contain relatively high chromium (18%-28%) and moderate amounts of nickel (1 to 8%). This combination of ferritic and austenitic structure is called Duplex. These grades exhibit high resistance to stress corrosion cracking and chloride ion attack and have higher yield strength than that of austenitic or ferritic grades. These grades are used in marine applications, offshore platforms, paper and pulp industry, chemical, petrochemical and desalination plants.

Figure 3 : Typical Composition of common Stainless steels for sugar industry.

(All figures in %)

Grade	Cr	Ni	Cu	Mn	N	C max
304	18-20	8-10.5	-	2	0.1	0.08
JSLAUS	16-18	4-6	1.5-2	6-8	0.1	0.08
204Cu	16-17.5	1.5-3.5	2-4	6.5-9	0.1-0.2	0.1
J4	15.5-16.5	1-2	1.5-2	8.5-10	1-2	0.1
409	10.5-11.8	0-0.6	-	0-1	0.03	0.03
MS		-	-	-	-	0.10

Corrosion in Sugar Industry

Most of the equipment is made in Sugar industry from Mild steel. This has resulted in the corrosion becoming a major factor to be addressed in the Sugar industry.

Color in sugar due to Iron Oxide: In India, plantation white sugar is manufactured, where, generally no further refining is carried out. Therefore it is important to minimize color imparting impurities (corrosion) in the process equipment. It is estimated that about 20-25 kg equivalent of Fe_2O_3 is mixed in the juice for every 1000 tones of Cane processed through sulphitation process. (Source: P Honig, Principles of Sugar Technology Part-I). Due to this corrosion, the color of juice darkens resulting in loss of whiteness.

Types of Corrosion

- **Atmospheric Corrosion**
- **Galvanic corrosion**
- **Pitting corrosion**
- **Crevice Corrosion**
- **Stress corrosion**
- **High temperature corrosion**
- **Corrosion erosion**

Continuous Working : As the sugar industry is working continuosly during the season, the breakdown cost is very high (of the order of Rs 4-10 lacs/ hour depending upon the size of plant). This makes the breakdowns unaffordable and in many processes, the standby equipments are provided resulting in higher capital cost.

Off Season Maintenance: One of the major reason of corrosion is the atmospheric oxidation of mild steel equipment during the off-season due to exposure to hot and humid conditions after the process is shut down. During restarting, most of this rust is transferred to Sugar which needs re-melting to reduce wastage.

Perishable Raw Material: The sugarcane is a perishable material and deterioration starts soon after harvesting. Therefore it becomes important that the sugarcane is processed as fast as possible (generally target is – 72 hrs after harvesting). Any breakdown in the equipment leads to a fall in recovery from the sugarcane, extra color formation and the loss of sugar from the in-process material. Besides this, there is a problem of managing the huge stock of sugarcane-laden wagons which may create law and order issues.

Hygiene : The tanks and equipment fabricated from the mild steel is not conducive to hygiene and the resultant sugar made from processes commands lower realization in the competitive market.

Due to these reasons, tackling the issue of corrosion has become a major challenge the world over. Most plants across the world have switched over to various grades of Stainless Steel. In India also, the plants engaged in manufacture of refined sugar have started shifting to the use of stainless steel in various equipment.

Why use Stainless Steel:

Stainless Steel not only offers higher resistance to corrosion than conventional material like Mild Steel, Cast Iron, Brass, etc. but also is better in terms of strength and properties like abrasion resistance, etc. Some of the reasons why stainless steel is the better material are as follows:

1. **Low / Negligible corrosion** : The Chromium oxide passive layer formed is resistant to most types of corrosive media (depending upon the grade used). Besides this, the layer is self healing in that any damage to this layer is self repaired in the presence of Oxygen in the atmosphere.

Grade	I_{Corr} (µA)	Corr rate (mmpy)	$I_{crit.}$ (µA)	E_{Pit} (mV)
MS	159.5	3.71	7765.5	-
409L	22.4	0.52	18.94	242
Brass	15.2	0.38	163.60	-140
430	17.4	0.40	19.28	166
JSL-Tube	13.3	0.31	14.30	146
J4	7.1	0.16	8.52	140
204Cu	2.5	0.05	7.96	690
JSL-AUS	1.7	0.04	6.19	855
304	0.046	0.01	3.51	460

Table 5 : Potentio dynamic corrosion results in sugar cane juice at room temperature (23 ^{0}C)

Merit consideration:

1. Lower is the I_{Corr} value, lower is the corrosion rate of the material.
2. Lower is the I_{Crit} value, faster the material passivates and better is its corrosion resistance.
3. Higher is the E_{Pit} (Pitting potential), higher is the resistance of a material against pitting.

2. **Strength:** Stainless steel is stronger than mild steel. As a result, in most cases it is possible to reduce the plate thickness by 20 - 30% without compromising on the structural strength. Also it offers better abrasion resistance than mild steel and hence it offers much higher life.

3. **Low corrosion allowance:** The average life expectancy of Stainless steel is 6 to 10 times that of Mild steel. Since the material is resistant to most media, there is no need to provide for corrosion allowances. This further brings down the equipment weight.

4. **Low maintenance:** Since in Stainless steel, no coatings/ protective painting is required, therefore, this recurring expenses are avoided

5. **Superior hygiene:** Stainless Steels are the recommended material for hygiene related equipment like food processing, pharmaceutical, etc.

6. **Better heat transfer:** Stainless Steel offers equivalent / better heat transfer than other material like brass etc. Also, since it has much less problem of scaling, there is little deterioration between the scheduled cleanings. Also, wear loss due to cleaning using cutter for descaling of brass tubes is reduced appreciably

7. **Lower operating cost** : Use of stainless steel can bring down the breakdown incidence appreciably resulting in lowering the cost of operations.

8. **Lifecycle cost:** It is established that the Stainless steel offers lower lifecycle cost as compared to mild steel. It is found that the savings by replacing mild steel with Stainless steel can result in 30-100% savings over the lifetime of the equipment

Factor	Mild Steel	Stainless steel
Material Price	Low	High
Weight of Material used	High	Low
Fabrication and Installation Cost	Low	Marginally High
Maintenance Costs (periodic)	High	Low
Replacement Frequency	High	Low
Cost of Lost Production	High	Low
Residual (Scrap) Value	(Low)	(High)

Figure 7 : Lifecycle cost comparison of Mild steel and Stainless steel

9. **Safety :** Not the least, stainless steel enhances safety throughout the plant due to reduction in accidents/ leakages.

Figure 8 : Typical Properties of Various grades of Stainless steel

Grade	Tensile Strength (Mpa)	Yield Strength (Mpa)	% Elongation	Hardness (HRB)
304	515	205	40	92
JSLAUS	550	205	40	95
204Cu	620	310	40	95
J4	650	325	40	98
409	450	275	20	90
MS	240-400	170	25	60-65

Replacing Brass Tubes with Stainless Steel Tubes

The world over most sugar mills have switched over to Stainless steel tubes. This is happening at a fast rate in India also. It is calculated that just by replacing the brass tubes with SS tubes (204Cu), a 5000 TCD plant can save upto **Rs 3 Crores** in the initial investment and additional upto **Rs 1 Crore** in recurring maintenance cost annually. The details of the comparison are provided below.

Figure 9 : Comparison of Brass vs Stainless steel Tube

Factor	Brass	Stainless Steel
Strength	Higher thickness-1.6/2 mm	Low thickness -1.2mm
Heat Transfer	Good	Good
Scaling	High	Low
Cleaning	High frequency	Less frequent
Initial cost	High	40% of Brass
Scrap value	Upto 75%	Upto 50%
Total life	2-4 season	10-12 seasons

Suggested Grades for various applications in Sugar Industry

The following grades are suggested for different applications in sugar industry after having consultation with Sugar mills, machinery manufacturers and industry consultants. This is not an exhaustive list and sugar mills can add more applications based on their confidence level after initially carrying out these modifications.

Factors affecting the selection of grades:

The following are the factors determining the selection of specific grade of stainless steel.

Abrasion-Erosion: Physical attack or destruction by mechanical factors like Sugarcane handling, wear and tear of conveyor, cutting and milling, etc comes in this category. For these application the material, which is hard and tough to withstand these mechanical forces, is needed. Stainless steels Ferritic / martensitic grades like 409M, 410, 420, are suitable in these working conditions as they offer better dry and wet-abrasion resistance, good slideability along with moderate corrosion resistance.

Acidic Corrosion: Due to the low pH of raw mixed juice and presence of SO_2 and other chemicals during processing, the applications involving higher corrosion should use the

austenitic grades like J4/JSLAUS, 204Cu and for some critical applications, 304 / 316 may be considered.

Guide for Stainless Steel grades in different processes

This guide suggest the Stainless Steel grades keeping in view the optimum performance to cost ratio.

S	Equipment	Working Environment	Existing Material	Suggested Material	Benefit
1	Cane Conveyor : Side plates, Chain links, pin, bushes & rollers	Abrasion, slidability, wear, corrosion	Mild Steel	J4	Increase in life, reduction in b/down
2	Milling : Donnelly chutes	Abrasion-Corrosion	MS	J4	Longer life
	Rake elevators, side plates, base plate	Corrosion	MS	J4	Longer life/ Hygiene
	Juice Trays/ Gutters	Corrosion	MS, Al, Cu lined	J4 204Cu	Hygiene/ longer life/ lower cost
	Trough & Screw Conveyors	Abrasion, corrosion	MS	JSL AUS	Longer Life
	Lining below Milling Head Stock	Corrosion	MS	JSL AUS	-do-
	Lining below Milling bearing base	Corrosion	MS	J4	-do-
	Bagasse carrier and conveyor	Corrosion	MS		-do-
4	Sulphur Station Juice Tanks/ pipelines Juice sulphitation	SO2 corrosion, High temperatute	MS/ cast iron	204Cu	Longer life
5	Juice/ syrup Tanks	Corrosion	MS (8mm)	J4	Avoid discoloration due to corrosion
6	Juice Heaters, Evaporator, Pans	Corrosion	MS	204Cu	No color from Fe2O3, reduced

					weight, longer life of SS tubes due to no galvanic corrosion
7	Tubes – Juice Heater, Evaporator, Pans	Corrosion, SO2 gas in juice heater tubes, high temp, scaling	Brass	204Cu	Reduced cost-savings of approx Rs 3 cr in initial investment and Rs 40-50 lacs in recurring maintenance for a 5000 TCD plant
8	Saveall, Vapor line, Condensers, Tail pipes	Corrosion due to – Acidic vapor, water vapor, High velocity	MS	204Cu	Longer life
9	Pipelines	Heavy corrosion	MS	JSL Tube	Longer life and safety due to no leakage
10	Hoppers	Abrasion, sugar looses lusture	MS/ Spring steel	J4	Wear resistance
11	Crystallizers and Centrifugals	Corrosion, iron contamination	MS/ SS	204Cu	No iron contamination
12	Whirling tank Raw juice Tanks Molasses tank/ cover Unsulphured syrup Sulphured syrup tank	Corrosion	MS	204Cu	Corrosion resistance and no discoloration, reduced painting
13	Juice Pumps	Corrosion	MS/ Cast iron	204Cu	Corrosion resistance/ low b/down
14	Vacuum filters	Corrosion	MS body with SS screens	204Cu	Corrosion resistance

Cost advantage of using Stainless steel in Representative application

The following table is prepared highlighting the benefit of using Stainless steel vs the existing norms for material. The advantages are compared basis the increase in investment due to the material cost versus the increase in the expected life (conservative estimates). The fabrication

costs have been assumed to be in proportion to the increase in cost and are not considered in the calculations.

In addition to the benefits given below, the savings will accrue due to less breakdowns, savings in the annual painting and the cleaning cost, regular repairs, etc.

Equipment	**Material**	**Plate Thick-ness**	**Weight (tons)**	**Material Cost * (Rs/ Kg)**	**Equip Cost (Rs '000)**	**Expe-cted Life**	**Life cycle Costs**	**Lifecycle cost % (SS/MS)**
Cane Carrier Slat side plates	MS	6-8 mm	17	40	680	3	1360	
	J4	5 mm	11	90	990	6	990	
	Benefit				-310		370	73%
Donnelly Chutes	MS	5-8 mm	6	40	240	3	640	
	J4	4mm	4	90	360	8	360	
	Benefit				-120		280	56%
Bagasse Carrier Side Plates	MS	8 mm	15	40	600	2	1500	
	J4	5mm	11	90	990	5	990	
	Benefit				-390		510	66%
Sulphur Station	MS	8 mm	10	50	500	3	1000	
	204Cu	4 mm	5	120	600	6	600	
	Benefit				-100		400	60%
Saveall	MS	6	6	50	300	3	1000	
	204Cu	3	3	120	360	10	360	
	Benefit				-60		640	36%

Relative Savings for Material for Juice Tanks, pan bodies etc

Equipment	Material	Plate Thickness	Weight (tons) for 100 sqm Area	Mat'l Cost*	Total Material price (Rs '000)	Expected Life	Life cycle Costs	Lifecycle Cost % (MS=100 %)
Juice Trays, Gutters,Bodies of Tanks, evaporators etc	MS	6	4.2	40	168	2	840	100%
	AL lined	2.5+ 6mm	4.9	200,40	308	10	462	55%
	J4 lined	2+ 4mm	4.4	90, 40	245	10	367	44%
	J4	4	2.8	90	252	15	252	30%

* Material Cost includes estimated fabrication cost also.

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1. Corrosion resistance of Conventional and New Material of construction, H A Shah, S K Sondhi, P K Aren , 39th Annual Convocation of STAI

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