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12,000 setts at 2—8—0 per 1,000	30—0—0
Planting setts.	6—0—0
Weeding	3—8—0
Earthing up	12—0—0
Trashing (twice)	7—0—0
Propping	18—0—0
Irrigation and drainage	8—0—0
Harvesting	30—0—0
Total	175—0—0

The cost of converting one ton of cane into jaggery comes to Rs. 3.

STUDIES IN SUGARCANE JAGGERY

IV. Some Properties of Jaggery in Relation to Moisture.*

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In an earlier communication (1) the long felt need for a systematic nvestigation into the several probable factors which govern the differential properties exhibited by jaggeries, as they are available in the market, was ndicated. In it, a preliminary review of the results of such an investigation was also given briefly. In what follows are embodied the results of the study made to understand the properties of jaggeries, in respect especially of their relations to various degrees of relative humidity.

For purposes of the present study, only two types of jaggeries, the distinctly good and the distinctly bad ones, were selected, based on the following empirical tests. It may be mentioned here that a number of samples of medium quality were also studied, but as their properties stood between those of the good and the bad ones, they are not included in this paper.

Test,	Good Jaggery.	Bad Jaggery.
1. Appearance & Consistency.	Generally dry, hard crystalline rigid solids.	Generally damp & some times sticky solids; (occasionally pastes & liquids also).
2. Grinding or crushing.	Reduced to a powder. The powder sometimes lumps up.	Soft pastes, which sometimes spread.
3. Sound produced when struck against a hard object.	A metallic sound is produced.	Only a thud is caused.
4. A scratch made on its surface.	It is white and persists as such for a long time.	No white streak is formed at all.
5. Pin point penetration.	It does not penetrate; it sometimes bends.	Penetrates easily and quickly.

* Paper presented before the twenty-fifth session of the Indian Science Congress held at Calcutta, 1938.

Experiment 1. A few good and bad jaggeries were exposed in duplicate to identical conditions of relative humidity and temperature, which ordinarily favour loss of moisture. At the end of eight days they were all weighed tentatively. It was found that they all lost moisture as expected

The figures point out that under the same conditions of humidity and temperature, the good type of jaggeries part with a far greater proportion of their moisture than the bad jaggeries. Further, the bad jaggeries retained considerably more water than the good ones. These observations hold good independently of the magnitude of their initial moisture contents.

Table I.

Moisture Contents of Jaggeries after Eight Days of Exposure to Dry Conditions.

Sample No.	Initial Moisture.	Moisture content at the end of eight days (dry basis).			Moisture loss (%) of initial moisture.
		'A'	'B'	Average	
	%	%	%	%	%
		Good Jaggeries.			
(9)	7·00	1·07	1·11	1 09	84·33
(10)	5·56	1·02	1·03	1·03	81·66
(15)	6·22	1·46	1·97	1·72	72·51
(18)	5·84	1·10	1·01	1 06	81·85
		Bad Jaggeries.			
(13)	7·57	4 25	3 88	4 07	46·24
(36)	7·10	3·98	4 04	4·01	43·52
(40)	5·36	3·17	3 08	3·13	41·78
(41)	6·24	3 54	3·68	3 61	42·15

Experiment 2. In order to ascertain how jaggery responds to different degrees of relative humidity, some typically good and some typically bad jaggeries were placed in enclosed atmospheres of the following relative humidities:

(i) 0·00%, (ii) 50%, (iii) 60%, (iv) 75% and (v) 100%. The temperature was maintained throughout the period of the experiment at 27°C by placing all the desiccators, containing the sulphuric acids of the requisite strengths, in an incubator kept at that temperature. The samples were weighed from time to time until equilibrium was attained, as evidenced by the constancy in weight. The original moistures in the samples were determined separately. In the cases of the samples R and T placed in 100% humidity chamber, it was observed that towards the final stages, there were signs of fungus growth, and consequently their final weights were taken at that stage.

The results are presented in Table 2.

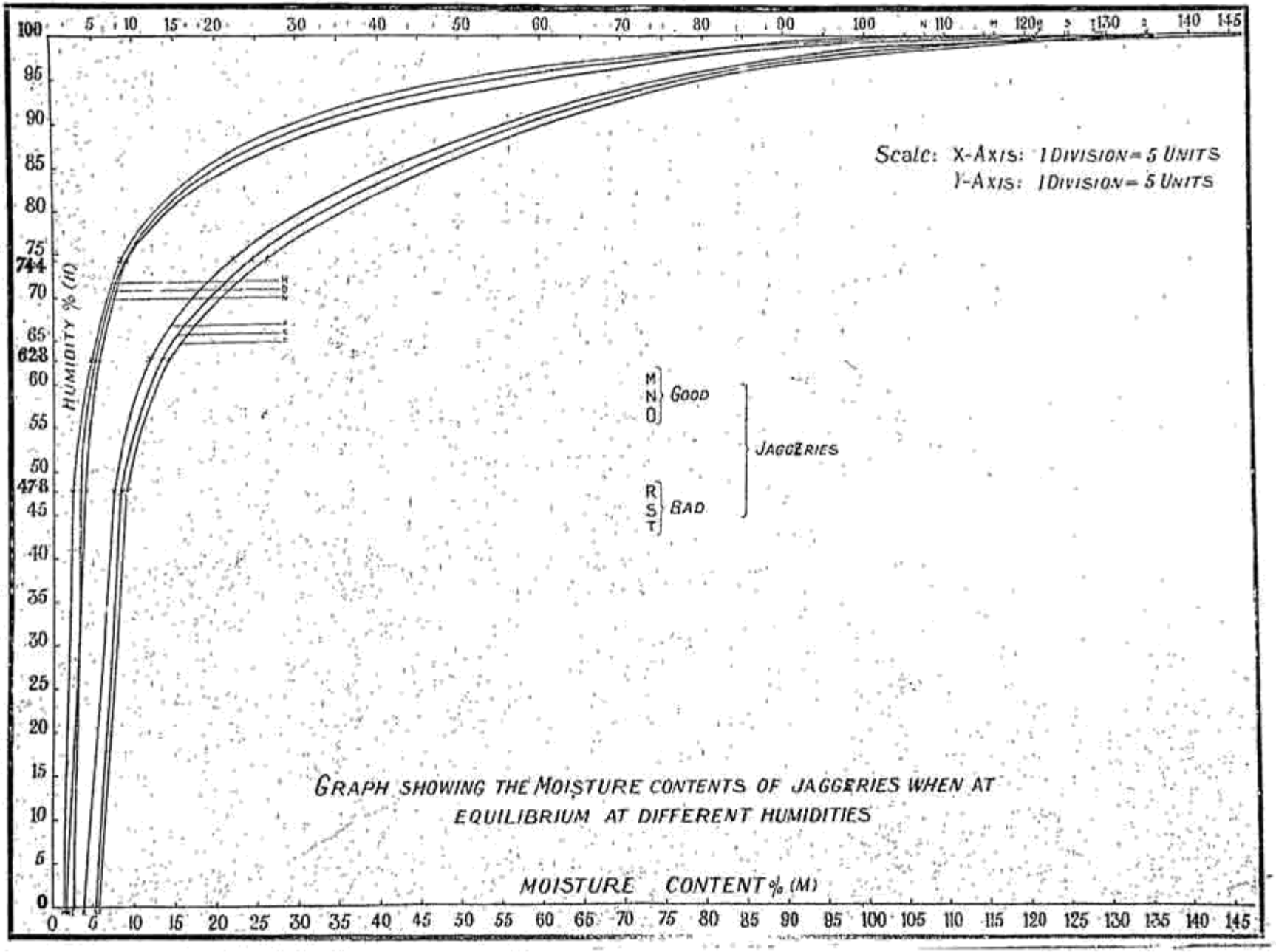
Scale: X-Axis: 1 Division = 5 Units
Y-Axis: 1 Division = 5 Units
M N O Good
R S T Bad
Jaggeries
Humidity % (H)
Moisture Content % (M)
Graph showing the Moisture contents of Jaggeries when at equilibrium at different humidities

Table 2.

Responses of Jaggeries to Different Relative Humidities at 27°C.

		Relative Humidities (27°C).									
		0·00%		50%		60%		75%		100%	
Sample No.	Initial moisture %	Moisture at equilibrium.	Moisture loss.	Moisture at equilibrium.	Moisture loss.	Moisture at equilibrium.	Moisture loss.	Moisture at equilibrium.	Moisture loss.	Moisture at equilibrium.	Moisture loss.
					Good Jaggeries.						
(M)	4·93	1·30	73 65	2·25	54·37	4·75	36·52	8·40	Gain	116·30	
(N)	7·78	1·83	76 08	3·58	53·98	5·55	28·61	8·92	Gain	107·40	
(O)	5·14	2·73	46·88	3·43	33·27	5·37	Practically no change.	8·92	Gain	134·80	
					Bad Jaggeries.						
(R)	10·63	3·95	62·85	7·34	30·95	11·96	Gain	22·41	Gain	124·40	
(S)	11·98	5 10	57·42	8·00	33·22	13·50	Gain	24·70	Gain	125·05	
(T)	12 83	5·56	56·75	8·74	32·03	14·12	Gain	26·23	Gain	130·00	

Note: (i) The moisture loss represents the percentage of the initial moisture.

(ii) The moisture at equilibrium represents the moisture content calculated on dry basis.

The moisture contents at equilibrium in the several humidities are also represented graphically. (Plate I).

From an examination of the data and of the graphs the following points become apparent:

1. (i) At equilibrium in any given humidity below 100%, the bad jaggeries always retain more water than the good ones. This confirms the observation made in the preliminary Experiment 1.

(ii) While the actual moisture contents vary with the degree of humidity, the relative differences between the two types of jaggeries are however always maintained.

These observations connote that with considerably unequal amounts of water in them, both the good and the bad jaggeries have the same vapour pressure when at equilibrium in any given humidity. From this it follows that the conditions in the two types of jaggeries may be so fundamentally different, that at any given humidity and temperature, more water is bound up with far greater tenacity in bad jaggeries than in the good ones, thereby rendering it unavailable for further evaporation under those conditions.

It may be mentioned here that in subsequent communications it will be shown that the two kinds of jaggeries differ conspicuously in their gross structure and in their microtexture, and also in the qualities of the impurities contained in them.

The observations in this experiment also seem to argue for the probable existence in jaggery of water in two forms, as the "free" and the "bound" water and that under any given set of conditions, this bound water is greater in the bad jaggeries.

$$\text{Jaggery. } nH_2O + x \text{ Free Water} \longrightarrow \text{Jaggery. } mH_2O$$

where the value of x is indefinite and depends mainly on external factors of humidity, temperature and wind velocity etc., while n is conditioned mainly by factors internal to jaggery. This may be considered as a quality factor.

It therefore looks to be possible that the amount of water bound up in jaggery at equilibrium at any given humidity below the saturation may do to serve as a measure of the quality of the jaggery.

2. The curves showing the moisture contents (Fig. I) of the two types of jaggeries are conspicuously separated, and their slopes are characteristic. Their continuity and smoothness are also significant in that they indicate no sudden changes in the nature of the forces holding the water and they are further suggestive of the probability that the water in the jaggery is held by forces of absorption.

3. At 50% relative humidity both the good and the bad jaggeries parted with their moisture. At 60% relative humidity the bad ones actually absorbed more moisture, while the good ones were still loosing it. At 75% humidity both types were taking up water. It would thus appear that between 50% and 60% relative humidity, there may lie an optimum humidity wherein the hygroscopic tendencies of both the types of jaggeries would not be manifested. This property may be useful in the study of the conditions for the storage of jaggery in bulk for commercial purposes.

Experiment 3. Both the good and the bad jaggeries were found to take up moisture at and above 75% relative humidity. Hence, to follow their rates of absorption of moisture 75% and 100% humidities were chosen. The samples of the 'A' and 'B' series used in Experiment 1 with their moisture contents after eight days of exposure to the dry atmosphere, were placed respectively in the 75 and the 100 per cent. humidity chambers. The progressive absorption of moisture was followed at intervals of two hours for a period of 32 hours. The concomittant changes in the consistencies of the jaggeries during the period were also noted.

At the end of this period the samples in the 'B' series which were placed in the 100% humidity chamber were rejected, and those of the 'A' series were allowed to continue to remain in the 75% humidity until equilibrium was attained, which took 28 days. (Tables 3 & 4).

Table 3.

Progressive Moisture Contents of Jaggery in 75% Relative Humidity.

Time in hours	Moisture content %	Consistency	Moisture content %	Consistency	Moisture content %	Consistency	Moisture content %	Consistency
				Good Jaggeries				
	(18)		(9)		(10)		(15)	
0	1·11		1·01		1·02		1·46	
2	2 05		2·04	dry	1·30		2 24	
4	2 78		2·91		1·22		2·95	
6	3·34		3·55		1·85		3·46	
8	3·91		3·76		2·36		4·14	
10	4·26		4·35	Moist but	2·69		4·59	
12	4·55		4·78	crystalline	3 07		4 96	
14	4·87	dry	5·17		3 18		5·42	
16	5·15		5·61		3·38		5 74	
18	5·29	moist but	5·91		3·38		5·93	
20	5·50	crystalline	6 11		3·53		6·17	
22	5·65		6·38	Moist appear-	3 63		6·38	
24	5·79		6·40	ance, but	3·65		6·54	
26	5·79		6·46	crystalline	3 63		6·56	
28	5·79		6·46		3·63		6·59	
30	5·88	" " "	6·46		3·60	The driest of	6·66	
32	5·88	" " "	6·34	Very moist appearance, but cryst.	3 60	all	6·70	Very moist but cryst.
28 days	10·53		11·72		7·57		12·13	
				Bad Jaggeries.				
	(13)		(36		(40)		(41)	
0	4·25		3·98		3·17		3·54	Moist
2	4 55	Moist	4·33		3·48		3·89	
4	4·81		4·66		3·70		4 19	
6	4 98	Extremely moist	4 83	Very moist	3·88	Extremely moist	4·43	
8	5·25		5·14		4·22		4·83	
10	5·44		5·75		4·37		5·00	
12	5·62		5·65		4·54		5·19	
14	5·80		5·96	Extremely	4·76	Tending to	5·48	
16	6·02		6·19	moist	4 91	collapse &	5·65	Extremely
18	6·19	Collapsing	6·26	Tending to	5·03	dissolve	5·77	moist
20	6·27		6·44	dissolve	5·19		5·93	
22	6 37		6·62		5·21		5·93	
24	6·52		6·82		5 35		6·07	
26	6·53		6·84		5·41		6·17	
28	6 58		6·95		5·42		6·23	
30	6·69		7·16		5·53		6·32	
32	6·77	" "	7·26	" "	5·63	" "	6·42	Collapsing
28 days	15·31		15.95		13.74		15.55	

Table 4.

Progressive Moisture Contents of Jaggery in 100% (Saturated) Relative Humidity

Time in hours.	Moisture content %	Consistency.	Moisture content %.	Consistency.	Moisture content %.	Consistency.	Moisture content %.	Consistency.
				Good Jaggaries.				
	(18)		(9)		(10)		(15)	
0	1·01		1·11		1·03		1·97	
2	5·05		5·76		5·83		5·52	
4	7·94		8·50		10·10		8·00	
6	9·74	Extremely	10·78	Extremely	12·67	Very moist.	9·54	Very moist.
8	11·25	moist.	12·86	moist.	14·74		10·16	Collapsing.
10	12·53	Collapsing.	14·33	Dissolving.	16·48	Collapsing.	12·37	
12	13·59		15·49		18·80	Running.	13·41	Running.
14	14·79		17·04		20·17		14·70	Running.
16	16·06	Running.	18·46	Running.	21·91		15·89	
18	17·12		19·61		23·17		16·90	
20	18·01		20·46		23·93		17·78	
22	18·78		21·32		25·26		18·84	
24	19·87		22·20		26·63		19·83	
26	20·64		22·98		27·32		20·58	
28	21·26		23·55		27·76		21·23	
30	22·24		25·26		29·97		22·86	
32	23·46	¾ soild.	26·32	¾ soild.	31·49	½ solid.	23·95	½ solid.
				Bad Jaggeries.				
	(13)		(36)		(40)		(41)	
0	3·88		4·04		3·08		3·68	
2	6·91	Extremely moist.	7·12	Extremely moist.	5·36	Very moist.	6·23	
4	9·15	Collapsing.	9·46	Callapsing	6·26	„ „	7·74	Extremely moist.
6	11·15	Running.	11·83	Running.	8·37	„ „	9·23	Collapsing.
8	12·94		13·96		9·60	Collapsing.	10·64	Running.
10	14·62		16·03		10·69	Running.	11·99	
12	16·07		17·77		11·68		13·16	
14	17·09		20·61		13·12		14·80	
16	19·80		22·58		14·46		16·22	
18	21·24		24·74		15·59		17·46	
20	22·30		26·38		16·37		18·24	
22	23·41		28·09		17·10		19·13	
24	24·67		30·52		18·19		20·20	
26	25·58		31·03		19·14		21·38	
28	26·35		32·02		19·93		22·12	
30	27·88	A thin	34·80		21·56		23·78	A thin fluid.
32	29·12	fluid.	36·14	A complete liquid.	22·69	The whole except a ¼th is liquid.	24·80	A speck of solid.

The data reveal some very interesting properties of jaggeries.

1. The good and bad jaggeries differ markedly in their rates of absorbing moisture as brought out by the following figures taken from Table 3.

	Good Jaggeries.					*Bad Jaggeries.*				
	18	9	10	15	Av.	13	38	40	41	Av.
(1) Initial moisture %	1·11	1·07	1·02	1·46	...	4·25	3 98	3·17	3 54	...
(2) Moisture after 32 hours %.	5·88	6·43	3·60	6·70	...	6·77	7·26	5·63	6 42	...
(3) Moisture absorbed in the interval %	4·77	5 36	2·58	5·23	4·25	4·84	2·52	3·28	2 49	2·79
(4) Moisture at equilibrium after 28 days %	10·53	12·72	7·57	12·13	10·48	15·31	15·95	13·74	15·55	15 14
(5) Moisture absorbed after stage (2) %.	4·65	5·29	3 97	5 43	4·49	8·54	8·69	8·11	9 13	8·62
(6) Moisture absorbed in the entire period %.	9 42	10·65	6·55	10·67	9 32	10·06	11 97	10·57	12·01	11·40

During the first 32 hours, the good jaggeries absorbed considerably more moisture (av. 4·85) than the bad ones (av. 2·79). In the second period extending up to 28 days, the moisture taken up by the bad jaggeries, is this time, far in excess (av. 8·62) of what is absorbed by the good ones, (av. 4·49).

Thus it becomes evident that good jaggeries take up less total moisture at greater rates, while the bad ones, under the same conditions, take up more water, but at considerably slower rates. This property argues for the probability that a good jaggery possesses a more open texture.

2. An examination of the moisture contents of jaggeries at certain phases in their consistencies which are presented below, as taken from Tables 3 & 4, reveals another important property by which the good jaggeries distinguish themselves from the bad ones, in that the former characteristically possess a greater strength of surface.

Moisture Contents of Jaggeries at certain Phases in their Consistencies.

Sample No.	100 % Relative Humidity			75 % Relative Humidity		
	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
	Good Jaggeries.					
(18)	9·74 to 11·25	12·55	14 79	5·88 Very dry	Not Reached	Not Reached
(9)	12·78 to 12 86	14 37	17·04 to 18·46	6·43 Just damp	,,	,,
(10)	12·67	14·74	18·80	3·60 Very dry	,,	,,
(15)	9 57	10·15	13 41	6·70	,,	,,
	Bad Jaggeries					
(13)	6 91	9 15	11·15	4·81 to 5·25	6 02 to 7 66	Not reached
(36)	7·12	9 46	11·83	4 82 to 6·18	6·26 to 7·26	,, ,,
(40)	6·26	9 60	10 69	3 88	4·54 to 5 63	,, ,,
(41)	7·74	9 23	10 64	5·64	6·61	,, ,,

Note: Phase I: When they are extremely moist
Phase II: When they just indicate a tendency to collapse
Phase III: When they begin to dissolve and run into liquid

It will be seen that in 75% relative humidity, the good jaggeries, with about the same moisture contents, ranging from 3% to 7%, as the bad ones, were still looking drier, and were within Phase I, while the bad ones already entered on Phase II.

Again, in 100% relative humidity all the three phases were attained by both the types of jaggeries, and at every phase, the good ones are conspicuous by their containing larger amounts of water than the bad jaggeries.

Thus, the good jaggeries are indicated to possess a greater strength of surface and are as such capable of holding considerably large amounts of water in surface solution, without collapsing or yielding their structures. In this respect the bad ones are too poor. With comparatively lower moisture contents these yield and change their shapes permanently.

The significance of these properties of jaggeries of the two types, and their responses to the changing seasonal and humidity conditions were discussed in the previous communication (loc. cit. 1).

II

A reference to literature showed that not much work was done on the relation of jaggeries to moisture. Only two references were to be had in this regard. Krishnamurti Rao and Ganapathy Aiyer (2) studied the moisture absorption of jaggeries prepared by them from a number of varieties of cane under known and controlled conditions. They prepared jaggeries (i) with and without addition of lime and (ii) with addition of substances like glucose, sodium chloride and potassium sulphate etc., to juice. They reported moisture contents of these jaggeries in saturated humidity after exposure for 9 days and for 26 days.

Lakshmana Rao (3) reported the moistures absorbed by jaggeries, prepared by him using different types of pans and furnaces, in 26 hours in saturated humidity.

The writer's data indicate that in about 26 days of exposure to any given humidity the equilibrium was almost attained, and that in the saturated humidity series the total amounts of water contained in the samples at equilibrium was in every case much above 100 per cent. calculated on dry matter. Thus these figures are nowhere within comparable limits of those given by Krishnamurti Rao and Ganapathy Aiyer. Their highest figure for total moisture was 38·9 after 26 days in saturated humidity, and the lowest was 5·6.

Taking the figures given by Lakshmana Rao who kept the jaggeries for 26 hours in saturated humidity, they appear to agree well with those of the writer. The writer's figures for moistures absorbed in 100% humidity after 26 hours range from 20% to 30%, while those of Lakshmana Rao vary from about 15—20%. The figures of Krishnamurti Rao and Ganapathy Aiyer given as moisture contents after 26 days compare with what the writer got in about 32 hours.

It must however be mentioned here that the details as regards the exact experimental conditions which obtained in the experiments are not mentioned by these workers.

Summary and Conclusions. 1. Responses of jaggeries, classified into good and bad ones based on some empirical tests, to different degrees of humidity, viz., 0", 50%, 60%, 75% and 100%, were studied.

2. The good and the bad jaggeries are sharply contrasted in their properties:

(i) The good jaggeries have a more open texture.

(ii) They contain comparatively smaller amounts of water when at equilibrium in any humidity below 100%.

(iii) They possess a far greater strength of surface, and are as such capable of holding large amounts of water in surface solution without collapsing or yielding their structure.

The bad jaggeries stand in striking contrast in all these respects.

3. It is probable that the water in jaggery is held by forces of absorp-n. There is evidence to suggest that the total water in jaggery might be existing in two forms as the "free" and the "bound" water, and that the "bound water" is held by forces of absorption.

4. It was suggested that the moisture content of jaggery at equilibrium in any given humidity below the saturation might serve as a reliable measure or single value to qualify and evaluate the quality of a given jaggery.

5. An optimum humidity might be lying between 50% and 60% relative humidity, in which both types of jaggeries would not manifest their hygroscopic tendencies. This observation, it was suggested, might prove useful in any study of the conditions for the preservation of jaggeries on a large scale.

The author takes this opportunity to express his grateful thanks to Rao Bahadur B. Viswa Nath, Director, Imperial Agricultural Research Institute, New Delhi, and to Mr. P. V. Ramiah, The Government Agricultural Chemist, Coimbatore, for the facilities and encouragement, they afforded throughout the course of the investigation.

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