

AN EVALUATION OF SUCROSE INVERSION AND MONOSACCHARIDE DEGRADATION ACROSS EVAPORATION AT DARNALL MILL

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Abstract

High temperature exhaust steam (180 to 190°C) is used in the Kestner pre-evaporators at Darnall mill. Experiments were undertaken to determine the effects of high steam temperatures and high retention times on sucrose and monosaccharide degradation. Gas chromatography was used to determine glucose, fructose and sucrose in and out of these vessels. Glucose losses were found to be negligible, and the glucose/brix and/or glucose/chloride ratios are sensitive indicators of inversion. Measured sucrose losses across the Kestners and evaporator tail were a function of retention time rather than steam temperature. Colour formation was noticeable, and was attributed to fructose degradation.

Introduction

The process staff at Darnall were concerned about several aspects of evaporator operations, viz.

- high exhaust steam temperatures (180 to 190°C)
- high syrup temperatures in the Hulvap last effect
- irregular syrup flow patterns in the Fletcher tail.

The layout of the Darnall evaporator station is shown in Figure 1.

The Sugar Milling Research Institute (SMRI) were approached to undertake an analytical survey of sucrose and monosaccharides across the evaporator station with a view to providing some answers to the above concerns.

The SMRI were keen to undertake this project as Darnall offered a unique opportunity to test current sampling and analytical techniques for the detection of inversion in an industrial situation.

Experimental Procedure

A project of this nature is meaningless unless extreme care is taken with the sampling and analytical procedures. The details of these are contained in Appendix 1.

Results

The analytical results and calculated ratios for the four days are tabulated in Appendices 2 to 5. Most of the results are referenced to either brix or chloride. The daily figures for each

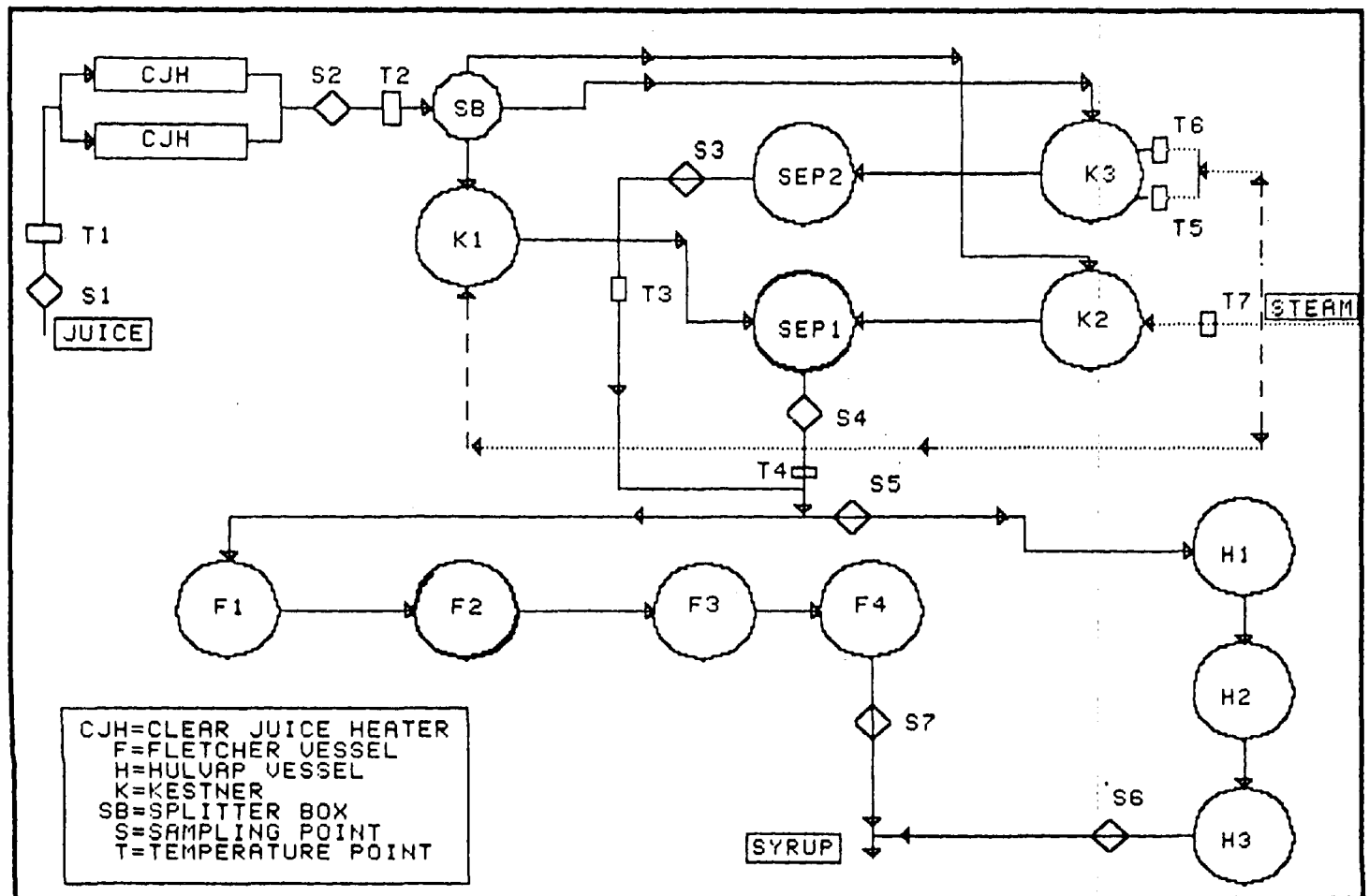


FIGURE 1 Evaporation station at DL (solid line = juice flow, dotted line = steam flow).

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stream were averaged, and normalised with clear juice (CJ) as the reference (Appendix 6).

The results and ratios relevant to this paper have been extracted from this data; these are presented in Table 1.

TABLE 1
Averaged ratios for measuring sugar losses

	CJ	CJH	SEP1	SEP2	KO	H3	F4
Brix	11,67	11,67	16,11	22,97	17,22	66,47	65,58
Bx/Cl	100,00	99,35	100,28	99,81	—	100,67	99,99
S/Cl	100,00	98,98	99,81	99,70	—	—	—
S/Bx	100,00	99,64	99,49	99,92	—	—	—
(F+G)/S	100,00	100,42	100,71	102,73	100,00	101,73	101,92
F/Cl	100,00	99,42	99,71	100,58	—	—	—
F/Bx	100,00	99,89	99,35	100,72	—	—	—
G/Cl	100,00	100,00	101,48	104,48	—	—	—
G/Bx	100,00	100,68	101,06	104,50	100,00	100,52	101,63
F/G	100,00	99,24	98,27	96,38	100,00	98,78	98,15

Discussion

Sucrose Inversion

Inversion was measured across the Kestners and across the last effects of the two evaporator tails. The brix/chloride ratios in Table 1 indicate that either brix or chloride can be used as a base to reference against. (Mean Bx/Cl ratio for the 6 products = 100,0, RSD = 0,4%).

(1) **Kestners:** Kestners 1 and 2 have a heating surface of 1677 m² each, and both discharge into separator 1. Kestner 3 has a larger heating surface of 1982 m², and this discharges into separator 2. The three Kestners are fed from a common splitter box. The brix of the juice leaving separator 2 was higher than that from separator 1 (Table 1). An inspection of the splitter box revealed that the juice was not being distributed to the Kestners in the ratio of their heating surfaces. This maldistribution resulted in a longer juice retention in Kestner 3 than in the other two vessels.

If sucrose is referenced against brix and chloride for CJ, CJH, SEP1, and SEP2, spurious relationships are obtained (Table 1). The levels of sucrose destroyed are extremely small, and these are of the same order of magnitude as accepted experimental error. This explains the anomalous results, and why these ratios are unacceptable as a method of measuring inversion.

Sucrose inversion is therefore often monitored indirectly by observing changes in the reducing sugars/pol ratio. These have been calculated for the evaporator front end using GC results (Table 1), and (F+G)/S ratios increase from CJ to the juice leaving the separators, with separator 2 giving a higher value than separator 1. A higher ratio from separator 2 coincides with a higher juice retention in Kestner 3 which discharges into this separator. This increasing ratio indicates that inversion is taking place across the CJ heaters and the Kestners.

A more sensitive method is now required to quantify the sucrose loss. The measurement of the changes in the fructose and glucose levels provides a possible basis for calculation of inversion by inference. If the fructose/glucose ratio is considered, it can be seen that the ratio decreases from CJ to juice leaving the separators (Table 1). Since fructose and glucose are produced in equal quantities during inversion, the decreasing ratio indicates a preferential destruction of fructose. The juice leaving separator 2 has a lower fructose/glucose ratio than that leaving separator 1, and therefore a higher rate of fructose destruction.

Clearly fructose is more labile than glucose, and is therefore unsatisfactory as an indicator of inversion.

Ignoring, for the moment, the possibility of glucose destruction, the percentage glucose production in the front end vessels is shown in Table 2.

TABLE 2
Percentage glucose increase based on G/Cl and G/Bx ratios

	CJ	% Glucose increase		
		CJH	SEP1	SEP2
G/Cl	0,0	0,0	1,5	4,5
G/Bx	0,0	0,7	1,1	4,5

These percentage increases are greater than the allowable experimental error, and can therefore be accepted as a sensitive indicator of inversion.

Since the juice concentrates during the process, glucose and sucrose must be referenced to brix and/or chloride before the percentage sucrose loss can be calculated using the following formula:

$$\% \text{ S lost} = \left\{ \frac{\left(\left(\frac{\%G}{\text{Bx}} \right)_{\text{out}} - \left(\frac{\%G}{\text{Bx}} \right)_{\text{in}} \right)}{\left(\frac{\%S}{\text{Bx}} \right)_{\text{in}} \times MW_G} MW_S \times 100 \right\} \quad (1)$$

where: MW = molecular weight,
S = sucrose,
G = glucose

Table 3 contains details of the percentage sucrose lost referenced against brix and chloride.

TABLE 3
Percentage sucrose loss in evaporator front end

	CJH	SEP1	SEP2
% G/Bx out	1,77	1,78	1,84
% G/Bx in	1,76	1,77	1,77
% S/Bx in	85,50	85,14	85,14
% G/Cl out × 0,1	33,62	34,17	34,61
% G/Cl in × 0,1	33,72	33,62	33,62
% S/Cl in × 0,1	1641,12	1623,53	1623,53
Mol. Wt. G	180	180	180
Mol. Wt. S	342	342	342
% S Loss/Bx	0,02	0,02	0,16
% S Loss/Cl	—	0,03	0,12
Ave % S Loss	0,02	0,025	0,14

Honig⁵ has calculated that the average sucrose losses during evaporation are very low (0,02%), and that the maximum loss should not exceed 0,2%. The sucrose loss can also be calculated using established inversion tables (6,11,12):

Assuming: CJ Temp 116°C
pH 6,2 at 116°C
Residence time 3 mins
Calculated % sucrose loss 0,04

The losses across the clear juice heaters and separator 1 (Table 3), appear to conform with these predicted values, but the losses across separator 2 are substantially higher. The heaters and Kestners are all supplied with superheated (180 to 190°C) exhaust steam, with no deleterious effects on the juice in the heaters and Kestners 1 and 2.

The extended juice retention in Kestner 3 is the only apparent reason for increased sucrose losses in this vessel. The superheated exhaust steam may accelerate this inversion, but the extent of its effect is not quantifiable.

The effects of glucose destruction on the calculation of sucrose losses must now be considered. Saprano⁹ & Koltschewa⁹ have carried out laboratory trials to study glucose losses, and

using this information, a revised sucrose loss can be calculated (Appendix 7).

Even when extremely adverse parameters are used in this calculation, compensation for glucose degradation increases the sucrose loss in Kestner 3 by only 0,03%.

Along with temperature and retention, pH is the other major variable affecting inversion. Target values are 7,0 to 7,1. The average CJ pH at 25°C during the test was 7,44. Therefore the reasonably low inversion rates encountered in separator 1 could partly be due to the marginally higher CI pH.

(2) **Sucrose inversion in the last effect evaporators:** The values of the monosaccharide/sucrose ratios of F4 and H3 when normalised to the combined juice leaving the Kestners, show that inversion is taking place (101,9 for F4 and 101,7 for H3, see Table 1).

The recovery ratios of G/Brix have been normalised with the composited Kestner out juice in Table 4.

TABLE 4

Glucose/ brix ratios in evaporator back end

G/Bx	KO	H3	F4
	100,00	100,52	101,63

Sucrose loss in these last effects can be calculated using equation 1 (Table 5).

TABLE 5

Percentage sucrose loss in evaporator back end

	KO	H3	F4
% G/Bx out	1,79	1,80	1,82
% G/Bx in	1,77	1,79	1,79
% S/Bx in	85,14	87,90	87,90
% G/Cl out × 0,1	34,84	34,85	35,00
% G/Cl in × 0,1	33,66	34,84	34,84
% S/Cl in × 0,1	1623,53	1706,43	1706,43
Mol. Wt. G	180	180	180
Mol. Wt. S	342	342	342
% S Loss/Bx	—	0,02	0,06
% S Loss/Cl	—	0,00	0,02
Ave % S Loss	—	0,01	0,04

The sucrose losses in the Fletchers are marginally higher than those in the Hulvaps. The syrup flow to the Fletchers is not automatically regulated, unlike that to the Hulvaps, and this often leads to reduced throughputs and therefore increased syrup retentions in these vessels. It is interesting to note that the average syrup temperature in the Fletchers was 8°C lower than the Hulvap syrup. This indicates that the effect of increased retention outweighed the effect of high temperature.

The higher than normal pH values of syrup in both the Hulvap and Fletcher (6,4 and 6,5 respectively), may have assisted in reducing the inversion rates.

Monosaccharide Degradation

The percentage fructose and glucose degradation from clear juice to syrup is clearly illustrated by referencing these two products against brix and chloride (Table 6).

TABLE 6

Percentage fructose and glucose degradation from clear juice to syrup

	CJ	CJH	SEPI	SEP2	KO	H3	F4
G/Bx	100,00	100,68	101,06	104,50	102,15	102,69	103,80
G/Cl	100,00	100,00	101,48	104,45	—	103,37	103,81
F/Bx	100,00	99,89	99,35	100,72	99,72	99,07	98,38
F/Cl	100,00	99,42	99,71	100,58	—	99,73	98,37

It has already been established that glucose degradation is negligible across the evaporator station. Fructose loss however is more significant.

An indication of the total fructose destruction that takes place can be obtained by determining the difference between the fructose and glucose levels in the two syrup streams (Table 6). This is based on the assumption that for every unit of glucose formed, a unit of fructose is formed, and that the initial quantities are equal. There was, in fact, a negligible difference between these two levels in clear juice (0,005%). The total fructose destructions are:

CJ to Hulvap Syrup 3,6%
CJ to Fletcher Syrup 5,4%

The fructose/glucose ratios across the evaporators confirms the preferential overall degradation of fructose. This is illustrated in Figure 2.

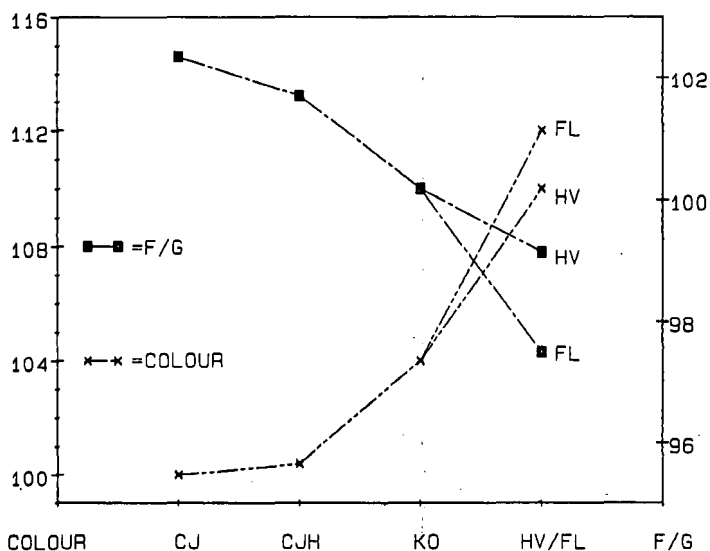


FIGURE 2 Colour and F/G changes during syrup production at DL.

There is an apparent purity (pol/brix) rise across the evaporator station, as shown in Appendix 6. This is caused by the reduced laevo-rotatory effect on pol measurement due to fructose destruction.

A small but noticeable rise in both colour and phenolics was observed (Figure 2 and Appendix 6). The colour increase is almost certainly due to fructose degradation. The increase in phenolics might have been due to the interference of fructose degradation products with the Folin-Ciocalteu reagent.⁴

Conclusion

The following conclusions can be drawn:

- Brix and chloride can be used as a base to monitor changes in glucose and fructose.
- Under the test conditions glucose was found to be a sensitive monitor of inversion, and the effect of glucose destruction on the estimated sucrose loss was minimal.
- Product retentions in Kestner 3 and the Fletcher vessels were abnormally high.
- The inversion and monosaccharide destruction rates were higher in the vessels with high product retention times.
- A high apparent purity rise across the evaporator station can be indicative of fructose destruction.
- Estimates of inversion using glucose as a monitor were much higher (0,1 to 0,2%) than estimates obtained using inversion tables.

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APPENDIX I

Experimental

Sampling - Samples from each sampling point (S1-S7 in Figure 1) were collected every 15 minutes over a four to six hour period for four consecutive days.

Sampling points - three existing points were used. They were clear juice out of the clarifier (S1), syrup out of the Hulvaps (S6), and syrup out of the Fletcher (S7). New sampling points were fitted to the outlets of the clear juice heater (S2), separator 2 (S3), separator 1 (S4) and a combined sample point leaving the Kestners (S5).

Cooling - The hot juice samples were passed through 4 metre copper coils (4 mm OD) which were suspended in 15 litre buckets. Prior to the sampling, cold water was added to the buckets, and juice was allowed to flow through the coils for one minute before sampling. Plastic 100 ml bottles were used to collect the samples. Syrup samples were not cooled.

Syrup Samples - These samples were collected in clear 2,5 litre glass bottles attached by means of a vacuum line to the outlet pipe of either H3 or F4 (Figure 1). Approximately two litres of syrup was obtained in 15 minutes. This approach was more reliable than the use of rotary gear pumps.

Storage - A 50 ml aliquot of each sample was sealed in a prelabelled plastic sachet. A drop of mercuric chloride preservative was added to the rest of the sample and a 50 ml aliquot of this was also sealed in a labelled sachet. Samples were rapidly frozen and stored in a freezer, and later transported to the SMRI.

Compositing - A daily composite of each stream (preserved and unpreserved) was prepared from all the individual sachets. Composites were split for the different analyses and then refrozen.

Temperature Measurement - Thermowells plus thermocouples were fitted (Figure 1) to the following steam and process streams.

- CJ out of clarifier (T1)
- CJ out of heater (T2)
- Juice out of separator 2 (T3)
- Juice out of separator 1 (T4)
- Steam into K3, mill side (T5)
- Steam into K3, boiler side (T6)
- Steam into K2 (T7)

The thermowells in the juice pipes were oil filled and the thermocouples pushed in and sealed with 'Prestick'. All 4 thermocouples were connected to a multi-pen recorder. The steam lines were fitted with large 0 to 200°C gauges and the temperatures were read manually every 15 minutes.

Analyses - The following analyses were performed on the composites:

- Brix and pol (1)
- Chloride (Cl) by potentiometric titration (3) on the unpreserved samples.
- Fructose (F), glucose (G) and sucrose (S) by GC (10).
- Total phenolics by Folin-Ciocalteu procedure (7).
- Total amino-nitrogen by the ninhydrin method (8).
- Colour at 420 nm (2).
- pH and temperature coefficients.

APPENDIX II

Day 1							
Analysis	CJ	CJH	SEP1	SEP2	KO	H3	F4
Brix	11,36	11,29	15,33	22,84	16,51	67,53	64,95
Chloride × 10	,59	,591	,789	1,183	,857	3,447	3,334
Pol	9,67	9,62	13,04	19,5	14,1	58,26	55,98
Sucrose	9,691	9,596	13	19,37	NA	NA	NA
Fructose	,224	,2214	,301	,4492	NA	NA	NA
Glucose	,214	,215	,294	,448	NA	NA	NA
Amino Acid	73	72	101	150	105	399	394
Phenols	593	599	789	1245	882	3739	3740
Colour	18400	18200	18000	19200	17900	19000	19700
Temp.	98	110	NA	NA	NA	NA	NA
Results							
Pol/Suc	,998	1,003	1,003	1,007	NA	NA	NA
Gluc/Suc	2,208	2,241	2,262	2,313	NA	NA	NA
Fruc/Suc	2,311	2,307	2,315	2,319	NA	NA	NA
Gluc/Cl × 0,1	,3627	,3638	,3726	,3787	NA	NA	NA
Fruc/Cl × 0,1	,3797	,3746	,3815	,3797	NA	NA	NA
Suc/Cl × 0,1	16,43	16,24	16,48	16,37	NA	NA	NA
Gluc/Bx	1,884	1,904	1,918	1,961	NA	NA	NA
Fruc/Bx	1,972	1,961	1,962	1,967	NA	NA	NA
Suc/Bx	85,31	85	84,8	84,81	NA	NA	NA
Pol/Bx	85,12	85,21	85,06	85,38	85,4	86,27	86,19
Fru/Glu	1,047	1,03	1,024	1,003	NA	NA	NA
Phen/Cl	1,005	1,014	1	1,052	1,029	1,085	1,122
Amin/Cl	,124	,122	,128	,127	,123	,116	,118

Notes: - All analyses are expressed in %W/W unless otherwise stated.
Amino acids and phenolics are expressed in ppm.
Colour is expressed in icumsa colour units.
CJ = Clear Juice. CJH = CJ Heater. SEP = Separator.
KO = Kestner Out. H3 = Hulvap out. F4 = Fletcher out.

APPENDIX III

Day 2							
Analysis	CJ	CJH	SEP1	SEP2	KO	H3	F4
Brix	11,45	11,45	15,96	22,34	17,51	67,74	67,05
Chloride × 10	,604	,605	,833	1,172	,901	3,595	3,557
Pol	9,82	9,82	12,95	19,26	15,1	58,71	58,32
Sucrose	9,765	9,788	13,466	19,2	NA	NA	NA
Fructose	,194	,196	,266	,385	NA	NA	NA
Glucose	,194	,194	,267	,394	NA	NA	NA
Amino Acid	62	63	86	120	100	380	366
Phenols	583	588	834	1211	930	3885	3915
Colour	17900	17600	17500	18200	18000	19200	20500
Temp.	99	113	NA	NA	NA	NA	NA
Results							
Pol/Suc	1,006	1,003	,962	1,003	NA	NA	NA
Gluc/Suc	1,987	1,982	1,983	2,052	NA	NA	NA
Fruc/Suc	1,987	2,002	1,975	2,005	NA	NA	NA
Gluc/Cl × 0,1	,3212	,3207	,3205	,3362	NA	NA	NA
Fruc/Cl × 0,1	,3212	,324	,3193	,3285	NA	NA	NA
Suc/Cl × 0,1	16,17	16,18	16,17	16,38	NA	NA	NA
Gluc/Bx	1,694	1,694	1,673	1,764	NA	NA	NA
Fruc/Bx	1,694	1,712	1,667	1,723	NA	NA	NA
Suc/Bx	85,28	85,48	84,37	85,94	NA	NA	NA
Pol/Bx	85,76	85,76	81,14	86,21	86,24	86,67	86,98
Fru/Glu	1	1,01	,996	,977	NA	NA	NA
Phen/Cl	,965	,972	1,001	1,033	1,032	1,081	1,101
Amin/Cl	,103	,104	,103	,102	,111	,106	,103

Sugar/Bx and sugar/sucrose ratios are expressed as percentages, where sugar refers to monosaccharides and sucrose

APPENDIX IV

Day 3							
Analysis	CJ	CJH	SEP1	SEP2	KO	H3	F4
Brix	11,97	11,99	16,55	22,99	17,6	67,11	65,28
Chloride × 10	,632	,631	,876	1,24	,928	3,55	3,487
Pol	10,17	10,18	14,14	19,7	15,03	57,99	56,22
Sucrose	10,257	10,179	14,146	19,645	NA	NA	NA
Fructose	,222	,22	,304	,423	NA	NA	NA
Glucose	,221	,223	,311	,441	NA	NA	NA
Amino Acid	73	75	100	145	113	400	443
Phenols	643	654	892	1418	1000	3968	4034
Colour	17000	16900	17200	18000	17300	19800	20500
Temp.	98	112	114	115	NA	NA	NA
Results							
Pol/Suc	,992	1	1	1,003	NA	NA	NA
Gluc/Suc	2,155	2,191	2,199	2,245	NA	NA	NA
Fruc/Suc	2,164	2,161	2,149	2,153	NA	NA	NA
Gluc/Cl × 0,1	,3497	,3534	,355	,3556	NA	NA	NA
Fruc/Cl × 0,1	,3513	,3487	,347	,3411	NA	NA	NA
Suc/Cl × 0,1	16,23	16,13	16,15	15,84	NA	NA	NA
Gluc/Bx	1,846	1,86	1,879	1,918	NA	NA	NA
Fruc/Bx	1,855	1,835	1,837	1,84	NA	NA	NA
Suc/Bx	85,69	84,9	85,47	85,45	NA	NA	NA
Pol/Bx	84,96	84,9	85,44	85,69	85,4	86,41	86,12
Fru/Glu	1,005	,987	,977	,959	NA	NA	NA
Phen/Cl	1,017	1,036	1,018	1,144	1,078	1,118	1,157
Amin/Cl	,116	,119	,114	,117	,122	,113	,127

APPENDIX V

Day 4							
Analysis	CJ	CJH	SEP1	SEP2	KO	H3	F4
Brix	11,91	11,93	16,61	23,69	17,27	63,48	65,04
Chloride × 10	,606	,619	,849	1,2	,861	3,169	3,288
Pol	10,23	10,27	14,34	20,44	14,92	56,97	55,32
Sucrose	10,2	10,179	14,204	20,238	NA	NA	NA
Fructose	,199	,2	,279	,406	NA	NA	NA
Glucose	,191	,193	,272	,403	NA	NA	NA
Amino Acid	77	78	110	159	118	432	406
Phenols	629	631	893	1285	913	3717	3753
Colour	17400	17100	17000	17300	17400	19000	20700
Temp.	99	113	116	116	NA	65	57
Results							
Pol/Suc	1,003	1,009	1,01	1,01	NA	NA	NA
Gluc/Suc	2,873	1,896	1,915	1,991	NA	NA	NA
Fruc/Suc	1,951	1,965	1,964	2,006	NA	NA	NA
Gluc/Cl × 0,1	,3152	,3118	,3204	,3358	NA	NA	NA
Fruc/Cl × 0,1	,3284	,3231	,3286	,3383	NA	NA	NA
Suc/Cl × 0,1	16,83	16,44	16,73	16,87	NA	NA	NA
Gluc/Bx	1,604	1,618	1,638	1,701	NA	NA	NA
Fruc/Bx	1,671	1,676	1,68	1,714	NA	NA	NA
Suc/Bx	85,64	85,32	85,51	85,43	NA	NA	NA
Pol/Bx	85,89	86,09	86,33	86,28	86,39	89,74	85,06
Fru/Glu	1,042	1,036	1,026	1,007	NA	NA	NA
Phen/Cl	1,038	1,019	1,052	1,071	1,06	1,173	1,141
Amin/Cl	,127	,126	,13	,133	,137	,136	,123

APPENDIX VI

Daily Average Ratios for Days 1 to 4							
Analysis	CJ	CJH	SEP1	SEP2	KO	H3	F4
Fructose	NA	NA	NA	NA	0,31	1,19	1,16
Glucose	NA	NA	NA	NA	0,31	1,20	1,20
Sucrose	9,98	9,94	13,70	19,61	15,14	57,29	56,75
Chloride × 10	0,61	0,61	0,84	1,20	NA	3,44	3,42
Pol/Suc	1,00	1,00	0,99	1,01	NA	NA	NA
Gluc/Suc	2,06	2,08	2,09	2,15	NA	NA	NA
Fruc/Suc	2,10	2,11	2,10	2,12	NA	NA	NA
Gluc/Cl × 0,1	0,34	0,34	0,34	0,35	NA	NA	NA
Fruc/Cl × 0,1	0,35	0,34	0,34	0,35	NA	NA	NA
Suc/Cl × 0,1	16,42	16,25	16,38	16,37	NA	NA	NA
Gluc/Bx	1,76	1,77	1,78	1,84	NA	NA	NA
Fru/Bx	1,80	1,80	1,79	1,81	NA	NA	NA
Suc/Bx	85,48	85,18	85,04	85,41	NA	NA	NA
Pol/Bx	85,43	85,49	84,49	85,89	85,86	87,27	86,09
Fru/Glu	1,02	1,02	1,01	0,99	NA	NA	NA
Phen/Cl	1,01	1,01	1,02	1,08	1,05	1,11	1,13
Amin/Cl	0,12	0,12	0,12	0,12	0,12	0,12	0,12
Colour	17675	17450	17425	18175	17650	19250	20350
Temp	99,00	112,00	115,00	116,00	NA	65,00	57,00
pH@25	7,44	7,41	7,15	7,05	7,18	6,43	6,54
ΔpH/ΔT	-0,01	-0,01	-0,01	-0,01	-0,01	-0,01	-0,01
pH@HTEMP	6,49	6,29	6,14	6,12	NA	6,11	6,25
Results							
Pol/Suc	100,00	100,40	99,40	100,60	NA	NA	NA
Gluc/Suc	100,00	101,07	101,65	104,57	NA	NA	NA
Fruc/Suc	100,00	100,24	99,86	100,81	NA	NA	NA
Gluc/Cl	100,00	100,00	101,48	104,45	NA	NA	NA
Fruc/Cl	100,00	99,42	99,71	100,58	NA	NA	NA
Suc/Cl	100,00	98,98	99,81	99,70	NA	NA	NA
Gluc/Bx	100,00	100,68	101,14	104,50	NA	NA	NA
Fru/Bx	100,00	99,89	99,39	100,72	NA	NA	NA
Suc/Bx	100,00	99,64	99,48	99,92	NA	NA	NA
Pol/Bx	100,00	100,07	98,90	100,53	100,00	101,65	100,27
Fru/Glu	100,00	99,22	98,24	96,39	NA	NA	NA
Phen->C.J	100,00	100,40	101,19	106,86	104,37	110,74	112,33
Phen->K.O	100,00	100,40	101,19	106,86	100,00	106,10	107,62
Amin->C.J	100,00	100,00	100,85	101,69	104,24	100,00	100,00
Amin->K.O	100,00	100,00	100,85	101,69	100,00	95,93	95,93
Col->C.J	100,00	98,73	98,59	102,83	99,86	108,91	115,13
Col->K.O	100,00	98,73	98,59	102,83	100,00	109,07	115,30

APPENDIX VII

COMPARISON BETWEEN ESTIMATES OF INVERSION WITH AND WITHOUT GLUCOSE LOSS COMPENSATION

Sapranov⁹ has carried out laboratory trials to study glucose losses. He found that for pH levels greater than 4,5 the rate of loss could be expressed in terms of temperature and pH:

$$\log_{10} k = 25,01 - \frac{10260}{T} - 0,017053T + 0,77pH \dots \dots \dots (2)$$

where:
 k = first order degradation constant of glucose (per min)
 T = temperature in degrees Kelvin

A first order reaction can be expressed by:

$$x = G_0 \cdot (1 - e^{-kt}) \dots \dots \dots (3)$$

where:
 x = glucose lost in time t (minutes)
 G₀ = original glucose concentration

The amount of glucose produced from sucrose can be derived as follows:

Let:
 G₀ = original glucose concentration (measured by GC)
 G_r = final glucose concentration (measured by GC)
 G_m = glucose made from sucrose
 G_i = glucose destroyed

Then:

$$G_r = G_0 + G_m - G_i$$

$$= G_0 + G_m - (G_0 + G_m) \cdot (1 - e^{-kt}) \dots \dots \dots (4)$$

Simplifying (4)

$$G_m = \frac{G_r}{e^{-kt}} - G_0 \dots \dots \dots (5)$$

Therefore, to estimate the amount of sucrose lost in the Kestners at Darnall, the following information is required:

Average juice temperature, pH at 25°C, ΔpH/ΔT, residence time, glucose in and glucose out of the Kestner. All these variables, except temperature, can be obtained with adequate accuracy. If an extreme juice temperature of 135°C is used, and the conditions prevailing in separator 2 are also used, it is possible to compensate for any glucose destruction by using equation (5) as shown in Table 7.

TABLE 7

Comparison between estimates of sucrose inversion with and without glucose loss compensation (separator 2).

Juice Temperature (C)	=	135
pH ₂₅	=	7,41
$\Delta\text{pH}/\Delta\text{T}$	=	-0,013
pH at 135°C	=	6,00
k (per min)	=	0,00335
Residence time (min)	=	3
% Glucose/Brix in	=	1,77
% Glucose/Brix out	=	1,84
% Sucrose/Brix in	=	85,50
% Glucose Made/Brix	=	$\frac{1,84}{(e^{(-0,00335)(3)})} - 1,77$

% Sucrose Loss (no G loss Compensation) = 0,16

% Sucrose Loss (G loss Compensation) = 0,19

Under the experimental conditions listed in Table 7, it is obvious that the effects of glucose destruction on the accuracy of estimating inversion are minimal (0,03%).