International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2019): 7.583

Suitability of Some Low Cost Stainless Steels as Fabrication Material in Cane Sugar Industry

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Abstract: ***Corrosion is the deterioration or destruction of a metal by the surrounding fluids by chemical or electrochemical reaction. Corrosion of process equipment & structures is a common problem in sugar industry too. The effect of some of the process parameters (pH, temperature and Brix) on corrosion rate of different stainless steel alloys in sugar cane juice have been studied. It has been found that the behavior of all the steel alloys (S. S -1, S.S -2, S.S -3 and S.S. -4) with respect to corrosion rate is almost similar with variations in process variables. However, the colour development in cane juice is more in case of S.S. -2 and S.S. -4 as compared to S.S. -1 and S.S. -3.***

Keywords: Stainless steel (S.S.), corrosion rate (mdd), colour (ICUMSA)

1. Introduction

The sugar industry like other process industries encounters the corrosion problem at most of the steps in conversion process of sugar cane to sugar [1], [16]. In a sugar factory, most of the process equipments are operated at elevated temperatures, higher hydrostatic head, higher flow rates and either in acidic or alkaline medium [10]. Due to continuous use under such operating conditions, the wear of equipments increases gradually due to corrosion and erosion. Scientists from various countries have reported the corrosion problem station wise in cane sugar manufacture and suggested few preventive measures also [9], [12]. In India, losses due to corrosion in sugar factories were estimated to be around over 10 billion which may be much higher at present [11]. The problem has assumed greater proportions in Indian sugar industry because of processing technology used i.e. Double Sulphitation Process.

In this process, the processing is carried out at lower pH & higher temperatures as well at some unit operation resulting is higher corrosion rates. In modern global scenario the quality of sugar has become most vital factor. Higher corrosion rates at various stages due to one or other reason may enhance colour development owing to its reactions with polyphenols present in process liquors [7], [13]. Factories producing refined sugar, use stainless steel essentially as fabrication material due to sugar quality and it is becoming very common in plantation white sugar factories also. Stainless steel is being used as tube materials in pans, evaporators and juice heaters. It is also being used in fabrication of juice and syrup storage tanks. The commonly used stainless steel in sugar factories has 7-8% Ni and its initial cost is very much on the higher side as compared to mild steel. The present study deals with the study of corrosion rates of different stainless steel alloys in sugar cane juice with regards to various process variables like pH, temperature and Brix. The effect of corrosion on development of colour has also been studied and results are discussed.

2. Materials & Methods

2.1 Preparation of Specimen

Rectangular specimens of same size of different S.S. alloys have been taken for the study. The composition of stainless steels under study is given in Table -1.

Table 1: Composition of Stainless Steels under Test

S. No	Chemical Composition in % wt.	S.S Alloys			
		S.S-1	S.S-2	S.S-3	S.S-4
1	C	0.09	0.061	0.071	0.094
2	Mn	9.0	0.88	7.63	9.49
3	S	0.005	0.004	0.005	0.004
4	P	0.06	0.033	0.055	0.053
5	Si	0.5	0.34	0.27	0.3
6	Ni	1.04	8.04	4.06	0.25
7	Cr	15.5	18.19	16.4	14.89
8	Cu	1.6	0.3	1.69	1.63
9	Mo	0.06	0.14	0.16	0.05
10	N	0.2	0.1	0.1	0.2
11	Fe-Balance	71.945	71.912	69.559	73.039

The specimens were drilled at the center of upper edge to provide suspension holes of 1 mm diameter. The edges of the specimens and the suspension holes were rounded off to remove burrs and were smoothened. The surface of the specimens was finished by rubbing successively with 0, 00 and 000 grade emery papers. The specimens were abraded first in the length wise direction then across the width and finally using a circular motion. They were then wiped with cotton to remove process of adhering metal powder. The specimens were degreased by wiping with cotton soaked in acetone. They were then dried and weighed before exposure.

a) Experimental:
The experiments were conducted to study the effect of variations on quantum of corrosion in cane juice pH, temperature, concentration (Brix) and effect on colour (ICUMSA) of cane juice. During the experiment all the parameters were kept constant except for one which was varied.

All the experiments were conducted with juice obtained by crushing fresh samples of sugar cane in laboratory crusher. To avoid the effect of microbial contamination during the experiments the freshly crushed cane juice was sterilized at 15 psi steam pressure for 30 minutes.

A total immersion test was adopted for analyzing the parameters [8]. Weighed specimens were exposed to cane juice in 250 ml. conical flasks under appropriate conditions and set aside for 360 hrs. in a sterilized chamber. For every value of the parameter studied, 3 specimens of each steel alloy were immersed and results of average value of 3 samples have been presented in graphs.

After completion of the exposure period, the specimens were withdrawn, rinsed for a few seconds in running tap water and the adherent corrosion products removed by hard brushing followed by immersion in distilled water. The specimens were dried and reweighed. The weight loss was measured and corrosion rates calculated in mg/sq.dm/day (mdd).

b) Juice Analysis

The juices after sterilization were analyzed for pH, temperature and Brix. All the analysis was done according to the standard procedures [4]. The juices had been analyzed before and after the sterilization but no significant change in the above mentioned parameters was observed due to the sterilization. Hence only the results of sterilized juice have been reported.

For measuring absorbance (colour), double beam UV-visible spectrophotometer (Chemito model Spectascan UV-2600, 220V, 50c/s, 300 made in Germany) was used. All weighing was carried out on single pan digital (LCD display) electronic balance (Metler 200 AE, 230volt, 50c/s). All the chemicals used in the investigation were of analytical grade. Brix was measured by Brix hydrometer (made in Germany).

c) Effect of pH

The pH of the sterilized juices was varied in the range of 3-8 by adding acetic acid or NaOH. For controlling the natural changes in pH of the juices, it was noted every 24 hrs. and adjusted with NaOH or acetic acid during the experimentation.

d) Temperature Variation

After setting up the experiment, conical flasks, containing juices and steel samples were placed in water baths maintained at temperatures of 30°C, 50°C, 70°C and 90°C. To compensate for evaporation, distilled water of the same pH values was added once every 12 hrs to each flask.

e) Effect of the Solids Concentration (BRIX)

Cane juice of 20 -22° Brix was taken and samples diluted to different Brix with distilled water. Addition of the distilled water in different amounts varied the concentration of dissolved oxygen so this was brought to a constant value by re-saturating all the samples of different Brix after sterilization.

f) Colour Determination

Three samples of each grade of S.S were tested for colour determination as per ICUMSA prescribed procedure. Fresh cane juice from lab crusher was taken and colour values were measured before exposure to S.S. The S.S. samples were suspended for 72 hrs. After exposure period, the S.S samples were withdrawn and the juices were analyzed for colour determination. The average colour values of all the samples of each S.S grade has been considered and presented in Fig.4 For determination of colour value, the standard procedure GS-2/3-10 was adopted [3].

3. Results and Discussion

The results of the experiments are shown in Figures 1,2,3,4, respectively.

1) The Effect of pH on Corrosion Rate

The change in corrosion rate of stainless steel samples i.e. S.S.-1, S.S-2, S.S.-3, SS.-4 with respect to pH is shown in Fig. 1. The analysis of the juice observed in the experiment is given in Table-2.

Table 2: Juice Analysis

S. No.	Particulars	Analysis
1	Brix	22.8°
2	Specific gravity	1.086
3	Ash Content by weight	0.7139%
4	Average temperature	27°C
5	Exposure time	360 hrs.

From Figure -1, it is clear that corrosion rate of various stainless steels in cane juice decreases with increasing pH value. The corrosion rate of different steel alloys under study decreases in the similar manner up to pH 4 and it differs slightly between 4 and 7 pH. The corrosion rate decreases rapidly from pH 3 to 5 and it is almost steady between 5-7. In case of S.S. -1, the corrosion rate becomes minimum between pH 5 -7. The corrosion rate depends only on rapidly diffused oxygen to the metal surface. The major diffusion barrier of hydrous chromium oxide is continuously renewed by the corrosion process. Regardless of the observed pH of solution within this range, the metal surface is always in contact with an alkaline saturated solution of hydrous chromium oxide, the observed pH of which is about 9.6. In the acid region (pH 3 and below), the chromium oxide film is dissolved, the surface pH falls, and S.S.-1 is more or less in direct contact with aqueous environment. The increased rate of reaction is then the sum of both an appreciable rate of hydrogen evolution and oxygen depolarization.

In the presence of strong acids like HCI or H_2SO_4, the diffusion barrier oxide film on surface is dissolved below pH 3 whereas, in weaker acids such as acetic acid and other similar acids, dissolution of the oxide film occurs at a higher pH when the corrosion rate increases, accompanied by hydrogen evolution at pH 5 or 6. In other words, at a given pH, there is more available H+ ions to react with and dissolve the barrier oxide film in the presence of weak acids, compared to a strong acid. This is due to the higher total acidity or neutralizing capacity of a partially dissociated acid at a given pH.

In the present experiments, acetic acid has been used for maintaining pH of cane juice. Further, several weak species such as aconitic and succinic acids, etc. are naturally present in cane juice. The presence of these weak acids may impart more total acidity or neutralizing capacity to the juice at a given pH. This may be the reason for the higher corrosion rate in juice below 7 pH. The overall behavior of all the steels is more or less same with respect to pH variations.

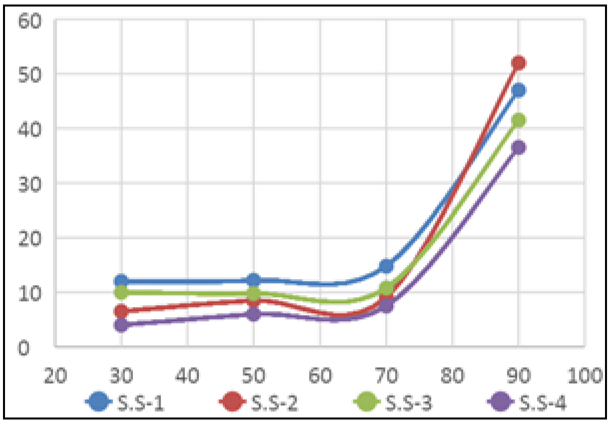

Figure 1: The change in corrosion rate of stainless steel samples with respect to pH

2) Temperature Effect on Corrosion Rate

Experimental results obtained on the temperature are shown in Fig.2. Variations in the corrosion rate of S.S-1, S.S.-2, S.S.-3 and S.S.-4 with respect to temperature in cane juice is shown in Fig.2. and juice analysis data is given in table number 3.

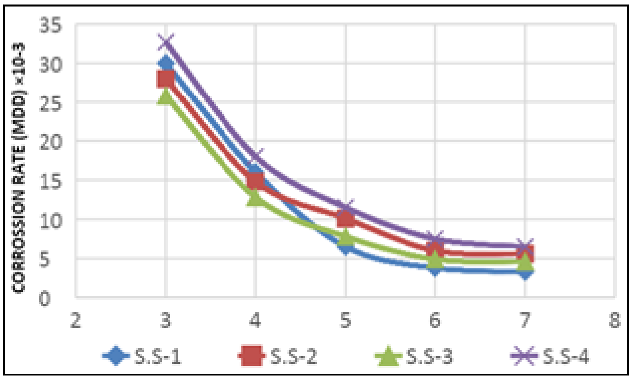

Figure 2: The change in corrosion rate of stainless steel samples with respect to temperature

Table 3: Juice analysis

S. No.	Particulars	Analysis
1	Brix	18.33°
2	Specific gravity	1.0732
3	Ash content by weight	0.74%
4	pH	3.5
5	Exposure time	360 hrs.

From the Figure, it is clear that the corrosion rates of S.S-1, S.S.-2, S.S.-3 and S.S.-4 is almost same in cane juice between 30-70°C. With increasing temperature, above 70°C, the rate increases rapidly.

In the present experiment, the solutions are of low pH because in the sugar manufacturing process low pH is very often encountered at some stages combination with high temperature. This low pH of the solutions may facilitate hydrogen evolution at higher temperature (above 70°C) and may be the reason for the increased corrosion rate above 70°C [1]. The corrosion rate is minimum for S.S.-4 and maximum for S.S-1. At a higher temperature, above 70°C the corrosion rate of S.S -2 increases more rapidly and it is maximum as compared to other S.S. alloys. The overall behavior of all the steels is more or less same with respect to variations in temperature.

3) Effect of Brix on Corrosion Rate

Fig.3 shows the change in corrosion rate of stainless steel samples at different Brix values in cane juice, authors reported lower solubility of dissolved oxygen at higher concentrations of dissolved solids [5]. In the present case, the dissolved oxygen at the start of the experiment was maintained at about the same level of 7.2 mg/l. Average temperature was 28°C, exposure time 360 hrs. and pH was 5.1.

In the initial stages of the experiment, the dissolved oxygen content remained constant in all the cases of S.S, i.e. S.S.-1, S.S-2, S.S.-3, S.S-4 but it may have changed in the final stages according to the Brix. The reduced solubility of oxygen can form the basis of the decreased corrosion rate at higher Brix [15]. tested the behavior of low carbon steels, stainless steels and brass exposed for 10-30 days to juice at 10, 30 or 65° Brix, at 100°C and pH 7.8-8.2 and reported that the corrosion of stainless steel and brass decreased with increasing Brix on the corrosion rate of soviet steels CT-3 and X18 HIOT and concluded that the low conductivity of the juice at higher Brix may be the reason for the phenomenon observed.

The results obtained in the present experiments, as shown in the Fig.3 are in conformity with the results reported by the above mentioned authors. Conductivity at higher Brix of the Juices may also be one of the reason for decreased corrosion rate in the present case.

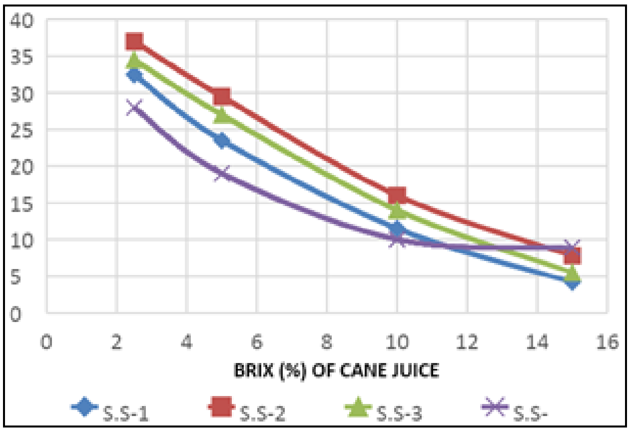

Figure 3: The change in corrosion rate of stainless steel samples with respect to different brix value in cane juice

The authors reported that when the dissolved impurities (Ca++, SO2) in juice from first evaporator effect increased by 30%, the corrosion resistance of steel greatly decreased [14]. Thus for a rapid increase in the Brix, the dissolved impurities rise according to the Brix. This may also be one of the reasons for the increased corrosion rate of stainless steel at lower Brix. In the present experiment the effect of Brix on corrosion rate of different S.S is almost similar except in case of S.S-4. In case of S.S-4, the corrosion rate is decreasing at a comparatively lower rate with increasing Brix value up to 9° Brix and it is almost steady below this value of Brix.

4) Colour Development

The results obtained by experiments for colour determination have been presented in Fig.4 The analysis of juice used in this experiment is given at Table-4.

The colour development in cane juice depends on the iron content of the liquor besides many other factors. The formation of colouring compounds as a result of reaction between iron and polyphenols (naturally present in cane juice) may alone increase the colour values of juice by 5-7% which in turn on crystallization may enhance the sugar colour by corresponding value.

In the present experiment the colour values of cane juice have increased in range 0.06% to 0.281%. It is minimum in case of S.S-1 and S.S-3 and maximum in case of S.S.-2 and S.S.-4. The reason may be clearly the percentage of iron and chromium in the particular S.S grade.

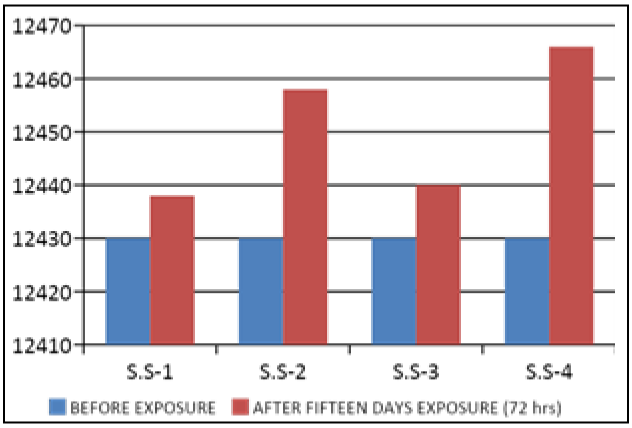

Figure 4: Effect of corrosion in stainless steel on colour value

Table 4

S. No.	Particulars	Analysis
1	Brix	16.26°
2	Specific gravity	1.0700
3	Ash content by weight	0.57%
4	pH	5.1
5	Exposure time	72 hrs.

4. Conclusion

The quantum of corrosion of different stainless steel alloys (S.S.-1, S.S.-2, S.S.-3 & S.S.-4) with variations in the process variables (pH, temperature and Brix) is almost similar. The mechanical properties, fabricability and weldability of these S.S alloys are almost similar [6]. Going through colour development due to these alloys in cane juice, it is less in case of S.S-1, S.S.-3 as compared to S.S-2 and S.S-4. The initial cost of S.S-1 and S.S-3 is also very less as compared to S.S-2 which has higher percentage of Ni. At present, mostly S.S-2 type of steel is being used which has a great potential to be replaced by S.S-1 or S.S.-3 type which is less in cost.

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