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FOULING OF ION–EXCHANGE RESINS DURING DEIONIZATION OF SUGARCANE JUICE

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ABSTRACT

One of the major problems in the commercialization of ion exchange resin process for deionization of sugarcane juice in sugar industry is capacity loss of ion exchange resins due to fouling. The laboratory experiments were carried out to study the fouling of commercially available anion (INDION–870) and cation (INDION–925) exchange resin by glucose, fructose and sucrose, considered as constituents of sugarcane juice. The temperature range was kept at 30°C to 50°C. The results show that the cation–exchange resin does not foul with sugars. The fouling was observed in anion–exchange resin except, in case of sucrose. The fouling is probably a result of reaction between anion exchange resin and sugars. The reaction was found to be first order with respect to the resin. The activation energy determined from Arrhenius plot is 11.8 Kcal/mol both for glucose and fructose.

Key words: Fouling, Ion exchange resins, Deionization of sugarcane juice.

INTRODUCTION

The sugarcane is the raw material for sugar manufacturing and the modern sugar plants involve various operations such as sugarcane crushing, extraction, ion exchange/clarification, evaporation, crystallization, drying, finishing and packing. The ion exchange process is conventionally used for the decolourization of sugarcane juice. The ionic impurities in sugars like SiO_2, MgO, K_2O, Fe_2O_3, Al_2O_3, CaO, Na_2O, P_2O_5, SO_3, KCl[1] get concentrated during the boiling operation prior to the crystallization. It results in low quality sugar i.e. yellowish sugar. Therefore it is desirable to remove ionic impurities from sugarcane juice. The use of ion exchange process for removing ionic impurities in sugarcane juice is new and still under development.

The use of ion exchange process for deionization of sugarcane juice was reported by Mukherjee and Srivastava[2]. The three methods of deionization namely reverse deionization, conventional deionization and mixed bed deionization were tried by the authors. The authors report that the mixed bed deionization gives better results in comparison to the conventional process which uses two separate cation and anion exchange beds. There are certain difficulties like separation of resins for regeneration and their mixing after regeneration.

One of the major problems in the commercialization of ion exchange process for the deionization of sugarcane juice in the sugar industry is the fouling of the resins. The fouling refers to the phenomenon by which the exchange capacity of resin decreases with its use. The ion–exchange resin fouling occurs in different forms like organic fouling, iron fouling, silica fouling, mud fouling etc.[3,4]. The organic fouling occurs during deionization of sugarcane juice. The most common organic constituents present in cane juice are sucrose, glucose and fructose as sugars, while cellulose, hemicellulose, lignin, pectin proteins, starch, tannin etc. as non sugars. All organic molecules are high molecular weight compounds. The ion exchange resin is heavily cross linked. The large organic molecules from sugarcane juice enter the resin and get trapped in the highly cross linked regions, thus results in reduction of active sites available for exchange. The fouling of resin has been explained by many authors. Lin et al.[5] and Elkader et al.[6] point out that fouling is due to the adsorption of coloring matter by anion exchange resins, while Srivastava et al.[7] report that glucose is responsible for organic fouling and sucrose solution free from glucose has no adverse effect on resins.

So far, the work on the effect of organic sugars and organic non sugars on capacity of anion and cation–exchange resin has not been reported extensively.

RESEARCH SIGNIFICANCE

The aim of investigation was to study fouling of anion and cation–exchange resins due to organic sugars (glucose, sucrose, and fructose) present in sugarcane juice.

MATERIALS

In order to investigate the fouling due to organic sugars, experiments were carried out in the laboratory, using analytical grade glucose, fructose and sucrose. The commercially available cation and anion exchange resins were used under the temperature range of 30 °C to 50 °C. The chemical analysis of sugars and ion exchange resins is given in Table 1 and Table 2, respectively.

Table 1. Chemical analysis of sugars

Sugar	Molecular formula	Molecular weight	Appearance	Supplier
D–Glucose	$C_6H_{12}O_6$	180.16	White crystalline powder	Sd Fine Chemicals
Fructose	$C_6H_{12}O_6$	180.2	White crystalline powder	Sd Fine Chemicals
Sucrose	$C_{12}H_{22}O_{11}$	342.3	White crystalline powder	Sigma Aldrich

Table 2. Ion exchange resins

Trade Name and Supplier	Description	Ionic form	Operating Capacity (meq/mL)*	Particle size, mm·
INDION –870 (Ion Exchange Ltd., Mumbai, India)	Weak base anion (polystyrene)	Hydroxyl	0.68	0.3–1.2
INDION–925 (Ion Exchange Ltd., Mumbai, India)	Strong acid cation (Styrene divinylbenzene)	Hydrogen	1.2	0.3–1.2

*Exchange capacity of resin indicates the total number of exchange sites available in the resin. It can be expressed as milliequivalent of exchangeable ions available, per g of resin or per mL of resin. An equivalent is the weight of a substance, which combines with or replaces one g–atomic weight of hydrogen. A meq is 1/1000 of an equivalent (Eq).

EXPERIMENTAL

The experiments were conducted in laboratory in shaker– mounted flasks. The shaker has a provision of mounting ten flasks at a time. The shaking was done laterally with a speed of 50 rpm. One batch of experiment comprised of ten flasks mounted on shaker, each containing 1.5 g of ion–exchange resin with 100 mL of sugar solutions. Temperature was set at a required level in the range of 30°C to 50°C. The composition and temperature of sugar solutions in presence of cation–exchange resin (Table 3) and anion exchange resin (Table 4) is given below. The sugar concentrations chosen were at the same level as that of the clarified sugarcane juice in the sugar manufacturing unit.

Table 3. Solution in contact with cation–exchange resin

Batch No.	Solution	Concentration %(w/v)	Temperature °C
1	Sucrose	15.5	30
2	Sucrose	15.5	40
3	Sucrose	15.5	50
4	Fructose	0.5	30
5	Fructose	0.5	40
6	Fructose	0.5	50
7	Glucose	0.5	30
8	Glucose	0.5	40
9	Glucose	0.5	50

Table 4. Solution in contact with anion–exchange resin

Batch No.	Solution	Concentration %(w/v)	Temperature °C
10	Sucrose	15.5	30
11	Sucrose	15.5	40
12	Sucrose	15.5	50
13	Fructose	0.5	30
14	Fructose	0.5	40
15	Fructose	0.5	50
16	Glucose	0.5	30
17	Glucose	0.5	40
18	Glucose	0.5	50

The shaking was carried out for 250 h. While doing the shaking, the flasks were demounted one by one at the interval of 50 h each. Then solution was analyzed to assess the level of fouling. The fouling of anion and cation exchange resins is assessed by two different methods described as follows –

To determine the total exchange capacity of a cation–exchange resin, it was kept in deionized water. The resin absorbs water and its volume and porosity increases. It was then used to determine the exchange capacity. The resin (1mL) was transferred to burette to form a uniform bed. A known amount (200 mL) of 0.1 M NaOH solution was passed through the bed. The NaOH solution coming out of the bed was collected in a beaker. Later 30 mL of deionized water was passed through bed and collected in a beaker. The effluent NaOH solution was titrated with 0.1M HCl. The total exchange capacity per mL of resin was determined from the known starting and final concentrations of NaOH.

In order to determine the total exchange capacity of an anion exchange resin, the same procedure was repeated, except that instead of NaOH solution, 0.1 M HCl solution was passed through the bed and the effluent was titrated with 0.1 M NaOH. The exchange capacity per mL of resin was calculated.

RESULTS AND DISCUSSION

The fouling of resin is measured by reduction in its ion exchange capacity, as indicated by titration results. The Fig. 1, Fig. 2 and Fig. 3 show the variation of exchange capacity of cation–exchange resins, with time, in presence of sucrose, fructose and glucose, respectively at the temperature of 30°C, 40°C and 50°C. The plots show that the fouling in cation–exchange resin is negligible.

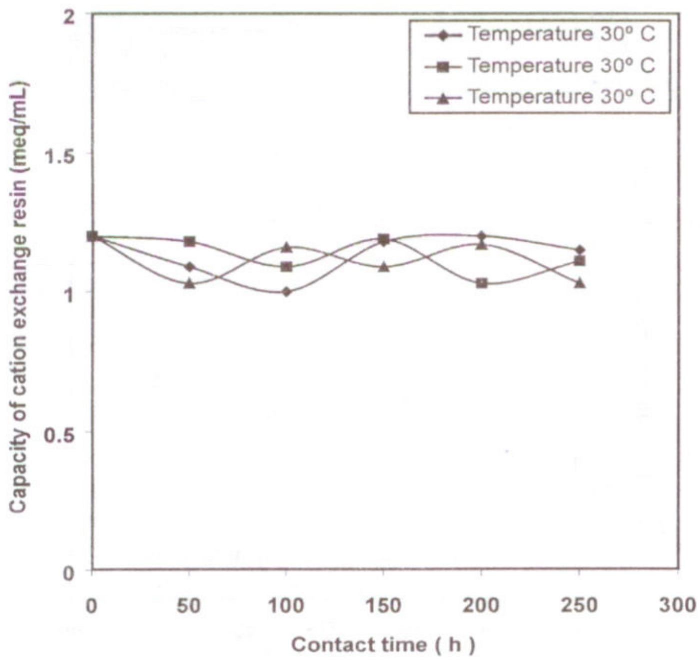


Figure 1. Organic fouling of cation–exchange resin in presence of surcrose

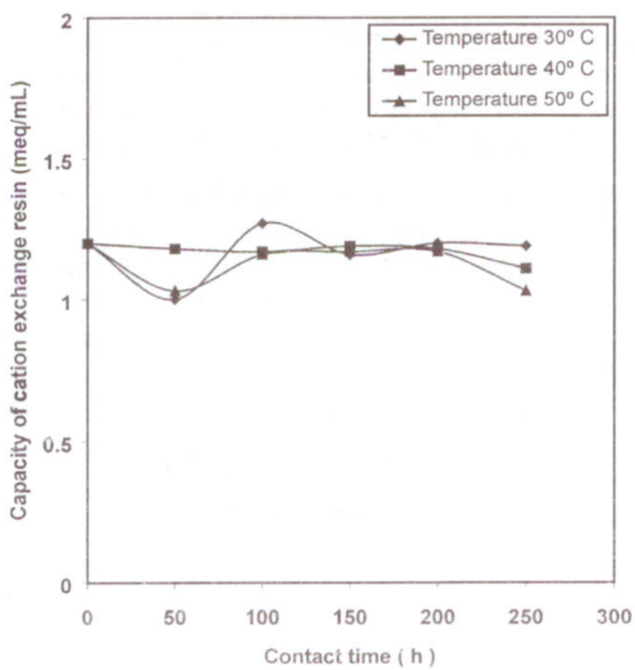


Figure 2. Organic fouling of cation–exchange resin in presence of fructose

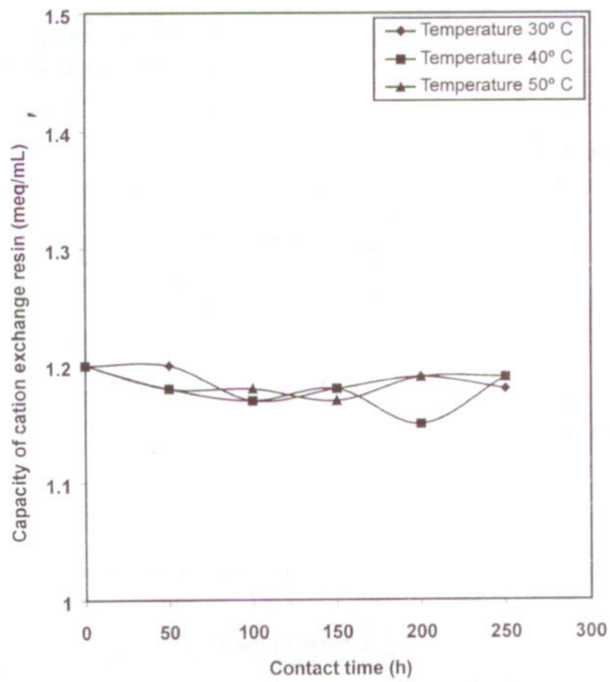
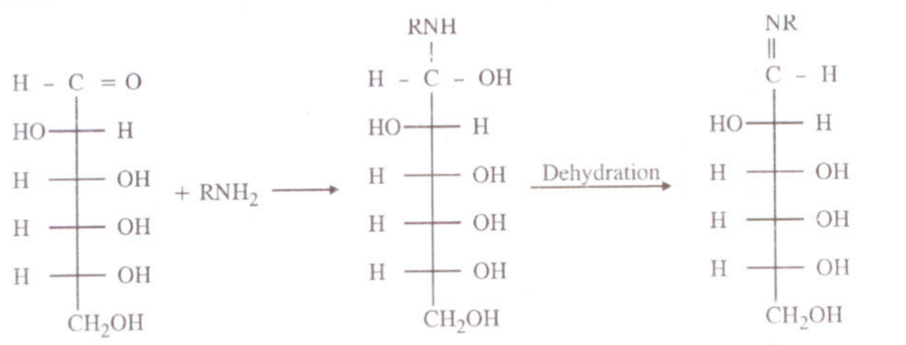


Figure 3. Organic fouling of cation exchange resin in presence of glucose

In the similar manner, the fouling in anion–exchange resin was measured and results were plotted in Fig. 4, Fig. 5 and Fig. 6 in presence of glucose, fructose and sucrose, respectively at the temperatures of 30°C, 40°C and 50°C. The plots show that the resin gets fouled due to glucose and fructose (Fig. 4 and Fig. 5). However no fouling occurs due to sucrose (Fig. 6).

The reason for fouling is the chemical reaction between the sugar and the resin. The probable reaction between glucose and anion–exchange resin is given below. The nature of chemical reaction between the resin and the fructose sugar is not fully understood.



Glucose (A) Resin (B) (C) Schiff's base of glucose (D)

Reaction between glucose and anion exchange resin

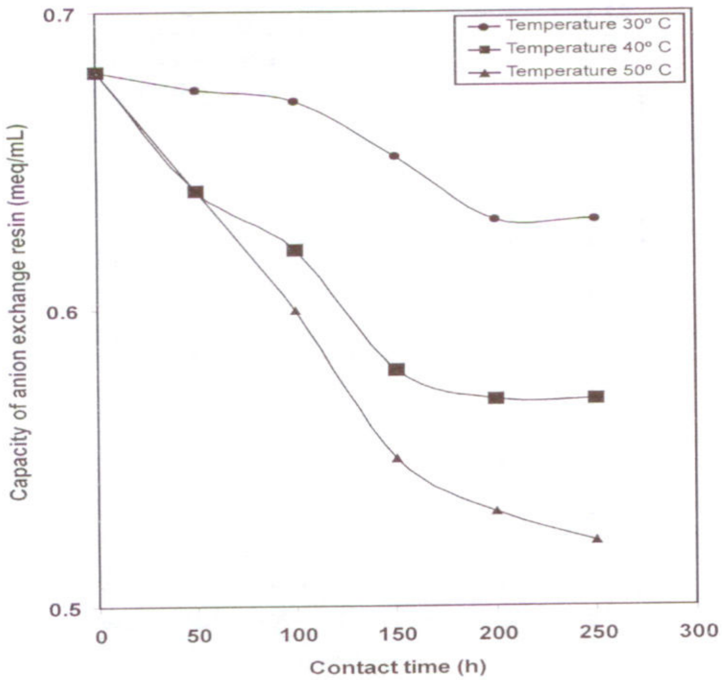


Figure 4. Organic fouling of anion exchange resin in presence of glucose

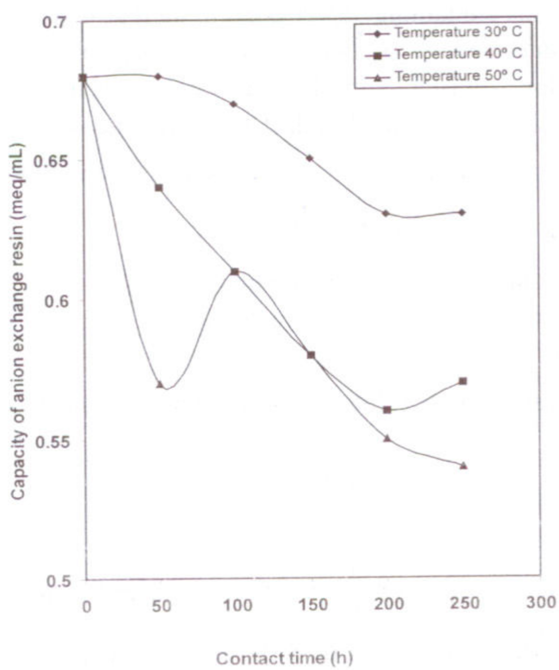


Figure 5. Organic fouling of anion exchange resin in presence of fructose

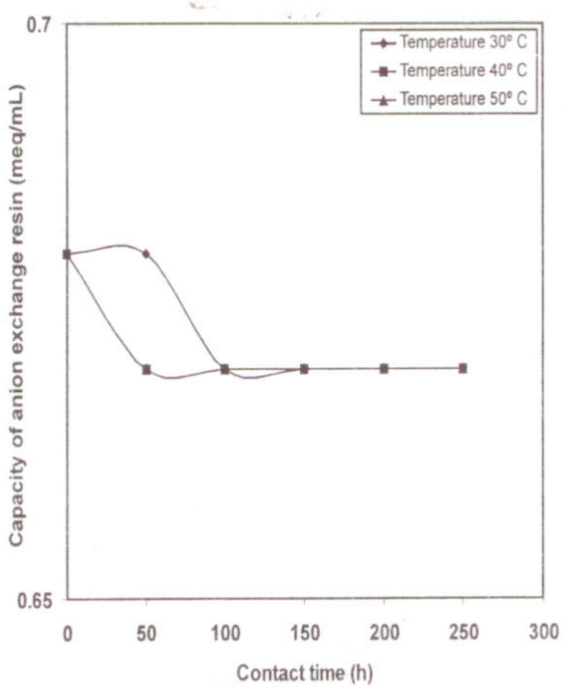


Figure 6. Organic fouling of anion exchange resin in presence of sucrose

The organic compounds containing –C=N bond in their structure are called Schiff's base type compounds. The intermediate product (**C**) 1–alkylamino–hexane–1,2,3,4,5,6–hexa–ol formed during the reaction is unstable and loses a water molecule and the final product (**D**) 6–alkylamino–hexane–1,2,3,4,5–penta–ol (Schiff's base of glucose compound) is formed.

The rate equation for the fouling reaction can be written as follows :

$$\frac{dc}{dt} = kC^n$$

where C is capacity of anion exchange resin meq/mL

C_o is initial capacity of anion exchange resin meq/mL

k is rate constant for the reaction

Assuming order of reaction n = 1, the equation can be integrated as follows

$$\int_{C_0}^{C} \frac{dc}{C} = k\int_{0}^{t} dt$$

As can be seen in Fig. 7. the plot of $\frac{C}{C_0}$ Vs 't' is a straight line passing through the origin. Therefore, the reaction is first order. The Fig. 8 shows the Arrhenius plot for the reaction. The activation energy was found to be 11.8 Kcal/mol for both; the glucose and fructose.

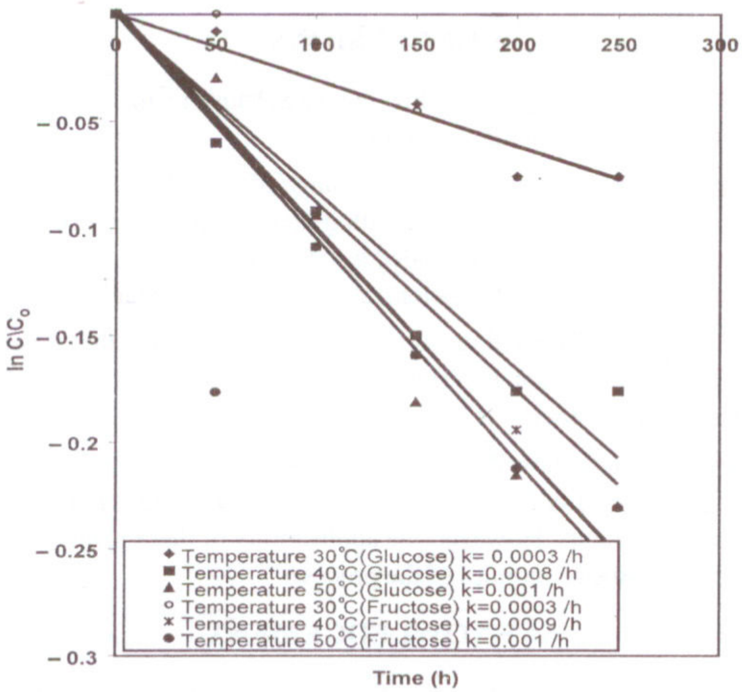


Figure 7. Order of reaction for fouling reaction

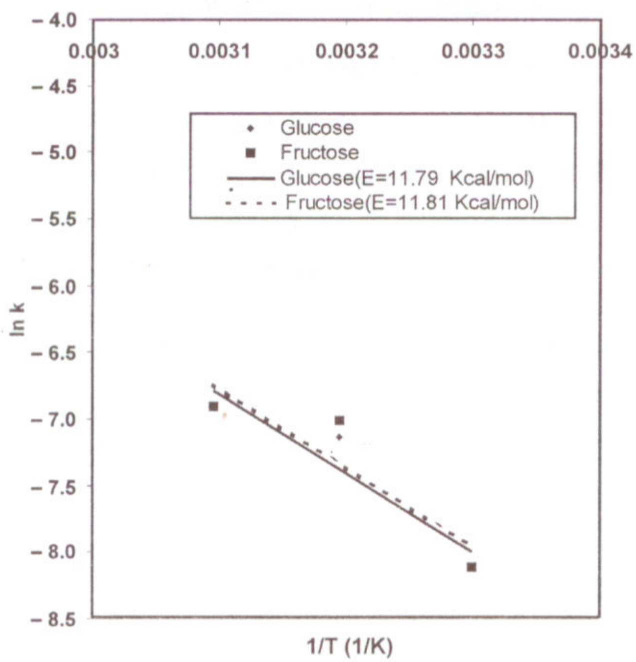


Figure 8. Arrhenious plot for fouling reaction

CONCLUSIONS

1. The extent and the nature of organic fouling in ion exchange resin due to organic sugars has not been reported extensively in the literature.
2. The laboratory experiments carried out in the range of 30°C to 50°C show that the strong acid cation–exchange resin does not foul with glucose, fructose and sucrose, whereas the weak base anion exchange resins are fouled by glucose and fructose. Both the varieties of the resins are conventionally used in deionization process in sugar industry.
3. The fouling is a result of chemical reaction between the resin and the sugars. The reaction between weak base anion exchange resin and glucose and fructose is first order with respect to resin and the activation energy is 11.8 Kcal/mol.
4. Thus the laboratory results show that both cation and anion exchange resins can be used for deionization of sugarcane juice. The life of cation exchange resin is longer as it does not get fouled due to organic sugars. However, the applicability of these resins for deionization of sugars will depend on the economics of the process.

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