SCALING OF EVAPORATOR TUBES OF NATAL SUGAR FACTORIES

Report on jnvestigations carried out in 1951 and 1952

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Introduction.

We are accustomed to regard scaling of evaporator tubes as a natural phenomenon which is largely outside our control. We know that scaling is heavy in some years and in others considerably less. We have a feeling that scaling tends to be more serious in factory A than in factory B, but quantitative data to confirm this feeling are usually lacking. We are so familiar with the occurrence of the phenomenon that we are even likely sometimes to underestimate the detrimental effects on processing.

These effects, however, are not slight. Not only does scaling force us to clean the evaporators weekly, but it seems also to be one of the causes of the undesirably low brix of syrup which is typical for Natal factories.

Studying scaling in the hope of finding means to reduce the rate at which the scale is deposited, or to alleviate its specific effect on heat transfer, is a rather thankless task, and has to be carried out in the firm belief that all bits of available knowledge, when systematically put together, will ultimately provide a clear picture which will allow us to control the phenomenon at our will. But we should not expect an easy solution of the problem which can be had for the taking.

In our plans for collecting more knowledge, however, we should be guided by a few well recognised principles and we should at all times be able to draw up a picture of the main facts which are known without a doubt, and of the questions which cannot definitely be answered: and in particular we should be able to recognise half-truths, the acceptance of which as full truths, may lead our work in the wrong direction.

I think we are safe in stating that scaling depends on two groups of factors: (*a*) juice properties, and (*b*) particulars of the evaporator plant, including the way it is operated. The importance of juice properties is immediately evident when we remember that carbonatation factories suffer far less from scaling than sulphitation and defecation factories, and that the normal rate of scaling of carbonatation factories can be reduced to an insignificant value by the application of ion-exchange. We must conclude that there is a definite correlation between the presence of certain components of the juice and the formation of the scale.

About the effect of particulars of the evaporator plant on the amount of scale deposited we have little definite information. Does an oversized quad scale more heavily than a correctly sized one, and what about the rate of circulation inside the vessels ?

In connection with the way the quad is operated the most important item is probably the brix to which the juice is concentrated. The higher the brix of the syrup, the heavier the scaling, and it has also been stated that working a quad intermittently, i.e. shutting it down for a few hours when less juice is produced, favours scaling.

In 1951 the S.M.R.I. started to collect data on the composition of the scale of some of the mills and some information was also gained on the amount of scale deposited in one week in the evaporator tubes of one mill (TS). The results of these tests were discussed in Communication from the S.M.R.I. No. 14, but they will also be shown here in so far as is necessary for a proper understanding of our conclusions. In 1952 the investigation was continued and it is envisaged that in coming years more work will be done on the subject.

The Chemical Composition of Natal Scales.

It is more or less ordinary routine for a chemist who wants to study scaling to ask what are the constituents of scale, but he should be quite aware of the limits of the information to be derived from analysing scale samples. Analytical data of scale samples can tell us:

(*a*) what components of the juice are not, or to a very slight extent only, present in scales, and are therefore probably not instrumental in scale formation;

(*b*) what are the main constituents of the scale. From this knowledge we may infer what components of the juice should be suspected of being most active in the scale forming phenomenon. We should, however, be careful, for knowledge of the amount of scale deposited is usually also required to draw definite conclusions;

(*c*) what chemicals are likely to be effective in cleaning operations.

They can also be used to find the correlation, if any, between the composition of the scale and its specific effect on heat transfer.

Since it is general experience—which was quantitatively confirmed by data found at TS mill in 1951 (Table 1)—that the rate of scaling rapidly increases from the first to the last vessel of the set, it was decided to study first the scaling of the last and penultimate vessels.

TABLE 1.

Average Weights in Grams of Dry Scale deposited in Six Days per square foot of H.S. in the Tubes of the Tongaat McNeil and Hagemann Quadruples.

	No. 1 vessel	No. 2 vessel	No. 3 vessel	No. 4 vessel
McNeil	0.12	1.68	3.68	10.5
Hagemann ...	0.32	2.56	4.24	10.3

Accordingly for 1952 an investigation was planned in which the mills were requested to collect quantitatively the scale formed, during one week in the middle of the season, in 15 tubes evenly distributed over the tube plate of No. 3 and No. 4 vessels respectively. The scale was to be dried, weighed and forwarded to the S.M.R.I. for analysis. It was requested that representative composite samples of mixed juice, clarified juice and syrup be collected simultaneously, and also some particulars concerning processing operations of that week.

The mills ZM, FX, AK, MV, TS and SZ responded to our request. Particulars of their evaporators are shown in Table 2.

[1] The calandria of the first vessel is divided into two equal sections both of which are heated by exhaust steam. The vapour from the first vessel heats the following vessel, and so on, in the normal way. The brix of the syrup was kept more or less constant throughout the week and averaged 52.9°. A "Superstat" was in use on the clarified juice between the Bach clarifier and the first vessel and operated on 0.85 amperes. The heating surface of No. 1 vessel is 10,000 sq. ft., of each of the following vessels 6,000 sq. ft. Brix ex first vessel was 17.9°.

[2] The evaporator is reported by the factory to consist of two pre-evaporators connected in series to two triple effects in parallel. The heating surfaces of the pre-evaporator are 8,400 and 7,000 sq. ft., of the triple effects 6,500 and 5,900 sq. ft. respectively. In general the brix is kept down at the beginning of the week. Vapour is used for heating purposes. The tubes of No. 2 triple effect are slightly larger than those of No. 1, which was sampled. Average brix of the syrup during the week of the tests was 49.2°.

[3] The four identical vessels have D calandria. The quad is working at a vacuum of 24 to 26 inches. The syrup standard density is set at 27° Bé (50°Bx) and the average daily brix values during the week of the tests were:

Monday	52.9°	Thursday	55.4°
Tuesday	56.9°	Friday	53.4°
Wednesday	54.4°	Saturday	51.5°

[4] The Melville Quadruple Effect Evaporator consists of four identical vessels. The type of calandria is the side D-downtake. Only exhaust steam is used for heating purposes. It is understood to keep the brix at 52° in the beginning of the week. The average brix of the syrup during the week of the tests was 51.0°.

TABLE 2

PARTICULARS OF THE EVAPORATORS INVESTIGATED

Factory	ZM	FX	AK	MV	TS McNeil	TS Hagemann	SZ No. 2	SZ No. 3
Number of vessels...	5[1]	2×4[2]	4[3]	4[4]	4[5]	4[5]	4[6]	4[6]
Total heating surface (sq. ft.)	34,000	27,800	25,500	9,500	24,000	15,000	8,000	15,000
Length of tubes, 1st vessel (ft.)	6–6¾	—	6–4⅝	5	—	—	5–0½	5
Diameter of tubes, 1st vessel (ins.) ...	1⅞	—	1 13/16	2	—	—	1⅞	1⅞
Diam. of tubes, following vessels (ins.)	do.	2	do.	do.	—	—	do.	do.
Number of tubes, 1st vessel	3,221	2,658/2,253	2,105	943	2,460	1,350	807	1,504
Number of tubes, 3rd and 4th vessels.	2,425	2,031/1,824	do.	do.	do.	do.	do.	do.
Tons cane crushed in week of test ...	13,637	12,798	12,752	5,167	23,696		11,370 (1)	
							12,221 (2)	
							12,702 (3)	

[5] The method of heating of the two quadruple effects is normal, with exhaust steam being supplied to the calandria of No. 1 vessel. It is not possible to give the amount of juice handled by each evaporator separately, but the Hagemann was shut down for 37 hours during the week while the McNeil worked continuously for the whole week, i.e. 142 hours. Average daily brix values during the week of the tests were:

Monday	49.8°	Thursday	49.2°
Tuesday	50.8°	Friday	49.7°
Wednesday	48.9°	Saturday	49.2°

[6] There is a third quadruple effect at SZ similar to No. 2 quad which was not operated during the week of the tests. No. 3 quad was operated continuously, No. 2 quad was reported to be shut down for about 25 per cent. of the time of the first week of the tests.

Brix syrup during the three weeks of the tests was: 54.6°, 54.5° and 55.1° respectively.

No vapour is used for heating purposes. The syrup brix on Saturdays is raised slightly (28° Bé) to improve preservation during week-ends.

TABLE 3

COMPOSITION OF SCALE SAMPLES COLLECTED FROM No. 3 VESSELS OF SOME NATAL MILLS IN 1951 AND 1952

Factory	ZM[1]	FX	EN	AK	—	MV	TS	TS	TS	—	SZ	SZ	SZ[6]	SZ[6]	SZ[6]	SZ[6]	SZ[6]	SZ
							McNeil	Hagemann	McNeil		No. 2	No. 3	No. 2 (1)	No. 2 (2)	No. 2 (3)	No. 3 (1)	No. 3 (2)	No. 3 (3)
	1951	1952	1951	1952	—	1952	1951[4]	1951[4]	1952	—	1951	1951	1952	1952	1952	1952	1952	1952
SiO_2 and matter insoluble in HCl (per cent.)	43.4	26.9	3.6	2.0	—	10.8[3]	11.2	1.2	15.3	—	66.7	65.7	64.9	72.9	55.0	31.7	5.4	Insufficient for analysis
$CaSO_4$	1.9	34.9	18.8	34.3	—	7.2	17.1	10.9	13.4	—	13.8	5.2	9.0	7.6	18.3	1.6	2.1	
$CaSO_3$	0.9	14.3	51.4	34.3	—	50.9	38.3	55.2	48.1	—	2.2	1.6	0.4	0.7	1.9	1.1	0.1	
CaO bound otherwise	0.3	2.2	—	3.0	—	4.9	4.6	4.2	1.3	—	3.3	7.1	0.5	1.2	0.7	7.5[5]	0.3	
P_2O_5	0.1	0.6	0.9	1.2	—	2.6	1.8	1.4	1.4	—	1.2	0.8	0.4	0.8	0.7	1.1	0.3	
$Fe_2O_3 + Al_2O_3$	0.7	0.4	0.1	0.7	—	1.4	0.8	0.7	0.4	—	0.4	1.1	0.1	0.4	0.3	0.6	0.1	
Organic matter, water in excess of moisture expelled at 105°C etc.	36.4	20.7	25.2	24.2[2]	—	22.2	26.2	26.4	19.6	—	12.4	18.5	18.0	16.3	23.1	56.5	91.7	

The vessel referred to is actually the penultimate, i.e., the fourth vessel.

[2] Copper present in some quantity.

[3] Sand present.

[4] Averages of nine samples taken at nine consecutive week-ends.

[5] CaO bound as oxalate 6.0 per cent.

[6] SZ—1952—samples were taken at three consecutive week-ends, here distinguished as (1), (2) and (3). Also see text.

TABLE 4

COMPOSITION OF SCALE SAMPLES COLLECTED FROM No. 4 VESSELS OF SOME NATAL MILLS IN 1951 AND 1952

Factory	ZM[1]	FX	EN	AK	DL[2]	MV	TS[4]	TS[4]	TS	RN	SZ	SZ	SZ[5]	SZ[5]	SZ[5]	SZ[5]	SZ[5]	SZ[5]
							McNeil	Hagemann	McNeil		No. 2	No. 3	No. 2 (1)	No. 2 (2)	No. 2 (3)	No. 3 (1)	No. 3 (2)	No. 3 (3)
	1951	1952	1951	1952	1951	1952	1951	1951	1952	1951	1951	1951	1952	1952	1952	1952	1952	1952
SiO_2 and matter insoluble in HCl (per cent.)	16.8	10.6	4.0	6.2	8.7	22.9[3]	11.6	10.9	8.3	5.8	17.2	29.3	10.6	16.6	12.4	19.4	20.4	18.4
$CaSO_4$	37.8	57.5	36.6	60.8	30.4	23.1	13.3	21.2	25.7	84.4	70.3	51.3	63.8	62.2	66.4	45.8	46.8	51.9
$CaSO_3$	7.4	8.8	42.0	26.7	48.3	39.4	40.3	38.9	48.8	2.9	3.0	4.2	2.0	2.1	2.5	3.4	3.5	3.4
CaO bound otherwise	0.3	0.6	2.2	—	1.0	1.0	6.8	5.2	1.2	—	0.2	—	0.8	0.1	—	0.4	1.1	0.2
P_2O_5	0.3	0.3	0.3	0.3	—	0.4	0.7	0.8	0.6	0.5	0.6	0.5	0.4	0.4	0.4	0.5	0.5	0.5
$Fe_2O_3 + Al_2O_3$	1.0	0.3	0.25	trace	0.5	0.7	(0.5)	—	0.2	0.4	0.3	0.3	0.3	0.2	0.2	0.8	0.2	0.3
Organic matter, water in excess of moisture expelled at 105°C etc.	29.2	21.8	14.6	7.6	11.1	12.4	26.8	31.9	15.2	6.0	7.0	14.4	22.1	18.3	18.4	29.7	27.5	25.3

[1] The vessel referred to is actually the last, i.e. the fifth vessel.

[2] Data kindly provided by I.C.I. Ltd.

[3] Sand present.

[4] Averages of nine samples taken at nine consecutive week-ends.

[5] SZ—1952—samples were taken at three consecutive week-ends, here distinguished as (1), (2) and (3). Also see text.

TABLE 5

TOTAL WEIGHTS, AND WEIGHTS PER SQUARE FOOT H.S. OF SCALE DEPOSITED IN ONE WEEK IN No. 3 and No. 4 VESSELS RESPECTIVELY

Name of Factory	ZM	FX	AK	MV	TS	SZ (small quad) (1)	SZ (small quad) (2)	SZ (small quad) (3)	SZ (large quad) (1)	SZ (large quad) (2)	SZ (large quad) (3)
No. 3 vessel, total weight (tons)	0.015	0.21	0.046	0.074	0.158	0.022	0.004	0.013	0.002	0.006	—
No. 3 vessel, g per sq. ft. H.S. .	2.31	32.9	6.32	29.2	23.9	10.2	1.91	5.82	0.38	1.57	—
No. 4 vessel, total weight (tons)	0.018	0.484	0.401	0.267	0.228	0.137	0.052	0.126	0.063	0.283	0.252
No. 4 vessel, g per sq. ft. H.S. .	2.69	75.8	55.2	104.7	34.5	62.6	23.6	57.3	15.5	69.5	61.9

Note.—The total weight figures for ZM refer to the last and penultimate vessels; those for FX to the last and penultimate vessels of No. 1 triple effect; those for TS to the McNeil quad.

The analytical data of the scale samples are shown in Tables 3 and 4. Data of samples collected in 1951 are also included. At SZ, in connection with a special investigation which will be discussed later on, the 1952 investigation covered a period of three weeks, and samples were collected at each of the three week-ends. They are denoted as (1), (2) and (3) respectively.

The weights of scale deposited.

The weights of the scale deposited in one week (six working days) were determined in 1952 only, by collecting the scale from fifteen tubes which had been properly cleaned the previous week-end. Collecting the samples was carried out by the mills' staff. The total weights were calculated, and also the weights of the scale deposited per square foot of heating surface, for the calculation of which the inner diameter of the tubes was used. The weights are shown in Table 5.

Composition of mixed and clarified juices.

During the week which preceded the taking of the scale samples both mixed and clarified juice were sampled. The composite samples were disinfected with formalin and forwarded to the S.M.R.I. for analysis.

The factory purity figures for the week are reported in Tables 6 and 7 and also the percentages of the inorganic constituents, expressed per 100 brix in order to allow for the dilution due to the addition of formalin.

A sample of syrup was also taken for the determination of the amount of suspended solids. This figure was required as a basis with which to compare the quantity of scale deposited.

TABLE 6

MIXED JUICE. SULPHATED ASH AND ASH COMPONENTS ARE EXPRESSED AS PER CENTS. ON REFRACTOMETER BR X

Factory	ZM	FX	AK	MV	TS	SZ (1)	SZ (2)	SZ (3)
Brix (f)	14.8	14.6	15.5	16.0	16.2	13.84	14.18	14.14
Purity (gr.)	87.0	85.6	86.8	87.4	87.6	86.8	87.1	87.0
Brix (sample)	15.0	15.3	14.9	16.5	16.6	14.4	—	14.8
Sulph. ash	3.45	3.20	2.96	3.11	4.09	2.84	—	2.67
SiO_2 + insol.	0.37	0.32	0.31	0.36	0.24	0.20	—	0.19
CaO	0.14	0.11	0.12	0.10	0.12	0.14	—	0.13
MgO	0.31	0.32	0.38	0.29	0.31	0.30	—	0.29
Sesquiox.	0.18	0.14	0.24	0.16	0.10	0.24	—	0.10
Total SO_3...	0.48	0.54	0.52	0.48	0.55	0.57	—	0.51
Total P_2O_5	0.20	0.19	0.19	0.19	0.23	0.16	—	0.19

TABLE 7

CLARIFIED JUICE. SULPHATED ASH AND ASH COMPONENTS ARE EXPRESSED AS PER CENTS. ON REFRACTOMETER BRIX, SUSPENDED SOLIDS IN SYRUP AS PER CENTS. ON SYRUP

Factory	ZM	FX	AK	MV	TS	SZ (1)	SZ (2)	SZ (3)
Brix	15.7	14.2	14.1	15.6	16.5	13.7	52.4*	14.6
Sulph. ash	3.59	3.96	3.18	3.04	4.27	2.85	2.59	2.73
SiO_2 + insol.	0.13	0.12	0.12	0.11	0.10	0.10	0.10	0.12
CaO	0.36	0.38	0.38	0.28	0.30	0.25	0.24	0.23
MgO	0.28	0.27	0.31	0.26	0.28	0.28	0.29	0.27
Sesquiox.	0.06	0.06	0.04	0.03	0.02	0.01	0.01	0.00
Total SO_3...	0.54	0.65	0.59	0.50	0.69	0.60	0.67	0.63
Total P_2O_5	0.02	0.03	0.02	0.02	0.018	0.015	0.017	0.015
Susp. solids (syrup)	0.54	0.32	0.28	0.25	0.16	0.38	0.23	0.21

* Unfortunately the juice samples of the second week of the test were thrown away in error. In Table 7 the syrup figures are substituted for the clarified juice figures.

Discussion.

There is a theory that when a bubble of vapour is formed at the surface of a tube the solids contained in the drop of juice which is evaporated will be deposited on that part of the tube where the bubble is formed. However, since juice will stream past the deposit immediately after the bubble is removed from its point of formation, it is difficult to see why it should not dissolve from the deposit those components in respect of which the juice is undersaturated. Or in other words only those components in respect of which the juice is supersaturated, or perhaps also, nearly saturated, are likely to remain in the scale.

Whether this theory is quite correct we do not know, but it explains satisfactorily that scaling, in respect of the dissolved solids in juice, is a selective phenomenon, and it is conceivable that the selective action has something to do with the solubility of the constituents. Sucrose and reducing sugars are not present in scale, neither are alkali salts, and even magnesium salts whose percentage in clarified juice is of the same order as the percentage of lime salts, are usually absent, or present to only a slight extent. When studying scaling we seem to be allowed to disregard in the first instance the presence of this type of juice component.

A glance at Table 4 shows that (with one exception —ZM) the most important group of components of No. 4 vessel scales are the lime salts, and that calcium is mainly present as sulphate or sulphite. Lime salts formed more than half of the scales which were analysed, and AK shows the maximum amount of $CaSO_4$ plus $CaSO_3$, viz. 87.5 per cent.

As to the nature of the lime salts it is interesting to quote a report from Imperial Chemical Industries Ltd., where it was found by X-ray analysis that part of the calcium of Darnall scale was present as gypsum ($CaSO_4.2H_2O$) and part as an unknown substance, maybe a mixed crystal of calcium sulphite and calcium sulphate, possibly hydrated.

At ZM, FX, SZ and RN there is more $CaSO_4$ in the scale, at other mills (EN, DL, MV, TS) sulphite is predominant. The amount of CaO not present as sulphate or sulphite is insignificant. It is impossible to offer at this stage an explanation for the fact that the ratio of sulphate to sulphite varies so much for mills working on similar lines, although we tried to correlate this ration to the SO_2 content of clarified juice.

The second most important group of components is the group which in analytical routine is described as SiO_2 plus matter insoluble in HCl. The highest figure is shown by SZ in the 1951 scale from No. 3 quad, viz. 29.3 per cent. The high figure for MV (22.9 per cent.) is explained by fairly big sand particles embedded in the scale.

The third group of importance consists of the components described as "Organic matter, water in excess of moisture expelled at 105°C., etc." The figures for this group make it clear that organic matter, although scaling seems to be largely an inorganic phenomenon, cannot completely be disregarded.

Sesquioxides and P_2O_5 are present in such small quantities that their effect on the scaling of No. 4 vessels is very probably insignificant.[1]

The scale of No. 3 vessels usually contains more SiO_2, etc., and organic matter, etc., than the corresponding No. 4 vessel scales. Calcium sulphite and sulphate are present to a lesser extent and although

[1] Scale of first and second bodies contain relatively more P_2O_5.

CaO "bound otherwise" is sometimes higher, total CaO is usually lower.

The percentages of sesquioxides and P_2O_5 tend to be somewhat higher in No. 3 vessel scale than in No. 4 vessel scale, but are quantitatively of little importance. If No. 4 vessel scale contains relatively more sulphate than sulphite, the same can be observed in the No. 3 vessel scale, and *vice versa.*

In some of the scales Cu was found to be present, in a certain case to some extent. The brass filings which could easily be observed in the samples, show that mechanical scrapers do not always remove scale only.

(*a*) 1952 *Tests at SZ.*

In 1951 our attention was drawn to the fact that in particular SZ-scale was rich in SiO_2 and since Bogtstra[1] has indicated that the percentage of the silica present in clarified juice which is deposited in the evaporator set diminishes rapidly at higher P_2O_5 content of the clarified juice, it was decided to carry out an investigation to test a practical implication of Bogtstra's statement. SZ kindly agreed to double the normal amount of phosphoric acid paste in the second week of a three-weekly period, in the first and third week of which the phosphoric dosage would be normal.

It was hoped by increasing the phosphoric dosage to increase the P_2O_5 content of clarified juice by which the amount of SiO_2 deposited should be reduced. SZ follows the normal Natal clarification method of pre-liming, gassing and tempering, the phosphoric paste being admixed in the tempering tanks.

The weights of chemical agents used in the three weeks of the test were:

	Tons			lbs. per 1,000 lbs. brix in mixed juice		
	1st week	2nd week	3rd week	1st week	2nd week	3rd keek.
lime... ...	37	40	42	23.3	23.3	23.2
sulphur ...	16.9	18.0	18.9	10.6	10.5	10.5
phosphoric paste ...	5.1	11.1	6	3.21	6.45	3.32

In Table 8 are shown the weights of scale and of silica in scale deposited in the tubes of the No. 3 and No. 4 vessels of both quads. Also the weights of SiO_2 in clarified juice having passed the quads in each week, and the percentages of these weights deposited in scale.

The main conclusion from Table 8 is that doubling the dose of phosphoric has not reduced the total weight of SiO_2, etc., deposited in the scale of No. 3 and No. 4 vessels of both quads. On the contrary, in the second week of the test the weight was highest.

According to Bogtstra the weight should have been reduced if doubling the phosphoric paste dose had resulted in a higher P_2O_5 content of the clarified juice. This, however, was hardly the case. P_2O_5 in clarified juice in the three weeks of the test averaged 0.015, 0.017 and 0.015 per cent. respectively. The increase in the second week is insufficient to anticipate any notable effect on the rate of scaling and *the main result of the test is that it seems not permissible to give a practical interpretation to Bogtstra's conclusion by inferring that an increased dosage of phosphoric paste will reduce the weight of silica deposited in No. 3 plus No. 4 vessels, expressed as a percentage of the total weight of SiO_2 in clarified juice concentrated in the period under observation.*

Bogtstra has not specified the nature of the P_2O_5 to which he related the SiO_2 precipitation. Since P_2O_5 may be present in the organic and the inorganic form, it is not impossible that later on an explanation may be found on such differentiation.

TABLE 8

WEIGHTS OF SCALE, WEIGHTS OF SiO_2, ETC., IN SCALE AND IN CLARIFIED JUICE. PERCENTAGES DEPOSITED

	Grams scale			Grams SiO_2 in scale		
	1st week	2nd week	3rd week	1st week	2nd week	3rd week
No. 2 (small) quad—No. 3 vessel ...	23,833	4,035	12,374	15,468	2,942	6,806
do. No. 4 vessel ...	129,012	49,280	120,619	13,675	8,180	14,957
No. 3 (large) quad—No. 3 vessel ...	1,454	6,016	200	461	325	—
do. No. 4 vessel ...	58,251	262,781	232,603	11,301	53,607	42,799
Total g of scale, and of SiO_2 in scale	212,550	322,112	365,796	40,905	65,054	64,562
Kilograms of SiO_2 in clarified juice ...	—	—	—	1,430	1,542	1,939
Percentage of SiO_2 etc. deposited in III plus IV	—	—	—	2.9	4.2	3.3

[1] Archief v. d., suikerindustrie in Nederl. Indie, 40, III (1932) 957.

TABLE 9

RATE OF SCALING EXPRESSED AS LBS. OF SCALE DEPOSITED FOR EACH TON OF WATER EVAPORATED

	ZM	FX[1]	AK	MV	TS[2]	SZ[3] (1)	SZ (2)	SZ (3)
No. 3 vessel	0.003	0.083	0.009	0.038	0.033	0.005	0.002	0.003
No. 4 vessel	0.004	0.193	0.087	0.137	0.048	0.044	0.073	0.077
No. 3 + No. 4 vessel ...	0.007	0.276	0.095	0.175	0.080	0.050	0.075	0.080

[1] Assuming that each of the effects evaporated half of the water.
[2] Assuming that the McNeil effect evaporated $^{24}/_{30}$ths. parts of the water.
[3] Sum of the weights of scale deposited in corresponding vessels.

On the whole the data of Table 8 are somewhat irregular. No. 4 vessels scaled more heavily than No. 3 vessels. No. 3 vessels of the large quad scaled considerably less than No. 3 vessel of the small quad. The heavy scaling of the small quad in the first week is probably due to that quad being shut down for 25 per cent. of the time, generally only for a few hours at a time, when the juice could be allowed to stand in the various vessels.

Finally it is interesting to note that the increased phosphoric paste dosage resulted—according to SZ—in a better quality white sugar, which paid for the extra expenditure due to this increased dosage.

(*b*) *The rate of scaling.*

There is some confusion in literature about the correct way to express the rate of scaling. From a practical point of view one would be most interested in the reduction of the heat transfer coefficients or the various vessels per ton of water evaporated per square foot H.S., but failing data on heat transfer, and mainly considering the chemical aspects of the problem, the appropriate figure seems to be the weight of scale deposited in a vessel per ton of water evaporated by the whole set. In cases where factories operate two or more parallel quads, to calculate the rate of scaling the volume of juice which passed each quad should be known, or else the weights of the scale in the corresponding vessels of each quad should be added. Table 9 shows the data concerning the factories which participated in the 1952 test.

The most striking feature of Table 9 is the slight rate of scaling, which perhaps is even more pronounced if the rate of scaling is expressed as parts of scale per million parts of water evaporated—see Table 10.

It is interesting to compare the weights of scale deposited in No. 3 and No. 4 vessels with the weights of suspended matter in syrup. To obtain these last figures samples of syrup were centrifuged and the deposits washed with diluted alcohol and dried. Unfortunately it was not possible to determine the percentage directly after the syrup sample had been taken, so some material may have been precipitated during the period before the sample was analysed.

The weight of suspended matter in syrup is of course not necessarily a yardstick for the total amount of matter which became supersaturated and consequently was precipitated during the concentration process, for the clarified juice may not have been completely clear. In spite of these limitations, however, suspended matter in syrup may be regarded as matter which could well have been deposited on the tube walls during the concentration process. The percentages which were actually deposited are shown in Table 11.

Conclusion from Tables 9 to 11 are:

(i) it is tentatively suggested that normal figures for the rate of scaling of evaporators in Natal sugar factories are:

No. 3 vessel—5-15 parts of scale deposited per million parts of water totally evaporated;

No. 4 vessel—20-60 parts of scale deposited per million parts of water totally evaporated.

(ii) since the weight of scale deposited in No. 3 plus No. 4 vessels amounts usually to less than 10 per cent. of the amount of suspended solids in the syrup produced in the period the scale was formed, it is not expected that the amount of suspended matter in syrup will materially be increased when—

TABLE 10

RATE OF SCALING EXPRESSED AS PARTS (mg) OF SCALE DEPOSITED FOR EACH MILLION PARTS (kg) OF WATER EVAPORATED

	ZM	FX	AK	MV	TS	SZ (1)	SZ (2)	SZ (3)
No. 3 vessel	1.6	41	4.5	19	17	2.5	1.0	1.5
No. 4 vessel	1.9	97	44	69	24	22	36	39
No. 3 + No. 4 vessel ...	3.5	138	48	88	40	25	37	40

TABLE 11

PERCENTAGES OF SUSPENDED MATTER IN SYRUP WHICH WERE DEPOSITED IN No. 3 AND No. 4 VESSELS OF THE EXAMINED EFFECTS

	ZM	FX	AK	MV	TS	SZ (1)	SZ (2)	SZ (3)
Tons of suspended matter in syrup	21.1	12.2	9.79	4.03	11.6	10.9	7.17	6.98
Scale in No. 3 plus No. 4 vessel % susp. matter .	1.6	11.4	4.6	8.5	5.4	2.1	4.8	5.6

by some at present unknown means—the formation of scale in the evaporator is prevented.

(iii) of particular interest for a better understanding of the mechanism of scaling would be an explanation of the low rate of scaling of No. 3 vessels at SZ and of No. 3 and No. 4 vessels at ZM, and of the excessive scaling at FX.

It was further felt important to compare the composition of the suspended matter in syrup with the composition of the scales. An analysis of the suspended matter isolated from ZM syrup revealed the following composition:

Ignition loss	59.6	—
Ash...	40.4	100
Pure silica	28.0	69.3
Matter insol. in HCl ...	29.2	72.4
Calcium oxide	9.6	23.8
Phosphorus pentoxide...	0.21	0.53
Sulphate...	present	present

There is more similarity between No. 3 vessel scale of ZM and the suspended matter in syrup than between this latter component and No. 4 vessel scale which consists of 50-65 per cent. of $CaSO_4$ and $CaSO_3$. This fact opens new lines of thought on the formation of sulphite-sulphate scale at higher concentrations which make further investigations desirable.

(*c*) *Rate of scaling and juice composition.*

Since neither the brix values of clarified juice nor the brix values of syrup differ substantially amongst the various mills one would expect that a certain correlation would exist between the rate at which lime salts are deposited as scale and the lime salts content of clarified juice.

Table 12 shows mg CaO per litre clarified juice and the rate of formation of lime salts in scale (expressed as mg CaO in scale per kg water evaporated).

In the same way Table 13 shows the rate of formation of SiO_2 in scale as a function of the SiO_2 content of the clarified juice which is concentrated.

TABLE 12

PARTS OF CaO IN SCALE OF No. 3 PLUS No. 4 VESSEL DEPOSITED PER MILLION PARTS OF WATER EVAPORATED, AND mg/l CaO IN CLARIFIED JUICE

	ZM	AK	FX	TS	MV	SZ (1)	SZ (2)	SZ (3)
mg/l CaO in clarified juice	584	581	540	503	442	348	347	332
Rate of scaling of CaO in 3rd plus 4th vessel ...	0.79	17.5	36.5	13.1	26.0	5.79	8.23	9.84

TABLE 13

PARTS OF SiO_2 IN SCALE OF No. 3 PLUS No. 4 VESSEL DEPOSITED PER MILLION PARTS OF WATER EVAPORATED, AND mg/l SiO_2 IN CLARIFIED JUICE

	ZM	AK	SZ (3)	MV	FX	TS	SZ (2)	SZ (1)
mg/l SiO_2 in clarified juice	210	183	174	173	170	168	145	139
Rate of scaling of SiO_2 in 3rd plus 4th vessel ...	1.00	3.60	6.85	17.8	21.4	4.51	1.56	5.30

TABLE 14

RATE OF SCALING AND EVAPORATOR PERFORMANCE

	SZ (3)	MV	SZ (2)	TS	SZ (1)	AK	FX	ZM
Tons of water evaporated per sq. ft. H.S. per week	0.422	0.410	0.400	0.398	0.392	0.371	0.363	0.282
Rate of scaling	5.6	8.5	4.8	5.4	2.1	4.6	11.4	1.6

The conclusion to be drawn from Tables 12 and 13 is that, although there obviously must be some relationship between the rate of deposition of CaO and SiO_2 in the scales of the 3rd plus 4th vessels (expressed as mg per kg of water evaporated) and the content of CaO and SiO_2 respectively in the clarified juice which is evaporated, this correlation seems to be obscured by other factors which to a great extent tend to affect the rate of scaling.

Bogtstra suggested that one such factor was the P_2O_5 content of the clarified juice. Our data do not confirm this suggestion.

When the analytical data for FX clarified juice are compared with those of the other mills, it is obvious that they do not offer an explanation for the heavy scaling of the FX tubes. This heavy scaling must be due either to a juice property not shown by the normal analytical data, or to a particular feature of the evaporator.

(*d*) *Rate of scaling and the performance of the evaporator.*

It has sometimes been suggested that an oversized quadruple will scale more seriously than a correctly sized one. To test this assumption the total weight of evaporated water was divided by the total heating surface of the evaporator, and the quotient, expressed as tons per square foot, compared with the rate of scaling. Table 14 shows the results.

A definite relationship between the performance of the evaporator and the rate of scaling is not shown in Table 14.

(*e*) *The low rate of scaling at ZM.*

The third conclusion based on the data of Tables 9 to 11 refers a.o. to the low rate of scaling of No. 3 and No. 4 vessels of ZM. The ZM evaporator scaled considerably less than the other sets and one is tempted to relate this feature to the Superstat being installed in this factory.

Scaling, however, is such an unpredictable phenomenon that the low rate of scaling may have been due to some other cause. Unfortunately it was not found possible to carry out a special investigation into the effect of the Superstat. It is, however, intended to study this effect in season 1953.

Conclusions.

1. The most striking result of an investigation carried out in 1951 and 1952 into the scaling of Natal evaporators seems to be, in spite of the fact that scaling in Natal is considered to be serious, that the rate of scaling when expressed as parts of scale deposited in No. 3 and No. 4 vessels per million parts of water evaporated by the set, is shown as a small figure. Normal figures for No. 3 vessels were found to be 5-15 parts, for No. 4 vessels 20-60 parts. Only a small percentage of the amount of suspended matter in syrup adheres apparently permanently to the wall of the tubes, forming what is usually called a scale.

2. The main constituents of No. 4 vessel scale are lime salts, generally sulphites and sulphates. Silica is also important, and the third group is denoted as "Organic matter, water not expelled at 105°C, etc." In No. 3 vessel scale the two last groups are relatively more important than in No. 4 vessel scales; lime salts may even be present to only a small extent.

3. An investigation carried out at SZ in which it was tried, following a conclusion mentioned in earlier work of Bogtstra, to reduce the amount of silica deposited by doubling the dosage of phosphoric paste, gave a negative result. Doubling the dosage of phosphoric paste did not increase the amount of P_2O_5 in clarified juice and did not reduce the quantity of SiO_2 deposited.

4. Scaling at ZM factory which has a Superstat installed was significantly less than scaling at other factories, but whether it is permitted to connect these factors still has to be investigated.

5. *One cannot but feel when trying to form a comprehensive picture of the scaling phenomenon in Natal that a better insight cannot be gained by studying only the relative rates of scaling of factories as functions of the composition of the clarified juices processed, because the differences in these compositions are relatively small and are probably not the main cause of the wide fluctuations of the rates of scaling which were observed.* Studying scaling in a specially constructed test apparatus where conditions are kept strictly constant may reveal more of the chemical

and physical laws to which scaling is subject, but a drawback here is also that an enormous quantity of water has to be evaporated to produce sufficient scale to be weighed and analysed. Nevertheless it is hoped to continue our investigation in this direction.

When doing this, it will probably be found necessary to see the scaling phenomenon as a process which is quite distinct from the fact that some of the constituents of the juice become supersaturated and insoluble by the concentration of the juice.

Acknowledgment.

The analysis of juice and scale samples was carried our by Dr. J. R. Parrish and Mr. J. B. Alexander of the staff of the Institute.

The S.M.R.I. wishes to thank the management and staff of the factories which collected samples and forwarded details of processing methods, thus enabling us to carry out this investigation.

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Durban.

Mr. Dymond said that the subject was one of considerable interest and some years ago, as a result of a resolution taken at Congress, it was decided to carry out investigations. Dr. Douwes Dekker was asked to carry these out. He congratulated Dr. Douwes Dekker on his paper and on the results of his investigations.

Dr. Parrish asked about the experiment with phosphoric paste at the Sezela factory. He said that although the amount of paste had been doubled, the amount of lime remained the same as in the first and third week. Did this mean that the juice had finished up in an acid state?

Dr. Douwes Dekker said the juice must have been a bit more acid. Perhaps the effect was not too great as the amount of phosphoric paste used was relatively small.

Mr. Galbraith, in reply to Dr. Parrish, stated that the pH of the clarified juice and syrup was kept normal throughout the three weeks' test. The actual syrup pH values for each week were 6.79, 6.90 and 6.84 respectively. He queried the lime figures given for Sezela in the paper, as there were no means of obtaining an accurate lime consumption figure weekly at present.

Dr. Douwes Dekker said the lime figures had been provided by Sezela. If their accuracy was doubted by Mr. Galbraith a note could be added to his paper to this effect.

Mr. McCulloch said he thought a better insight of scaling in the tube could be obtained if samples were taken along the whole length of the tube. If it was contended that scale was formed as a result of bubble formation it might be expected that more scale would be formed at the bottom of the tube.

Dr. Douwes Dekker said that the possibility that scale was not homogenous had been considered before. As far as he knew the composition of the scale did not vary with the height, but it had been found that sometimes several layers could be discerned and that these layers were of different composition, in particular if the nature of the juice at the beginning differed from that at the end of the period in which the scale was formed.

Mr. Rault congratulated Dr. Douwes Dekker and his staff on their fact-finding work on the subject of evaporator incrustation in South Africa. Although the rate of evaporation (8.5 to 9 lbs. per sq. ft. per hour) at his factory could be considered high, mainly due to the handling of brilliantly filtered juices from the carbonatation process, the heating surface was not free of scale and had to be cleared every week-end, neither did the soluble lime salts reach the low level found in beet carbonatation, clarified juices or even cane carbonatation juices mentioned by Honing in Spencer Meade's book.

Lately the lime salts had been reduced by the systematic use of soda ash, with remarkable lowering of the ash content of the final refined sugar. Natal Estates laboratory had for years determined as a routine test the amount of lime salts left in the juice going to the evaporator. In the past they had used the "soap test", which demands a certain amount of judgment and experience from the analyst. It had now been replaced by the quicker and more accurate versanate titration. He hoped that all factories would now follow suit for next season.

The results of reduced scaling at Z.S.M. were not convincing as this factory showed the lowest evaporation per sq. ft. heating surface, a factor which would tend to throw down less mineral matter. The ultimate object of this research was to find conditions that would lead to our factories running for two to three weeks without having to clean the evaporators. So far he did not know of any factory that was bold enough to try this.

Mr. Ash asked whether the water added to the cane during crushing had anything to do with scale formation. He suggested that some factories obtaining good results might be using sweet water.

Dr. Douwes Dekker said he had tried to answer the question regarding the correlation of water used in the milling processes and the rate of scaling. He was not able to find any correlation. He was not prepared to say whether the quality of inbibition water had anything to do with the rate of scaling.

Dr. Dekker said he wanted to refer to the observation made by Mr. Bentley during Mr. McCulloch's

paper when he stressed the difficulties raised with boiler water in Natal. Mr. Bentley had referred to the lack of instrumentation. The N.S.M.A. had appointed an instrument maker who was stationed at the S.M.R.I. and whose sole job was to keep the instruments in proper working condition. Mr. Viljoen would in future be able to look after instruments at the mills, so that the need for better instrumentation referred to by Mr. Bentley would fall away.

Mr. Dymond suggested that the higher the amount of lime used in the clarification the higher the amount found in the juice. He asked whether this had any connection with an increased formation of scale.

Dr. Douwes Dekker said that the correlation between the amount of lime salts and the rate of scaling, although obviously existing, was—at least in Natal mills—obscured by other factors affecting the rate of scaling. He was, however, not prepared to confirm Mr. Dymond's statement that using more lime inevitably resulted in a higher lime salts content of clarified juice.

Mr. Main asked whether Dr. Douwes Dekker could express an opinion on the relative methods of the sulphur burning processes used in Java compared with the normal Natal processes. He mentioned that if wet air entered the sulphur burners trouble could be experienced with scale, the inference being that dry air should be used.

Dr. Douwes Dekker said that he agreed with Mr. Main that sulphitation as carried out in many countries where not sulphur towers, but sulphitation tanks, were used had definite advantages, in particular with respect to a better control of pH during the clarification process. Tank sulphitation required the closed type of sulphur burners and the air blown into these burners was usually dried with unslaked lime. The efficiency of the drying, however, was doubtful and in many cases no difference in the clarification effect had been observed when the drying chambers were cut out altogether. He did not know of any case where cutting out driers had had any effect on the rate of scaling.

Mr. Galbraith asked whether the conditions in which sulphur was burned had any effect on scaling. There was a variation in opinion on this point, as he had noticed that while some factories made no attempt to cool the gases before entering the tower, others went to a lot of trouble to ensure the lowest temperature possible. He thought there must be some difference caused by the temperature of the gases entering the juices.

Dr. Douwes Dekker said he was not in favour of very hot burner gases being drawn into the sulphur tower.

Mr. Wheeler said he thought he might answer Mr. Main's question. He was used to drying the air before he came to South Africa. He had fitted a drier but had found that it made no difference to scaling. What he had noticed was that if the baffles in the sulphur tower were heavily coated they had a cleaner evaporator.

Mr. Perk said the juices of Amatikulu were darker than those of Felixton and the view was expressed that this was caused because at Amatikulu they did not cool the gas.

Mr. Dymond said that at Umbogintwini they burnt 50 tons of sulphur a day and cooling it was quite a simple procedure. In making acqueous SO_2 it was necessary to cool the gases. He asked the meeting to accord Dr. Douwes Dekker a hearty vote of thanks for his interesting paper.