

# Use of Chrome Manganese Austenitic Stainless Steel in Sugar Industry - A Conceptual Approach

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The acidic nature of the sugar cane juice and toxicity associated with gaseous products encountered in the manufacture of sugar, pose a serious challenge to sugar industry. Trend has been to progressively use stainless steels to overcome the problem. The most common stainless steel grades currently being used are AISI 304 and 3Cr12/AISI 409. Substantial use of 304 will render the investment cost very high. Based on an elaborate corrosion study in sugarcane juice, use of four indigenously manufactured Chrome-Manganese austenitic stainless steels are suggested to keep the performance-cost ratio reasonably high

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Sugar manufacturing in India and in most of the tropical countries is a booming enterprise. Sugar production being a seasonal cyclic activity, continuous uninterrupted production in a narrow time period is essential for viability of a plant. Therefore, material plays a very important role in production cost economy. The traditional structural material, carbon steel is progressively being replaced by stainless steels in order to increase the life of vital components, reduce unplanned down time, reduce annual maintenance cost and above all to improve the hygienic condition of the mill and the product. Among the stainless steels, the austenitic type 304 and ferritic type 409L are currently popular in sugar industry in India. In Australia, South Africa and in some European countries, 3Cr12, a 12%Cr steel is a major stainless steel material used in sugar mills. The objective of using stainless steel is to at least increase the life span of components to 10 years from present level of 3-4 years where carbon steels are used.

The essential properties that are looked for are:

- a) Corrosion and erosion resistance
- b) Abrasion resistance – Particularly resistant to wet abrasion
- c) High strength and light weight
- d) Good fabricability
  - Welding
  - Bending
  - Cutting & Shearing
  - Forming
- e) Good white colouration
- f) Availability at affordable cost

The type 304 fulfils all the above attributes except that it is an expensive material and its price is extremely sensitive to the rise or fall in international nickel price. Type 409 is largely used in handling dry or semi-dry products mainly to exercise cost economy. However many users face difficulties in fabrication of 409 and use type 304 in non critical areas adding cost to the project.

With a twin objective of exercising cost economy in building up of new sugar plants and ensuring an uninterrupted indigenous supply source, Jindal Stainless Ltd. has conducted extensive lab studies on some Chrome-Manganese austenitic stainless steel grades as possible substitute to type 304 or 409L as the case may be

The grades selected for the studies were

- JSL AUS – a 16Cr-4Ni austenitic stainless steel
- J204Cu – a 16Cr-1.5Ni austenitic stainless steel
- J4 – a 15.5 Cr-1Ni austenitic stainless steel
- JSL-Tube – Austenitic Nickel-free stainless steel
- 409L – a 11% Cr ferritic stainless steel for comparison
- 304 - 18-8 stainless steel for comparison

The grade JSL-AUS, 204Cu, J4 and JSL-Tube generally belongs to 200 series of austenitic stainless steels with minor modification in composition to maintain cost-performance balance. These alloys are endowed with high strength, good drawability, weldability and corrosion resistance at a lower cost. These have been successfully used in several applications covered earlier by AISI 201, 301 and 304. On account of their higher strength, they generally also exhibit superior wear, erosion and abrasion resistance compared to Chrome-Nickel grades.

These grades contain Chromium (15.5%-18%), Nickel (upto 5.0%) along with appropriate combination of Manganese, Copper and Nitrogen.

Copper reduces  $M_s$  &  $M_d$  temperatures sharply, increases the stacking fault energy and reduces work hardening rate<sup>1</sup> which facilitates cold rolling as well as forming. Copper also improves chloride stress corrosion cracking resistance in relatively mild conditions such as hot water environment<sup>2</sup> as well as in boiling magnesium chloride solution. It improves corrosion resistance of stainless steel in sulfuric acid environment<sup>3</sup>. Thus copper has a beneficial effect on formability, drawability and corrosion resistance in certain media. Copper has also been added to several 300 series grades to improve deep drawability, and corrosion resistance. Jindal Stainless supplies grades J4 (modified UNS S20430), J204Cu (UNS S 20430) & JSL AUS (modified UNS S20100) which represent drawing quality, deep drawing quality and extra deep drawing quality stainless steels respectively. JSL-Tube has similarity with NHS104 developed by Nisshin steel, which has more rust resistance than that of AISI 430 while having good weldability and formability. Chemical compositions and the mechanical properties are shown in table-1 and table-2. respectively.

As can be seen, the tensile strengths of JSLAUS, J204Cu, J4 and JSL-Tube are 20-30% higher than that of type 304 while the ductility is almost similar. This gives a good incentive for weight reduction in design giving opportunity for cost saving. However, since these grades require about 20% higher force for bending and forming, the equipment capacity available in the shop floor needs to be examined.

**Table1: Chemical Composition**

GRADE	Elements	%C	%Mn	%S	%P	%Si	%Cr	%Ni	%N	%Cu
J4	Min.	-	8.5	-	-	-	15.5	1	-	1.5
	Max.	0.1	10	0.005	0.06	0.75	16.5	2	0.2	2
J204Cu	Min.	-	6.5	-	-	-	16	1.5	0.1	2
	Max.	0.1	9	0.005	0.06	0.75	17.5	3.5	0.2	4
JSLAUS	Min.	-	6	-	-	-	16	4	-	1.5
	Max.	0.08	8	0.005	0.06	0.75	18	6	0.1	2
JSL- Tube	Min.	-	9.5	-	-	-	15	-	0.1	1.5
	Max.	0.1	10.5	0.01	0.08	0.5	15.5	0.4	0.2	2
409L	Min.	-	-	-	-	-	10.5	-	-	-
	Max.	0.03	1	0.03	0.04	1	11.75	0.6	-	-
AISI 304	Min.	-	-	-	-	-	18	8	-	-
	Max.	0.08	2	0.03	0.045	0.75	20	10.5	0.1	-

**Table2: Mechanical Properties**

GRADE		UTS (Mpa)	YS (Mpa)	% Elongation	Hardness (HRB)	Erichsen Cupping Value
J4	Co. Std	650 min.	325 min.	40 min.	100 max.	-
	Typical	860	480	50	96	11.8
J204Cu	Co. Std	650 min.	310 min.	40 min.	100 max.	-
	Typical	795	415	50	96	12.1
JSL AUS	Co. Std	620 min.	265 min.	40 min.	95 max.	-
	Typical	665	310	55	87	12.9
JSL-Tube	Co. Std	650 min	325 min	40 min	100 max	-
	Typical	850	450	62	98	11.8
409L	Co. Std	360 min.	175 min.	25 min	80 max.	-
	Typical					-
AISI 304	Co. Std	515 min.	205 min.	40 min.	92 max.	-
	Typical	560	262	55	83	13.1

**Corrosion Studies**

The corrosion behaviour of Chrome-Manganese austenitic grade has been extensively studied in acids encountered in different food

processing media at room temperature. It was also investigated in salt solution. The corrosion rates were very low and close to 304. The results of these studies are summarized in table-3

**Table-3: Corrosion in Food Application Media**

Test Media	Corrosion rate (mmpy)					
	J4	J204Cu	J201	JSL AUS	301	304
3% NaCl for 720 hrs at RT (25°C)	A	A	A	A	A	A
3% NaCl for 100 hrs at Boiling Temperature.	A	A	A	A	A	A
0.5% Citric + 0.5 % Tartaric for 720 hrs at RT	A	A	A	A	A	A
0.5% Citric + 0.5 % Tartaric for 100 hrs Boiling	A	A	A	A	A	A
0.5% Acetic + 0.5% Lactic for 720 hrs at RT	A	A	A	A	A	A
0.5% Acetic + 0.5 % Lactic for 100 hrs at Boiling Temperature.	A	A	A	A	A	A

## Salt Spray Test (As per ASTM B117)

<b>Test Media</b>	J4	JSL-AUS	J204Cu	JSL-Tube	304
<b>In NaCl environment (for 120 hrs)</b>	A	A	A	A	A

A < 0.1 mmpy, B – 0.1-1 mmpy, C – 1-3 mmpy, D – 3-10 mmpy, E > 10 mmpy<sup>4</sup>

### Corrosion in sugar cane juice –

In the context of sugar industries, an elaborate study was conducted to assess the behaviour of these grades in sugar cane juice

### Experimental work:

The corrosion studies include

- Room temperature corrosion
- Corrosion at boiling point
- Corrosion at constant temperature bath (70°C)
- Salt spray tests in 3% NaCl

Freshly prepared sugarcane juice with pH value 5.3 was used for the study. The study points out that austenitic Chrome-Manganese grades behave fairly well in all the above conditions (Table 4).

The weight loss values were compared with 304 and 409L. As per merit of gradation, based on corrosion resistance in sugarcane juice, the

performance of the grades under investigation followed the following trend in descending order while falling in the quality spectrum 'A'.

**304 > JSL AUS > 204Cu > J4 > JSL-Tube > 409**

In room temperature, the alloys were held for 120 hours in solution of pH falling from 5.3-4.5. No stain was observed in 304, JSL AUS, 204Cu and J4 while 409L developed bluish stain on the surface and JSL-Tube developed light brownish tint. In 3% NaCl fog test, no pitting was observed in all the above grades after holding for 120 hrs. However, initiation of corrosion was observed on 409L surface followed by light corrosion on J4 samples. JSL-Tube behave better than J4 with light edge colouration. In constant temperature bath (70 °C) after holding 120 hours, 409L developed blue surface and JSL-Tube developed light brownish colour. Surface of all other grades remain unaffected.

**Table-4 Corrosion rate in different operating conditions**

Test condition	Weight loss (mmpy)					
	J4	JSL AUS	204Cu	JSL-Tube	409L	304
<b>Room Temp. 27 °C pH 5.3 - 4.5</b>	0.000791	0.000437	0.000682	0.001121	0.001961	0.000098
<b>Boiling Temp. 98 ± 2 °C pH 5.3 - 5.5</b>	0.002871	0.002137	0.002472	0.00298	0.010016	0.000219
<b>Constant bath Temp. 68 ± 2 °C pH 5.2 - 5.4</b>	0.001724	0.001137	0.001314	0.001921	0.005112	0.000208
<b>Salt spray 3% NaCl</b>	0.000257	0.000218	0.000287	0.000288	0.001211	0.000075

**Suggestions for alternative materials:**

In Fig-1 a general process flow for production of sugar comprising double sulphitation is shown indicating pH condition at different sections. Comparative corrosion rates encountered in various areas were earlier studied by Ram Kumar et al of National Sugar Institute, Kanpur<sup>5</sup> using mild steel and brass samples. The published results are summarized in Table-5. According to the studies highest corrosion rate (mdd) was found in mixed raw juice handling area. Mild steel corroded 17.8 times more than brass. Lower corrosion rates (mdd) were observed in final molasses handling area wherein mild steel corroded 4.4 times more than brass. Stainless steels being more corrosion resistant to brass, use of stainless steels

will definitely bring cost-performance synergy in sugarcane industry. Sri V.Singh has explicitly expressed this view while dealing with corrosion in sugar cane industry<sup>6</sup>.

The raw mixed juice handling, sulphitation, boiling house, clarification and vacuum filtration as well as the associated condenser system are subjected to more aggressive conditions. The tubes in these areas not only carry corrosive acidic fumes consisting SO<sub>2</sub>, CO<sub>2</sub>, O<sub>2</sub> and ammonia, but also experience thermal load. Systems that handle clear juice, evaporation chambers, pan boiling and centrifuge encounter less corrosive condition and lower temperatures. Other areas handling dry sugar like hoppers, storage bins are relatively less critical from the point of corrosion, but encounter abrasion and wear.

**Table5:** Medium Analysis of Cane sugar Manufacturing Station & Corrosion rates encountered in mild steel and brass<sup>5</sup>

S.No.	Station/medium	pH	Temperature °C	Av.Corrosion rate in MS (mdd)	Corrosion rate in brass (mdd)
1	Condenser water	6.8	41	401.91	26.75
2	Mixed (raw) juice	5.5	29	942.33	53.54
3	Sulphitated juice	7.1	64	213.18	24.30
4	Classified juice	6.9	98	655.50	38.79
5	Filtered juice	6.5	76	734.89	67.06
6	Sulphitated juice	5.1	46	405.18	84.75
7	Final molasses	5.7	45	100.65	22.95

Considering the above demanding conditions a cost effective materials management for sugar mills is suggested below

### Sheet metal

**304** : sulphitation and clarification segment including boiling house (102°C), vacuum filter, condenser and syrup tank

**204 Cu** : raw juice handling, mixed juice tank, boiling house, clear juice tank, evaporation chamber, pan boiling house, crystallizer and centrifuge

**J4** : hopper, storage bin and all dry handling section

### Pipes & Tubes

**JSL-AUS/304** : condenser pipeline and vac. filter pipeline and clarifier heat exchanger tubes

**204Cu** : Calandria pipes and evaporation, pan boiling, crystallization and other wet circulating areas

**JSL-Tube** : all dry air pipelines

The mill that finds limitations in bending and forming of heavy sections of 204Cu or J4 with existing machinery can opt for JSL-AUS because it is softer than J4 and 204Cu and requires lower force during forming and bending

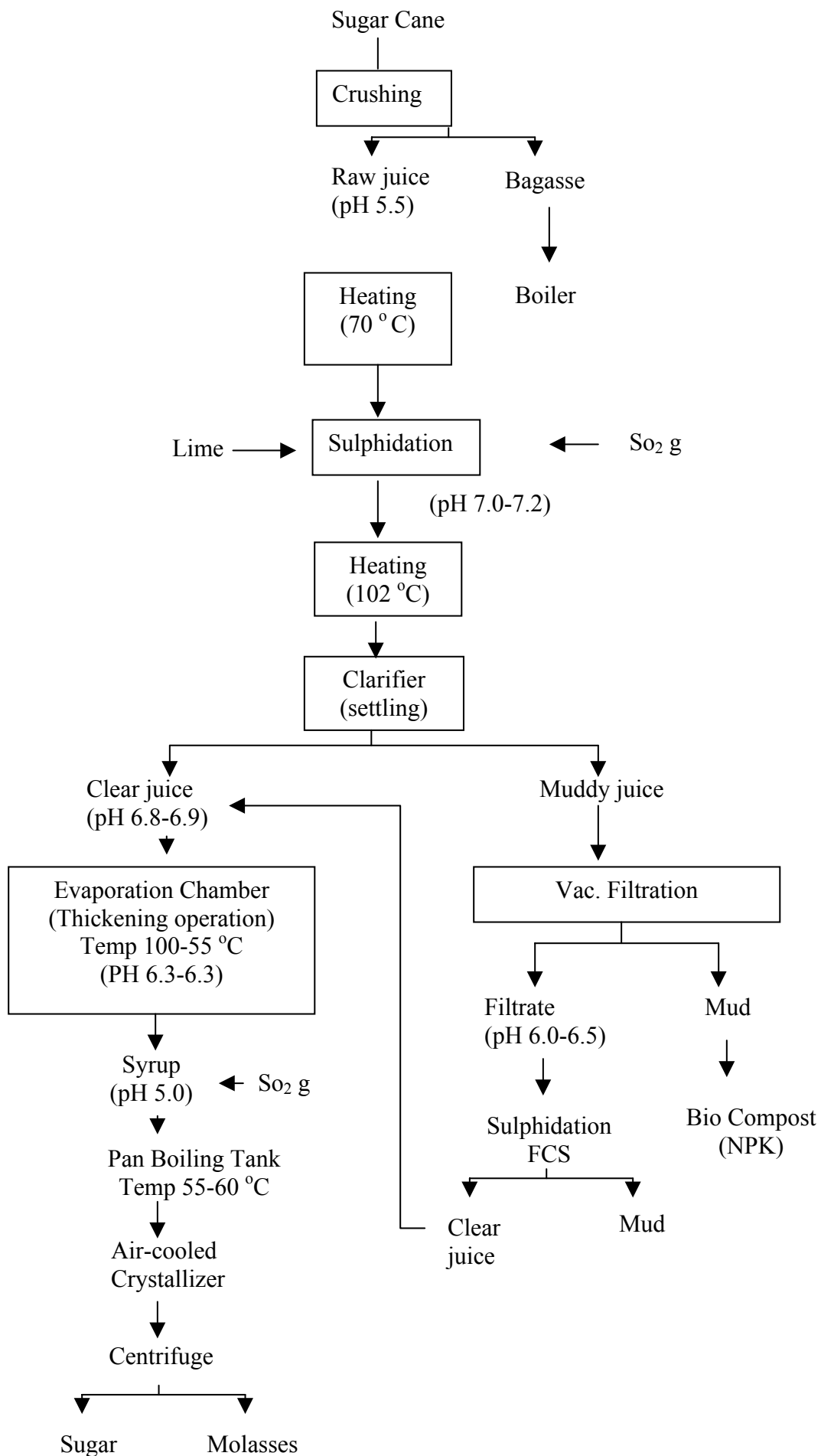
### Conclusion:

The Chrome-Manganese austenitic stainless steels containing low nickel hold great promise to provide a viable cost effective alternative material system in sugar processing industry. The austenitic structure is known for its strength, ductility, formability and weldability and hence no problem is anticipated in making welded structure using these materials. Moreover these alloys demonstrate superior corrosion resistance in sugar cane juice

compared to 409L. Their high strength coupled with higher hardness gives better abrasion and wear resistance. The strength and toughness combination provides bonus for cost reduction by way of thickness reduction in design. It is, therefore, time that a beginning is made to use these materials judiciously for techno economics gains.

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**Fig. 1 – General Process Flow For Manufacturing of Sugar**