SUGAR CANE JUICE
DEIONIZATION

by
Angel L. Javellana

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May 24, 1954.

Signature of author Signature redacted

Signature of Thesis Supervisor Signature redacted

Signature of Head of Department________________________

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ABSTRACT

"SUGAR CANE JUICE DEIONIZATION"

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Angel L. Javellana

Submitted to the Department of Chemical Engineering on May 24, 1954 in partial fulfillment of the requirements for the degree of Master of Science.

A preliminary cost estimate was made on a plant unit for the purification of sugar cane juice by ion-exchange. The deionization units were designed for a sugar mill in the Philippines having a capacity of 3600 tons of cane per day and working 24 hours a day for a campaign period of 150 days a year.

The cost figures are:

Initial investment on building and equipment		\$ 348,000
Annual income	\$4,034,000	
Annual operating costs	150,000	
Gross profit per year		\$3,884,000

The profit will be made from the sale of white sugar instead of brown sugar which is made possible through the use of ion-exchange.

The deionization units offer the following advantages: 1) the quality of the sugar is improved; 2) the sugar extraction is increased from 84% to at least 92% extraction.

It is recommended that pilot plant work be commenced as soon as practicable to obtain the necessary data so that an accurate comparison could be made between the above process and the conventional process of sugar refining.

Thesis Supervisor: Raymond F. Baddour
Title: Assistant Professor of Chemical Engineering

Hayden (Chem. Eng'g) Dec. 31, 1957

Massachusetts Institute of Technology
Cambridge 39, Mass.

May 24, 1954.

Prof. Leicester F. Hamilton
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Mass.

Dear Sir:

In accordance with the regulations of the Faculty, this thesis entitled "Sugar Cane Juice Deionization" is hereby submitted in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering Practice.

Respectfully submitted,

Signature redacted

Angel L. Javellana

CONTENTS

TABLES AND FIGURES

SUMMARY

The demand for locally produced white sugar in the Philippines has increased considerably in the past few years.

The M-M Sugar Mills in the Philippines, at present producing brown sugar, asked the Chelo Chemical Corporation to investigate the processes which may be used to produce white sugar and to make a preliminary cost estimate and the necessary recommendations.

The first cost figures made by the Chelo Chemical Corporation were for the process of sugar cane juice purification by ion-exchange. Since the work so far will be limited to sugar cane juice deionization no attempts will be made to compare the above process with the present method of sugar refining using bonechar.

Amberlite IRA-410 and Amberlite IRC-50 will be used in a reverse deionization system with sodium hydroxide and sulfuric acid as anion and cation resin regenerants respectively.

The present capacity of the plant, for which the deionization units were designed, is 3600 tons of sugar cane per day working 24 hours a day for a campaign period of 150 days a year.

The following cost figures were arrived at:

Initial investment for building and equipment		\$ 348,000
Annual income	\$4,034,000	
Annual operating costs	150,000	
Gross profit per year		\$3,884,000

The gross profit to be realized from the sale of white sugar instead of brown sugar may be considerably less than the calculated value because the sale price taken is on the high side.

The pay-off time may, however, be expected with in a year or two.

Some of the advantages to be gained from the use of the deionization units are:

1) the quality of the sugar is improved;

2) the annual production of sugar will be increased by at least 9.6% making the total production 915,000 piculs (139.44 lb./picul) per year.

The following recommendation is made: pilot plant work should be started as soon as practicable to get the necessary data so that an accurate comparison could be made between sugar cane juice deionization and the present process of sugar refining using bonechar.

The construction and operation of a commercial unit for the purification of sugar cane juice by ion-exchange would depend upon the results of the above comparison.

INTRODUCTION

Since she acquired her independence in 1946 the Philippines has been confronted with the problem of decreasing the importation of goods which may be produced locally. One of the steps taken to help solve the problem is to exercise strict control on the importation of certain items. Among these items is white sugar. At present there are less than five sugar refineries in the Philippines. Some thirty odd sugar mills have facilities for producing only brown sugar.

The M-M Sugar Mills, at present producing only brown sugar, thought it profitable to be prepared for the forthcoming increased demands for locally produced white sugar. The M-M Sugar Mills, therefore, engaged the Chelo Chemical Corporation to make a study of the possible processes which may be used to produce white sugar, make a preliminary cost estimate and to make the necessary recommendations.

The first process considered by the Chelo Chemical Corporation was the purification of the sugar cane juice by ion-exchange. One of the main reasons for choosing this process was that the process is being used with some success for purifying sugar beet juice in the United States (4). Also, big strides are being taken in the field of ion-exchange, and should the process prove profitable at the present standing of ion-exchange it would certainly be more promising when further improvements have been made, since it will be some time before the M-M Sugar Mills will consider seriously to invest in this new field.

Already available in the field of ion-exchange are three methods of operation for deionization, namely, the conventional, reverse and mixed-bed deionization processes. The conventional method removes the cations from solution first while the reverse method removes the anions before the cations. In the mixed-bed operation the cations and anions are removed simultaneously.

Ion-exchange resins can also be tailor-made for the occasion and each day we are that much closer to the advent of resins having a maximum exchange efficiency. A wide variety of regenerants that may be used is an asset especially in localities where the availability of chemicals is a problem. Finally, enough experimental data are available to make possible a preliminary cost estimate on a plant unit for the purification of sugar cane juice by ion-exchange.

Before any calculations had been made the Chelo Chemical Corporation knew that the method of operation would affect the amount of sugar produced and that the chemicals used as regenerant would form a large percentage of the total operating costs. It was therefore decided to use the reverse deionization process since the conventional deionization caused the inversion of sucrose thus lowering the sugar yield. However, the mixed-bed deionization process was not to be totally ignored.

A comparison was to be made between the costs of ammonia and sodium hydroxide as anion resin regenerant. Ammonia because of its recoverability and sodium hydroxide because of its high regeneration efficiency.

Since the investigation so far will be concentrated on sugar cane juice deionization no comparisons will be made with the other processes of sugar refining, particularly, the present conventional method using bonechar.

PROCEDURE

The first deionization process to be seriously considered was the reverse deionization using ammonia as the anion resin regenrant. The first assumption made was that the ions present in the sugar cane juice solution were Na^+ and Cl^-. This assumption was made to simplify the calculations without departing too far away from what really happens during the deionization process.

The reactions during the service or exhaustion cycle are:

anion cell: $NaCl + ROH = RCl + NaOH$

cation cell: $NaOH + R'NH_4 = R'Na + NH_4OH$

where R represents the anion resin molecule,

and R' represents the cation resin molecule.

The ammonium hydroxide will come out of the system with the sugar cane juice effluent and will be recoverable from the condensate in the evaporators.

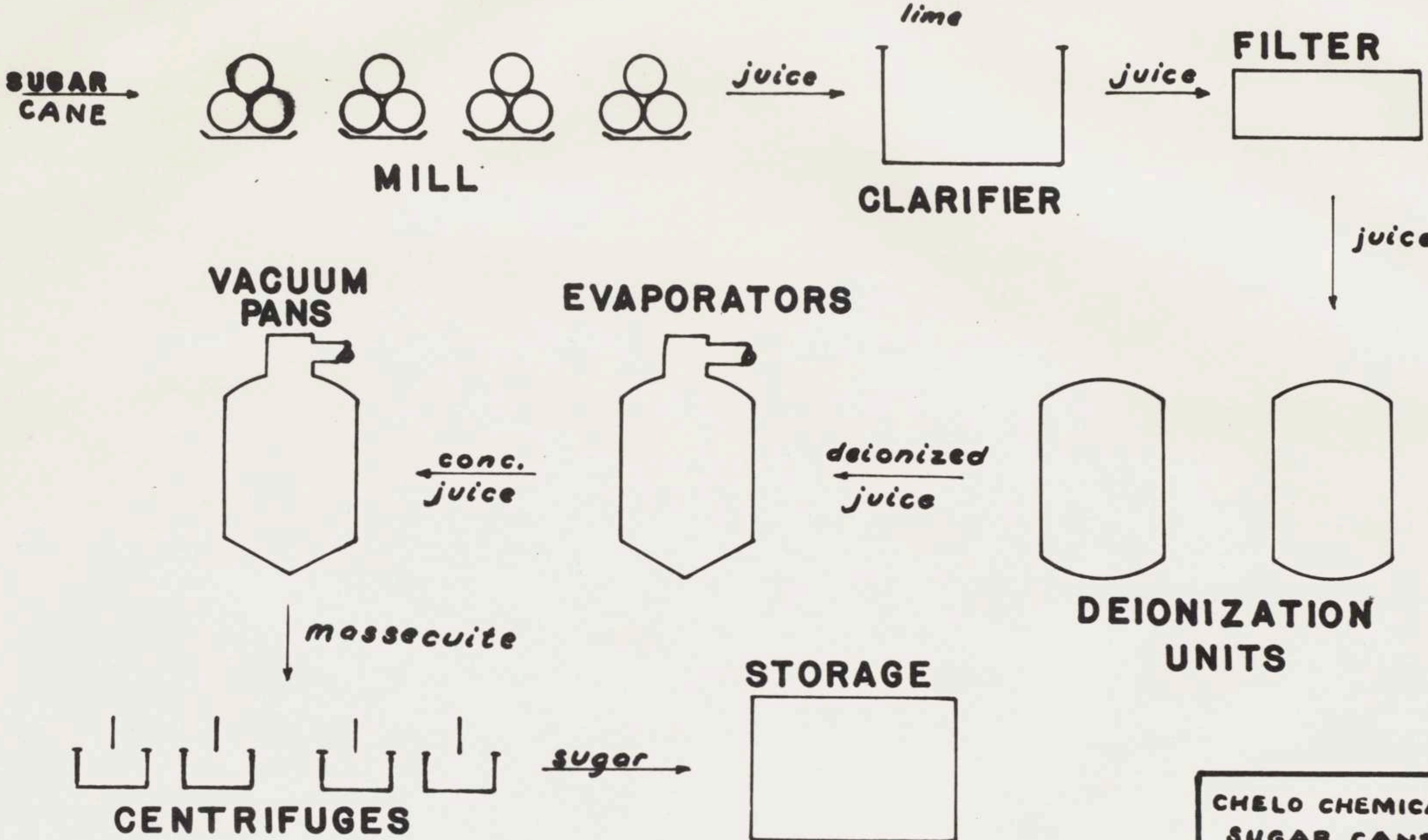
During regeneration the reactions are:

anion cell: $RCl + NH_4OH = ROH + NH_4Cl$

The ammonium chloride solution coming out as effluent from the anion cell may be utilized to regenerate the cation bed and the reaction is:

cation cell: $R'Na + NH_4Cl = R'NH_4 + NaCl$

The second deionization process to be evaluated was the reverse deionization using sodium hydroxide to regenerate the anion resin and sulfuric acid for the cation resin. The same assumption as above was made in the



CANE SUGAR EXTRACTION WITH DEIONIZATION

CHELO CHEMICAL CORP. SUGAR CANE JUICE DEIONIZATION	
M-M-1	FIG. 1
5-24-54	ALJ

calculations but to avoid confusion in the reaction equations below the anion will be designated as A^+ and the cation as C^-.

The reactions during the service cycle are:

anion cell: $CA + ROH = RC + AOH$

cation cell: $AOH + R'H = R'A + HOH$

The reactions during regeneration are:

anion cell: $RC + NaOH = ROH + NaC$

cation cell: $2R'A + H_2SO_4 = 2R'H + A_2SO_4$

After clarification and filtration the sugar cane juice will be passed through the anion cell and then through the cation cell. When one pair of cells is exhausted the juice will be rerouted through a second pair of cells while the first pair will be backwashed, regenerated and rinsed. The juice leaving the deionization units will be sent to the evaporators and the final steps of sugar extraction.

RESULTS

The process chosen was that using sodium hydroxide as the anion resin regenerant since it was found to be economically profitable and cheaper than the process using ammonia as the anion resin regenerant.

The results presented are those only for the "sodium hydroxide" process since the conclusion that sugar cane juice purification by ion-exchange will prove profitable was based only on these results.

Table I gives the amounts of juice treated, resin and regenerant used per one-hour service period.

Table II gives the time distribution per cycle.

Table III gives the number of pieces of major equipment needed and their costs.

Table IV gives the initial investment costs.

Table V gives the operating costs for a campaign period of 150 days a year working 24 hours a day. The daily capacity of the plant is 3600 tons of cane a day.

Table VI gives the sales and gross profit per season to be realized from the sale of white sugar instead of brown sugar through the use of deionization units in a mill equipped to produce only brown sugar.

TABLE I

Amounts of Resin, Regenerant and Juice

Basis: 60 minute exhaustion period per cycle

	ANION CELL	CATION CELL
Resin	Amberlite IRA410	Amberlite IRC-50
Capacity of resin	0.0371 lb.eq./cu.ft.	0.237 lb.eq./ft^3
Equivalents of resin	23.2 lb.eq.	15.2 lb.eq.
Volume of resin	372 cu.ft.	58.2 cu.ft.
Regenerant	4% NaOH	4% H_2SO_4
Amount of regenerant	16.5 lb.eq.	14.0 lb.eq.
Volume of regenerant	2140 gal.	2050 gal
Equivalents of juice	13.8 lb.eq.	13.8 lb.eq.
Volume of juice	36900 gal.	36900 gal.

TABLE II

Time Distribution per Cycle

Basis: 1 cycle

Period	ANION CELL		CATION CELL	
	Exhaustion	Regeneration	Exhaustion	Regeneration
service	60 minutes		60 minutes	
backwash		10 minutes		10 min.
regeneration		8.4 "		8.3 "
first rinse		30 "		30 "
second rinse		40 "		40 "
Total	60	88.4 "		88.3 "

TABLE III

Plant Equipment

Number and cost

	ANION CELL			CATION CELL		
	No.	cost/unit	Total cost	No.	cost/unit	Total cost
Cells (tank + resins)	3	\$29000	\$87000	3	\$11000	\$33000
Pumps + motrs (juice)	5	672	3360	7	590	4130
Regenerant Storage tank	1	1920	1920	1	1100	1100
Regenerant mixing tank w/agitator	1	1150	1150	1	1100	1100
Pumps + motor (regenerant)	1	720	720	1	300	300
Pump + motor (water)	1	720	720	1	720	720
Total			\$94870			\$40350

Total delivered equipment cost = \$94,870 + \$40,350

= \$135,220 $\cong$ \$135,000

TABLE IV

Total Investment cost

Delivered equipment	$135,000
Installation	58,000
Building	38,600
Piping	116,000
Total	$347,600

The total investment cost is approximately $348,000.

TABLE V

Annual Operating Costs

Labor for operation	$ 2,250
Labor for maintenance	1,875
Anion resin replacement*	2,740
Cation resin replacement*	1,000
Caustic regenerant	67,000
Acid regenerant	28,000
Water for washing	8,760
Extra sacks	4,000
Allowance for depreciation	34,800
Total	$150,425 $\cong$ $150,000
Cost of production	$0.164/picul

* Resin replacementsare calculated at 10% of the original cost

TABLE VI

Sales and Gross Profit

Income from increased quality of sugar	$3,050,000
Income from extra sugar produced	984,000
Total income	4,034,000
Cost of production	150,000
Gross profit	$3,884,000

DISCUSSION OF RESULTS

The anion resin used in this design is a strong-base anion resin and, therefore, needs a strong base as regenerant. Use of ammonia, a weak base, requires a high regeneration level while the capacity of the resin remains at an unsatisfactory low value. It was for this reason that sodium hydroxide was chosen as the anion resin regenerant. Ammonia would prove highly uneconomical.

The use of ammonia as regenerant should not , however, be disregarded, for the mere fact that it is recoverable is an offer for economic possibilities if properly utilized. Studies should, therefore, be made to find out if the use of a weak-base anion resin instead of a strong one would give the purity desired in the juice because it would be practical then to use ammonia as regenerant.

In using a weak-base anion resin conventional deionization may have to be resorted to since the weak-base resin exhibits a low exchange "potential" in reacting with the salt of a strong base. If this be the case, studies should also be made to compare losses due to the inversion of sucrose with the gain from the recovery of ammonia.

Investigations should also be carried out to determine the possible use of mixed-bed deionization (11). The investigators should be forewarned that only a strong-base anion resin may be used (7).

Table I

The anion resin to be used is Amberlite IRA-410. The volume of resin required to handle 4940 cu.ft. of juice containing 13.8 lb.eq. of ions is 372 cu.ft. containing 23.2 lb.eq. of resin. The resin has a capacity of 0.0371 lb.eq. per cu.ft. of resin at a regeneration level of 0.05 lb.eq. of sodium hydroxide per cu.ft. of resin; this would give a leakage of 5%.

Amberlite IRC-50 will be the cation resin. Not enough experimental work has been done on this resin to give exact values of capacity and regeneration level, however, the range of values are given and the figures used in this design are on the conservative side. The capacity was taken as 0.237 lb.eq. per cu.ft. of resin at a regeneration level of 0.24 lb.eq. of sulfuric acid per cu.ft. of resin. Work should, therefore,be done to get accurate values for the cation resin.

The volume of cation resin needed to accomplish the desired ion-exchange is 58.2 cu.ft., containing 15.2 lb.eq. of resin, however, 205 cu.ft. of resin are required to attain the recommended exhaustion flow rate of 3gal./min./cu.ft. of resin. In calculating the amount of regenerant required the value of 58.2 was used since it is only this volume of resin that is exhausted. Experimental work is recommended to verify this, for more acid may be required due to the "dilution" effect of spreading out the 58.2 cu.ft. to 205 cu.ft.

Table II

The exhaustion period of 60 minutes was chosen for the following reasons: the regeneration and rinsing periods are directly proportional to the exhaustion period due to the volume of resin involved; three pairs of cells would be the minimum requirement for a continous operation; a 60-minute exhaustion period gives an ample free period of 30 minutes between cycles for a particular pair of cells. A shorter exhaustion period would require less resins but would also give a shorter free period between cycles and this may not be practical should minor difficulties occur during operation. Alonger exhaustion period would require more resin and give a longer free period between cycles but this combination would prove uneconomical.

The total operating time per cycle is 148 minutes.

Table III

About 64.5% of the total equipment cost will be for the anion resin (including cell). This item would certainly deserve more attention. It is, therefore, recommended that work be done to get better operating conditions for Amberlite IRA-410 and if need be to look for resins which would be more economical.

Table IV

The delivered equipment cost of $135,000 may be on the low side. Several factors have not been included in the calculations which may increase the delivered equipment cost by a substantial amount. Extra freight and handling charges and taxes have not been included due to lack of information. In future work it is recommended that a proper evaluation of the unaccounted for items be made.

Building costs though not included may not be necessary since the present building housing the sugar mill may have enough space for the deionization units. However, foundations would still have to be made for the deionization units.

Estimating the piping costs at 86% of the delivered equipment cost (13) may be too high as not too much piping will be needed. This item is, therefore, recommended for a more detailed evaluation. However, the overestimation made on the piping may compensate for the cost of instrumentation which was not included in the preliminary cost estimate.

Table V

The caustic to be used as anion resin regenerant will take care of 45% of the annual operating cost. Cutting down the expense on this item would be highly desirable. The same recommendations are therefore made as were made for the anion resin: studies for better operating conditions and/or better resins.

Table VI

For a mill working 24 hours a day, 150 days a year with a capacity of 3600 tons of cane a day and attaining a sugar extraction of 92%, instead of the normal 84% (without D-I units), the annual production will be 915,000 piculs (139.44 lb./picul). The sugar extraction estimated at 92% is on the conservative side since this is the present recovery obtained (5). And with improved resins and techniques it is expected to attain a 95-96% recovery.

The initial building and equipment cost will be ,

$348,000 and it will be depreciated over a period of ten years at the end of which it will have no value.

The sale price of the white sugar was taken at $12.30 per picul and for comparison the brown sugar was to be sold at $8.65 per picul (12).

The income to be realized from the use of the deionization units would come from two sources: the increase in quality of the brown sugar ordinarily produced and the excess sugar produced by the use of the deionization units. The sales from the former would amount to $3,050,000 and from the latter $984,000. The gross profit will be $3,884,000.

Since the sale prices of the sugar taken are on the high side the gross profit to be realized may be considerably less than the calculated value. A more accurate sale price should therefore be used in future work because a small difference in the unit price is amplified in the gross profit due to the large amount of sugar involved.

The cost of production based on the total output of 915,000 piculs per campaign will be $0.164 per picul.

It should be noted that the increased in sugar production will not increase the cost of evaporating and centrifuging the sugar solution since the bulk of material to be handled will not increase. The increase in production is because less sucrose goes with the molasses than what usually goes in the case of undeionized sugar cane juice.

It is therefore recommended that pilot plant work be commenced as soon as practicable to get all the necessary data so that the deionization process may be compared with the present process of sugar refining using bonechar.

General

The first attraction of the deionization process is the production of white sugar without going through the conventional refining process using bonechar. Added to this is the fact that more sugar is recoverable with a corresponding decrease of molasses. The molasses is also improved in taste and color giving it more edible qualities.

The deionization process also removes from the sugar cane juice those impurities which normally would form boiler scales in the evaporators. This, of course effects a savings in time, labor and chemicals which would have to be utilized to maintain proper operating conditions in the evaporators. However, the absence of the impurities present other problems (5). The juice of higher purity will require new operating techniques in the boiling process. Also the impurities will not be present to offer a buffering action and thus prevent or minimize the inversion of the sucrose during the rest of the process. Studies are therefore recommended to determine the exact nature of the absence of the impurities removed by deionization.

Other problems which may be anticipated and for good reasons are: loss of resins during washing; channeling through the bed thus causing incomplete regeneration and/or exhaustion; physical and/or chemical breakdown of the resins and inefficient exhaustion and/or regeneration due to the covering of the resin particles by sludge brought in by the juice. The exact nature of these problems could not be determined until at least pilot plant work is done.

CONCLUSIONS

1. The total initial investment will be $348,000.

2. The annual operating cost of $150,000 will give a unit cost of production of $0.164 per picul.

3. The gross profit to be realized from the sale of white sugar instead of brown sugar by the use of the deionization units will be $3,884,000 giving a pay-off time of one year.

4. For a plant with a capacity of 3600 tons of sugar cane a day, working 24 hours a day, 150 days a year and attaining a 92% sugar extraction with the deionization units the annual production will be 915,000 piculs (139.44 lb./picul).

5. Three pairs of cells using the reverse deionization process will be used. A 60-minute exhaustion period was found to be the practical one giving a total of 148 minutes per cycle per pair of cells.

6. Sodium hydroxide is cheaper and more efficient than ammonia in regenerating a strong-base anion resin.

7. The anion resin cost was found to be 64.5% of the total plant equipment cost; while the anion resin regenerant formed 45% of the annual operating costs.

RECOMMENDATIONS

1. Pilot plant work should be started as soon as practicable to get the necessary data so that an accurate comparison could be made between sugar cane juice deionization and the present sugar refining process using bone char.
2. In future work the following cost items will need more data for a more accurate evaluation: delivered equipment cost, anion resin, caustic regenerant, and the sale prices of the sugar.
3. During the pilot plant work special attention should be given to the following: amount of cation resin regenerant required, operating conditions to get the optimum volumes for the anion resin and its regenerant, behaviour of the resin beds during operation under different conditions and possible changes in the technique of evaporating the high-purity juice.
4. It is recommended that the use of a mixed-bed deionization unit be investigated.
5. The use of a weak-base anion resin is recommended for study, special attention being given to the degree of purity of the juice being attained.

ACKNOWLEDGEMENTS

The author would like to express his gratitude to all those who in one way or another helped in the preparation of this thesis. Special thanks are due to Professor Raymond F. Baddour under whose guidance this work has reached its final form and to Brother Hugh, F.S.C., who supplied the pertinent information from the Philippines.

APPENDIX

DETAILS OF PROCEDURE

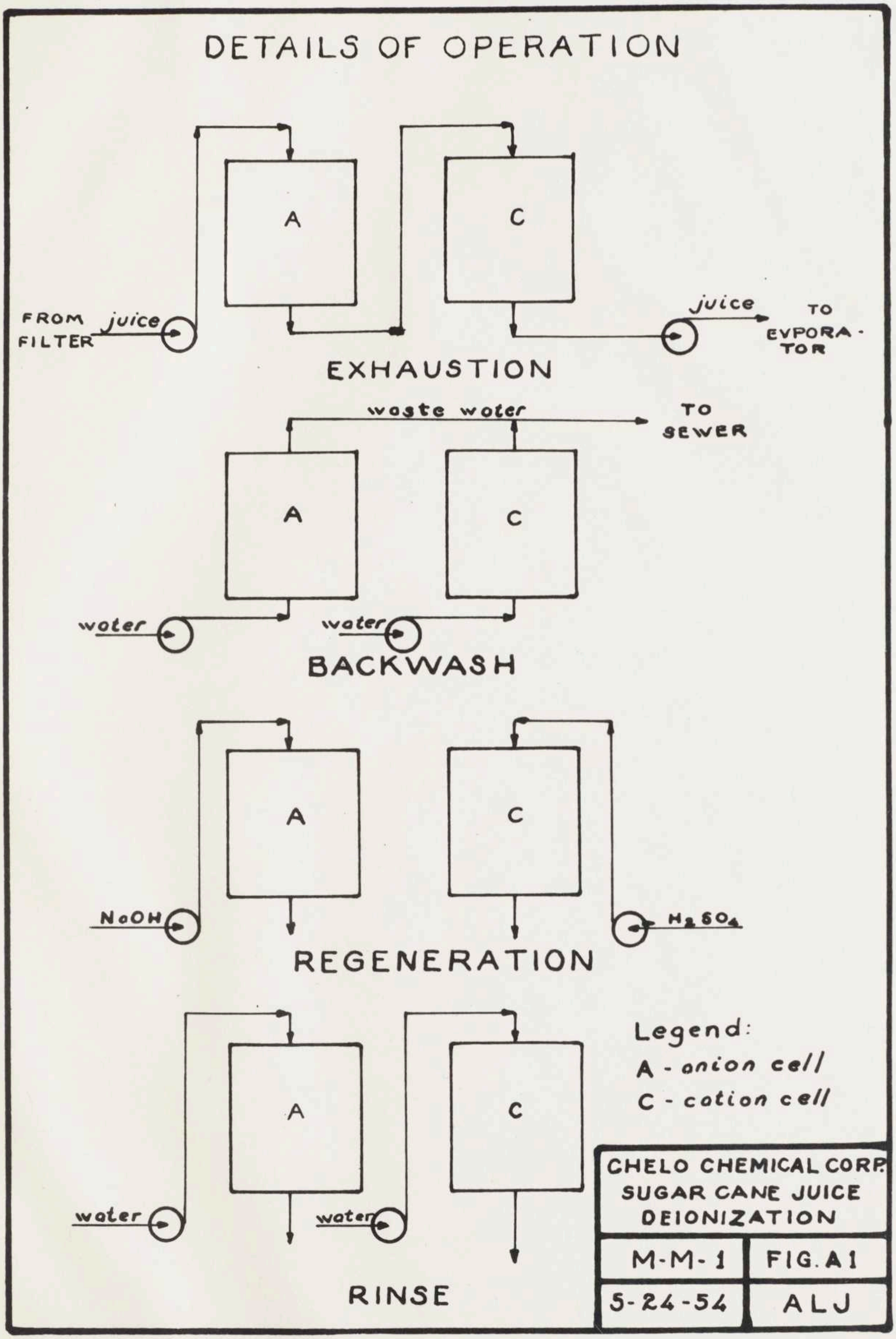
The process to be used will be the reverse method. The advantage to be gained from this is that in no time during the process is the juice acidic, as in the case of the conventional method, thus the inversion of the sucrose is minimized if not completely eliminated.

The plant will make use of 3 pairs of anion and cation cells and the necessary accesories that go with them. The accesories consist of: 1) the valve assembly with adequate headers to direct the flow of fluids during various phases of the operation; 2) common to all the units will be a set of tanks to store and dilute the regenerants; 3) pumps for pushing the regenerants through the beds; 4) a set of controls including: rate of flow indicators, conductivity meters, specific gravity recorders, positive displacement meters, recording thermometers, etc.; 5) bulk handling equipment for the unloading and storing of carload lots of concentrated acid and alkali. It should be noted that all the pieces of equipment that come in contact with acid, liquor and juice are to be rubber-lined.

To operate this section of the mill only one man and a helper will be needed per shift.

The deionization cycle will consist of: 1) sweetening on period; 2) service cycle; 3) sweetening off period; 4) backwash; 5) regeneration; 6) rinse.

At the start both of the anion and cation cells will have their voids full of water and when the juice is allow-



DETAILS OF OPERATION
A
C
FROM FILTER
juice
juice
TO EVPORA-TOR
EXHAUSTION
waste water
TO SEWER
A
C
water
water
BACKWASH
A
C
NaOH
H_2SO_4
REGENERATION
A
C
water
water
RINSE
Legend:
A - anion cell
C - cation cell
CHELO CHEMICAL CORP.
SUGAR CANE JUICE
DEIONIZATION
M-M-1
FIG. A1
5-24-54
ALJ

ed to flow through both sells the first effluent is pure deionized water. The effluent gradually increases in sugar content until it reaches full sugar strength. Up to this point has been the"sweetening on" period. The flow of juice is continued for the "service cycle" until the anticipated break-through point is reached. It has been found preferable to anticipate the break-through rather than wait for it. At the end of the service cycle the juice is shunted off to the next unit while pure water is run through the unit under discussion. The effluent will still contain sugar which will gradually decrease in concentration. The effluent is added on to the other juice until the sugar content is too low for an economical evaporation. Whatever effluent follows is sent to the sewer. This is the "sweetening off"period. When the bachwash no longer contains sugar the "backwash" is s started with hot water (which has been found better than cold water). The purpose of this is to remove the colloidal matter and sediment that have collected on the beds and to reclassify the resins in the cells. The cells are backwashed individually. The cells are now ready for regeneration and the regenerants are pumped into the cells separately. After the desired regeneration level has been reached both cells are rinsed independently with pure water to remove excess regenerant. It must be remembered that the economics of the process and not the completeness of the regeneration determines the degree of regeneration. After all these the unit is all set for another round.

CALCULATIONS

The ion-exchange unit will be designed to handle the total capacity of the M-M Sugar Mills. The mill operates on a 150-day campaign period.

daily capacity=	= 3600 tons of cane
sugar in cane = 3600 x 0.14	= 504 tons
sugar extracted= 504 x 0.922	= 464 tons
sugar sol'n. to beds = $464 \times \frac{1}{0.12} \times 2000$	= 7,740,000 lb.
density of juice = 62.4 x 1.0465	=65.2 lb./cu.ft.
vol. rate of flow = 7740000/65.2 x 24	= 4940 cu.ft./hr.
= 4940 x 7.48/60	= 615 gpm

It will be assumed that the present sugar recovery of 84% will be increased to 92% using ion-exchange purification of the sugar cane juice. This is a conservative estimate since present operations (5) give a 92% recovery and with better resins and techniques it is expected that a 95-96% recovery would be possible.

Extra sugar produced/year= 464 x 2000 (0.92 - 0.84) x 150/139.44

= 80,000 piculs

Total sugar produced/year= 464 x 0.92 x 2000 x 150/139.44

= 915,000 piculs

where, 139.44 = lb./picul

The plant equipment cost figures will be calculated first based on the 1949 prices. These figures will then be multiplied by the Marshall and Stevens index ratio $\frac{183.1}{164.5}$ to get the prices for 1953.

The composition of the juice varies for every type of cane and may also vary from year to year for one type of cane. Due to the unavailability of the desired data, the composition of a Louisiana sugar cane will be used (10).

Basis: loo lb. of sugar cane

water	74.5 lb.
ash	o.5 lb.
fiber	10.0
sugars	14.0
Nitrogenous bodies	0.4
fat and wax	0.2
pectin (gums)	0.2
free acids	0.08
combined acids	0.12
	100.00 lb.

The ash which contains the ions to be removed has the following composition (based on 100 lb. of cane):

silica, SiO_2	0.25 lb.
potash, K_2O	0.12
soda, Na_2O	0.01
lime, CaO	0.02
Magnesia, MgO	0.01
iron, Fe_2O_3	trace
phosphoric acid, P_2O_5	0.07
sulfuric acid, SO_3	0.02
chlorine, Cl	trace

The amount of minerals removed during clarification are calculated from results obtained by R.H.King (6). According to him the amount of minerals removed after defecation at pH8 are:

P_2O_5	80-85%
silicates	35%
magnesium	maximum at pH 9, small at lower pH's
iron	nearly completely removed (95%)
calcium	increases by 200%

The amount of minerals left, based on 100 lb. of cane are:

SiO_2 = 0.25 (1 - 0.35) = 0.1625 lb.

P_2O_5 = 0.07 (1 - 0.80) = 0.014

CaO = 0.02 (3.00) = 0.06

The sugar juice that will be pushed through the beds w will be diluted to 12° Brix. The sugar in the solution will then be 12% by weight.

Basis: 100 lb. of solution

$CaO = 0.06 \times \frac{12}{14} \times \frac{2}{56.08} = 0.00183$ lb.eq.

$K_2O = 0.12 \times \frac{12}{14} \times \frac{2}{94.19} = 0.00218$

$Na_2O = 0.01 \times \frac{12}{14} \times \frac{2}{61.99} = 0.000276$

total= = 0.00429 lb.eq.

volume of sol'n. = 100/65.2 = 1.535 cu.ft.

mineral salts per hour = $\frac{0.00429}{1.535} \times 4940 = 13.8$ lb.eq./hr.

Anion Cell

resin - Amberlite IRA-410

capacity - o.0371 lb. eq./ cu.ft. of resin

exhaustion period - 1 hour per cycle

juice - 4940 cu.ft. containing 13.8 lb.eq. of mineral salts

resin - 372 cu.ft. containing 23.2 lb.eq.

cost of resin - 372 x \$66 x 1.11 = \$27,400

where, 1.11 is the Marshall and Stevens index ratio $\frac{183.1}{164.5}$.

exhaustion flow rate = $\frac{4940 \times 7.48}{60 \times 372}$ = 1.65 gal./cu.ft./min.

Therefore, the flow rate is good since it is below the maximum of 2-3 gal./cu/ft/min. recommended for a satisfactory operation (8).

bed dimensions - the height of the resin bed is taken at one-half the diameter

diameter = 10 ft.

height of bed = 4.74

wt. of regenerant = 372 x 2 = 744 lb.

where 2 is the weight of sodium hydroxide required to regenerate the resin back to a capacity of 0.0371 lb.eq./ cu.ft. of resin.

equivalents of regenerant = 744/40 = 16.5 lb. eq.

A 4% solution of NaOH will be used as regenerant.

4% sol'n. = 2.6 lb. NaOH/cu.ft. of sol'n.

vol. of regenerant = 744 x 7.48/2.6 = 2140 gal.

regeneration time = 2140/372 x 0.5 = 8.4 min.

cost of regenerant = 744 x 24 x 150 x $\frac{2.50}{100}$ = \$67,000

Cells and Tanks

Cells were designed for twice the volume of the resin bed to allow for the expansion of the bed during backwashing.

Storage tanks were designed to hold a week's supply of concentrated alkali.

Mixing tanks were designed to hold enough solution for one cycle.

The costs for the cells and tanks were based on the weight of steel required using $^1/_4$ in. steel plates.

Washing

Backwashing will be done for 10 minutes (before regeneration) at a flow rate of 3 gal./ft.^{2}/min. to accomplish a 61% bed expansion.

Vol. of backwash water = 3 x 78.5 x 10 = 2360 gal.

After regeneration the resin beds are to be rinsed with 75 gal. of water per cu.ft. of resin. Due to the large volume of water needed studies should be made to see if some of it could not be used more than once.

The first 1/5 of the rinse water will be pushed through at a rate of 0.5 gal./cu.ft./min. while the last 4/5 will be pushed through at a rate of 1.5 gal/cu.ft./min.

Volume of wash water = 372 x 75 = 27900 gal.

First rinse time = 27900 (1/5)/0.5 x 372 = 30 min.

Second rinse time = 27900 (4/5)/1.5 x 372 = 40 min.

The cost of the water was calculated at $0.05 per 1000 gal.

Similar calculations were made for the cation cells the results of which are found in Tables I, II and III.

Building and Equipment Costs

From Table III the total delivered plant equipment cost = $135,000

Installation costs= 43% of the delivered equipment cost (13)

= 135,000 (0.43) = $58,000

Installed equipment cost = 135,000 + 58,000 = $193,000

Building cost = 20% of the installed equipment cost (13)

= 193,000 (0.20) = $38,600

Piping cost = 86% of the delivered equipment cost (13)

Total Building and Equipment cost = 135,000 + 58,000 + 38,600 + 116,000

= $ 347,600 or $348,000

The building and equipment will be depreciated over a period of 10 years at the end of which it will have no value.

Allowance for depreciation = 348,000 (0.10) = $34,800/yr.

Operating costs

Labor for operation: 2 men per shift at $2.50 per man per day

= 2 x 3 x 2.50 x 150 = $2250

Labor for maintenance: 3 men working one shift a day for 250 days a year at $2.50 per man per day

Labor for maintenance = 3 x 1 x 2.50 x 250 = $1875

Anion resin replacement: 10% of the resin volume are assumed to be added each season.

cost of anion resin replacement = 24600 x 0.10 = \$2460

cost of cation resin replacement = 8950 x 0.10 = \$895

(both costs are at the 1949 price level)

The 1953 prices are \$2740 and \$1000 respectively.

Cost of caustic per season = \$67,000

Cost of acid per season = \$28,000

cost of water for washing = \$8760

cost of extra sacks = \$0.05 x 80,000 = \$4,000

Allowance for depreciation = \$34,800

Total operating costs = \$150,000

Sales and Gross profit

Cost of sugar, refined = \$12.30 per picul

Cost of sugar, raw = \$8.65 per picul

The actual income attributable to the deionization units would be the increase in quality of the first 84% extracted plus the extra 8% extracted due to the use of the deionization units.

Income = 835,000 (12.30 - 8.65) + 80,000 (12.30)

= \$4,034,000

Gross profit = \$4,034,000 - \$150,000 = \$3,884,000

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