Storage of Rice XIV.

Removal of Moisture from the Air in a Granary and the Hulled Rice Stored therein by a Desiccating Material.

By

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Introductior.

For the safe storage of hulled rice, the desiccation of the atmosphere in the granary, as well as of the rice itself, is the most important consideration. There are, of course, many ways whereby both the granary atmosphere and the rice may be dried, but the practical problem is to devise a process that removes a definite amount of moisture from both, so that the grain will not contain an amount in excess of the proper limit, as determined by previous experiments. The authors believe that the data given in the present paper furnish a ready means for calcutation of the amount of moisture that must be removed.

I. Desiccation of the Atmosphere in a Granary and the Quantity of Moisture to be Removed.

The humidity and temperature in a granary always vary with the season, as is well known, but the following formula is always true :

T = Temperature at present.

H = Relative humidity at present.

H' = Required low relative humidity.

V = Quantity of moisture in one cubic meter of the atmosphere, when saturated at T. This can be found in a meteorological table.

W = Quantity of moisture to be removed by desiccation.

If the temperature is constant, then

$$W = V \times \frac{H}{100} - V \times \frac{H'}{100} = V\left(\frac{H-H'}{100}\right) \qquad \text{(a)}$$

If the temperature falls some degrees, at the same time,

T' = The lowered temperature.

V' = Quantity of moisture in one cubic meter of the atmosphere, when saturated with moisture at T' temperature, then

$$W = V \times \frac{H}{100} - V' \frac{H'}{100} \quad \text{.................................(b)}$$

Example 1.

If the present temperature in a granary is 30°C., the present relative humidity 90%, and the desired relative humidity 60%, then the quantity of a moisture to be removed is, according to (a) 9 g., as the following equation shows:

$$V^* = 30\text{ g}, \quad H = 90\%, \quad H' = 60\%$$

$$\therefore \quad W = 30 \times \frac{90-60}{100} = 9\text{ g}.$$

Example 2.

If the present temperature in a granary is 30°C., the present relative humidity 80%, and the desired relative humidity 60%, then 6 g. of water must be removed from one cubic meter; also if the desired relative humidity is 70%, then 3 g. of water must be removed.

Example 3.

If in a granary the present temperature is 30°C., the present relative humidity 90%, the desired temperature 20°C. and the desired relative humidity 60%, then the amount of water to be removed from one cubic meter is, according to formula (b), 16.7 g., as the following equation shows:

$$\begin{cases} V^* = 30\text{ g.} \\ H = 90\% \\ T = 30°\text{C.} \end{cases} \qquad \begin{cases} {}^*V' = 17.2\text{ g.} \\ H' = 60\% \\ T' = 20°\text{C.} \end{cases}$$

$$\therefore \quad W = 30 \times \frac{90}{100} - 17.2 \times \frac{60}{100} = 16.7\text{ g.}$$

Example 4.

If in a granary the present temperature is 30°C., the present relative humidity 80%, the desired temperature 20°C. and the desired relative humidity 60%, then 13.7 g. water should be removed from one cubic meter of the air, also if the desired relative humidity is 70%, then 10.7 g. water must be removed.

As in the above examples, we can find by calculation the quantity of water to be removed, at any temperature and any humidity. Table 1 shows the representative cases.

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* Derived from the meteorological table.

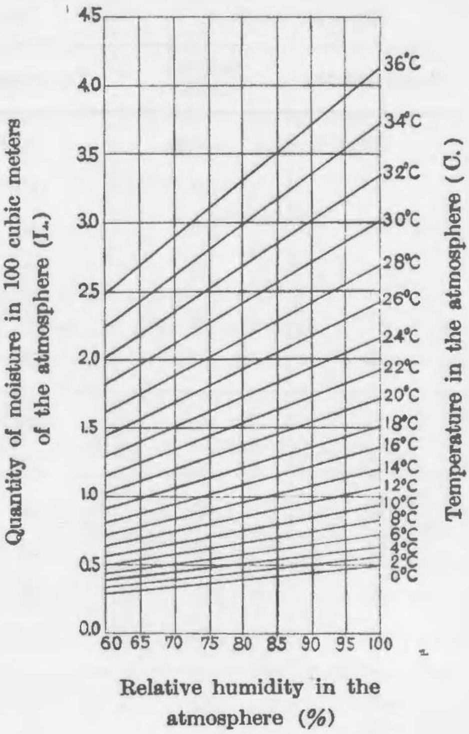
Table 1.

Quantity of Moisture Removed from 100 Cubic Meters of Atmosphere in a Granary.

Present condition		Desired condition		Moisture removed from 100 cubic meters of atmosphere
Temperature	Relative humidity	Temperature	Relative humidity	
30°C.	90%	30°C.	60%	0.900 L.
30	80	30	60	0.600
30	70	30	60	0.300
30	90	20	60	1.668
30	80	20	60	1.368
30	70	20	60	1.068
25	90	25	60	0.684
25	80	25	60	0.456
25	70	25	60	0.228
25	90	20	60	1.020
25	80	20	60	0.792
25	70	20	60	0.564
20	90	20	60	0.513
20	80	20	60	0.342
20	70	20	60	0.171
15	90	15	60	0.381
15	80	15	60	0.254
15	70	15	60	0.127
10	90	10	60	0.279
10	80	10	60	0.186
10	70	10	60	0.093
5	90	5	60	0.204
5	80	5	60	0.136
5	70	5	60	0.068

In regard to the practical application, the following figure is so constructed that, at a given temperature and relative humidity, the moisture content of

100 cubic meters of the atmosphere can be easily found. The abscissa shows the relative humidity, the ordinate the quantity of moisture (L.) in 100 cubic meters of atmosphere and the oblique lines the moisture content of 100 cubic meters of the atmosphere at each temperature. By the figure, for instance, it can be easily found, that the moisture content in 100 cubic meters of atmosphere at 30°C. and with the relative humidity of 90% is really 2.7 L., and at 20°C. and with the humidity of 60% 1.03L. ; the difference is 1.7L., which should be removed by desiccation, when it is required to dry the atmosphere.



An actual example is here noted. In a granary of the institute, the temperature, as well as the relative humidity, was actually as shown in Table 2. If the desired humidity is 60% and at the same time the temperature is lowered, especially in summer to 20°C., then the moisture in the atmosphere should be removed in an amount given in Table 2 :—

Table 2.

Example of the Temperature as well as the Relative Humidity in a Granary.

Months		January – February	June-July	August	October – November
Temperature	at present	4.6°C.	22.7°C.	26.9°C.	14.4°C.
Rel. humidity	at present	73.0%	84.7%	77.4%	75.4%
Temperature	desired	4.6°C.	20.0°C.	20.0°C.	14.4°C.
Rel. humidity	desired	60%	60%	60%	60%
Amount of a moisture to be removed from 100 cubic meteres of the atmosphere		0.1L.	0.7L.	0.9L.	0.2L.

II. Desiccation of Rice Kernels and the Quantity of Moisture to be Removed.

Assuming that, there are lots of hulled rice with a varying moisture content and it is desired to dry the rice to a definite content, then the quantity of water calculated by the following formula must be removed :—

A = Weight of one koku * of the hulled rice, kg.

B = Moisture content of the hulled rice at present.

C = Desired moisture content of the hulled rice.

X = Quantity of water to be removed from one koku of the hulled rice by desiccation.

$$A - A(1-B) \div (1-C) = X \quad \text{(c)}$$

When lots of rice with a moisture content of 18, 17, 16, 15 and 14 per cent respectively were dried to a moisture content of 13 per cent, the following quantities of water should be removed by desiccation :

Table 3.

Quantity of Water to be Removed from one Koku of Hulled Rice.

Variety	Initial moisture content of hulled rice (B)	Weight of one koku of hulled rice (A)	Desired moisture content (C)	Quantity of water to be removed from one koku of rice (X)
"Shinriki"	18%	141.40 kg.	13%	8.13 L.
	17	141.89	13	6.52
	16	143.38	13	4.95
	15	144.74	13	3.33
	14	146.10	13	1.68
"Omachi"	18	133.50	13	7.67
	17	138.04	13	6.35
	16	142.58	13	4.92
	15	145.11	13	3.34
	14	147.64	13	1.70

III. Desiccation of the Atmosphere in a Granary and the Hulled Rice Stored therein.

As a further contribution to the subject, the desiccation of both the atmosphere in a granary and the rice itself stored therein was studied. Assuming

* One koku = 0.18039 kilolitre.

that the granary is to one-third, two-thirds or entirely filled with rice, and the granary with the rice stored therein is required to be dried to a certain extent, then the quantity of moisture to be removed can be found in the following way :—

Example 1.

If the initial temperature is 30°C., the relative humidity in a granary 80% and the granary is filled with rice with a moisture content of 16%, then 2733.2 L. of moisture must be removed from each 100 cubic meters of the granary, if 65% relative humidity and 13% moisture content of the rice are required, as the following calculation shows : 100 cubic meters = 554.4 koku ; if one koku of rice with a moisture content of 16% is to be desiccated to a moisture content of 13%, 4.93 L of water should be removed. It is necessary therefore, to remove 2733.2 L. of water from the rice, when it entirely fills the capacity of 100 cubic meters, as the following equation shows :— $4.93\,\text{L.} \times 554.4 = 2733.192\,\text{L.}$

Example 2.

Having the hulled rice with a moisture content of 16% filling two-thirds of the capacity of a granary, the other conditions are quite the same as in Example 1.

When the present granary temperature is 30°C., the present relative humidity of the atmosphere 80%, and the required relative humidity 65%, then 0.45 L. of water must be removed from 100 cubic meters of atmosphere, as the following equation shows : $30\left(\frac{80-65}{100}\right) \times 100 = 450\,\text{g.} = 0.45\,\text{L.}$

Therefore, if one-third of the capacity of the granary is empty, then $0.45 \times \frac{1}{3} = 0.15\,\text{L.}$ of water must be removed.

When two-thirds of the capacity of a granary is filled with rice, then 1822.128 L. of water should be removed from the rice — that is, since 2733.192 L. must be removed from every 100 cubic meters of rice, as shown in Example 1, two-thirds of that amount is equal to 1822.128 L.

Therefore, the total quantity of water to be removed from the granary and the rice therein is equal to $1822.128 + 0.15 = 1822.3$ L. for each 100 cubic meters of the capacity of the granary.

Example 3.

When the same rice is stored to one-third of the capacity of the granary, 911.9 L. of water per 100 cubic meters of the capacity of the granary should be removed, as the following calculation shows :

Water removed from the granary············$0.450 \times \frac{2}{3} = 0.300\,\text{L.}$

Water removed from the rice···········$2733.192 \times \frac{1}{3} = 911.64\,\text{L.}$

Therefore, the total quantity of water removed, is equal to 911.9 L.

From the above examples 2 and 3, we notice that the quantity of water removed from the atmosphere in the granary, in comparison with that from the rice itself, is so small that it can be entirely ignored without appreciably influencing the result. In practice, the calculation can be carried out satisfactorily considering the quantity of rice and its moisture content.

IV. Application of Calcium Chloride as a Desiccating Material.

In connection with the calcium chloride as a desiccating material for rice, from July to September, 1931, the authors studied the moisture absorption power of that chemical. Placed in the atmosphere of the laboratory, one kilograms of it absorbed moisture reaching 1818 g., after 52 days; placed in a damper atmosphere, it absorbed 1937 g. and remained constant. The results are given in Table 4.

Table 4.

Absorption of Moisture by one kg. of Calcium Chloride.

Date	July 14	July 19	July 24	July 28	Aug. 2	Aug. 7	Aug. 12	Aug. 17	Aug. 22	Aug. 27	Sept. 3	Sept.* 6
Period, days . . .	1	6	11	15	20	25	30	35	40	45	52	55
Weight, g.	1000	1621	1792	1941	2071	2227	2353	2494	2673	2784	2818	2937
Absorbed moisture, g.	0	621	792	941	1071	1227	1353	1494	1673	1784	1818	1937

* Damp atmosphere.

Reducing the results to kilograms, it was observed that in an ordinary atmosphere the moisture absorption of one kg. of calcium chloride reached the maximum of about 1.8 kg., but in a damp atmosphere it absorbed 1.9 kg. and reached saturation.

Assuming that one kg. of calcium chloride can absorb 1.8 kg. of water from the atmosphere, the authors calculated the quantity of calcium chloride needed for desiccation of an atmosphere of 100 cubic meters in a granary as summarized in Table 5.

(See Table 5 on the next page.)

According to Table 5, it will be noted, that the quantity of $CaCl_2$ required for the desiccation of the atmosphere of a granary is very small.

Again assuming that one kg. of $CaCl_2$ can absorb 1.8 kg. of water from the rice kernels, the authors further calculated the quantity of $CaCl_2$ needed for the desiccation of kernels with moisture content of 14 to 18 per cent. The results are given in Table 6.

Table 5.

Quantity of Calcium Chloride Required for the Desiccation of an Atmosphere of 100 Cubic Meters in a Granary.

At present		Required		Required quantity of $CaCl_2$ for desiccation of 100 cubic meters of the atmosphere
Temperature °C.	Relative humidity %	Temperature °C.	Relative humidity %	
30	90	30	60	0.90 / 1.8 = 0.50 kg.
30	80	30	60	0.60 / 1.8 = 0.33
30	70	30	60	0.30 / 1.8 = 0.17
30	90	20	60	1.67 / 1.8 = 0.93
30	80	20	60	1.37 / 1.8 = 0.76
30	70	20	60	1.07 / 1.8 = 0.59
25	90	25	60	0.68 / 1.8 = 0.38
25	80	25	60	0.46 / 1.8 = 0.26
25	70	25	60	0.23 / 1.8 = 0.13
25	90	20	60	1.02 / 1.8 = 0.57
25	80	20	60	0.79 / 1.8 = 0.44
25	70	20	60	0.56 / 1.8 = 0.31
20	90	20	60	0.51 / 1.8 = 0.28
20	80	20	60	0.34 / 1.8 = 0.19
20	70	20	60	0.17 / 1.8 = 0.09
15	90	15	60	0.38 / 1.8 = 0.21
15	80	15	60	0.25 / 1.8 = 0.14
15	70	15	60	0.13 / 1.8 = 0.07
10	90	10	60	0.28 / 1.8 = 0.16
10	80	10	60	0.19 / 1.8 = 0.11
10	70	10	60	0.09 / 1.8 = 0.05
5	90	5	60	0.20 / 1.8 = 0.11
5	80	5	60	0.14 / 1.8 = 0.08
5	70	5	60	0.07 / 1.8 = 0.04

Table 6.

Quantity of Calcium Chloride Needed for the Desiccation of one Koku of Hulled Rice.

Moisture Content of Rice		Quantity of $CaCl_2$ needed for desiccation of one koku of rice		
At present	After desiccation	"Shinriki"	"Omachi"	Average
18%	13%	8.13 / 1.8 = 4.52 kg.	7.67 / 1.8 = 4.26 kg.	4.39 kg.
17	13	6.52 / 1.8 = 3.62	6.35 / 1.8 = 3.53	3.58
16	13	4.95 / 1.8 = 2.75	4.92 / 1.8 = 2.75	2.75
15	13	3.33 / 1.8 = 1.85	3.34 / 1.8 = 1.86	1.86
14	13	1.68 / 1.8 = 0.93	1.70 / 1.8 = 0.94	0.94

From Table 6 it is evident that, for the absorption of one per cent of moisture from rice, the addition of calcium chloride in the proportion of one kg. to one koku of hulled rice would be needed. In practice, it is necessary, however, to add more calcium chloride than above mentioned, because it is not so easy to absorb the moisture of the rice kernels as that of the atmosphere and it is also necessary to desiccate the rice as rapidly as possible before summer. In the earlier papers, the authors[1),2)] reported that, having stored the underdried rice with addition of three kg. of calcium chloride for each koku of rice in a sealed container, they obtained good results. At that time, the authors reported that the efficiency of the absorption of calcium chloride is 50 to 60 per cent of the calculated value in the atmosphere.

V. Comparison of Calcium Chloride, Calcium Oxide and "Dryer".

There are several kinds of desiccating materials other than calcium chloride, such as calcium oxide, "Adosor", "Dryer" etc., which may be used for the desiccation as well as the storage of rice. The authors nexed studied, the comparative moisture absorption power (desiccating power) of calcium chloride, calcium oxide and "Dryer". The experiment was carried on in March 1934. For each kg. of the material absorbed in the laboratory, the moisture in the quantities given in Table 7 is required. After 21 days, the absorption reached the maximum, then the materials were placed again in a damp atmosphere to allow further absorption of moisture. After 26 days the materials were quite saturated with the moisture.

Table 7.

Absorption of Moisture by one kg. of Desiccating Material.

Date	Period of absorption	Calcium chloride		Calcium oxide		"Dryer"		
		Weight	Absorbed moisture	Weight	Absorbed moisture	Weight	Absorbed moisture	
March 23, 1934	Days 0	kg. 1.000	g. 0	kg. 1.000	g. 0	kg. 1.000	g. 0	Laboratory
„ 28, „	5	1.526	526	1.216	216	1.143	143	
April 2, „	10	1.931	931	1.342	342	1.198	198	
„ 7, „	15	2.094	1094	1.388	388	1.231	231	
„ 13, „	21	2.275	1275	1.423	423	1.287	287	
April 18, 1934	26	2.934	1934	1.459	459	1.314	314	Damp atmosphere

1) 2) Storage of rice XII, XIII, Ber. Ōhara-Inst., VI: 335—339, 1934, VII: 99—102, 1935.

As regards the moisture absorption, calcium chloride is the strongest, calcium oxide the next, and " Dryer " the weakest.

Comparison of the absorption power of the three materials in the laboratory shows that, after 21 days, it was about in the ratio of 100 : 33 : 23, and in a damp atmosphere about 100 : 24 : 16. The authors further calculated the velocity of absorption, i.e. the period (days) needed for the absorption of one gram of moisture by one kilogram of the material, and found that calcium oxide absorbs moisture more rapidly than calcium chloride and " Dryer ", as shown in Table 8.

Table 8.

Period Needed for Absorption of one gram of Moisture by one kg. of the Material.

Calcium oxide	Calcium chloride	" Dryer "
6.92 Days	8.12 Days	8.02 Days

In the above experiments, it was brought out that calcium oxide absorbs moisture much more quickly than calcium chloride, even though on the contrary its absorption capacity is only one-third or one-quarter of that of calcium chloride.

To test the above results, the authors carried out two similar experiments. Taking calcium chloride, calcium oxide and " Dryer " in the quantities of the ratio of 1 : 3 : 4.6, the underdried hulled rice was desiccated, and it was found that, as expected, the three kinds of materials absorbed the moisture of the rice in the same degree, and that calcium oxide desiccated the rice more rapidly than the other materials. This confirms the preceding experiment. There is no doubt, therefore, that a quantity of calcium oxide three times that of calcium chloride can desiccate the rice kernels to the same degree and much more rapidly than the latter. Moreover, there is the advantage, that calcium oxide is much cheaper than calcium chloride and very convenient. Not only is calcium chloride more expensive, but it is dfficult to handle, when it deliquesces. " Dryer " is much dearer than calcium chloride, as well as calcium oxide, and its absorption efficiency is much less. In conclusion, it is therefore justified, to recommend the use of calcium oxide, in a quantity three times or more that of calcium chloride, for the thorough and rapid desiccation of rice during storage.

VI. Conclusion and Summary.

1) During the period from 1931 to 1934, the authors studied the desiccation of the atmosphere in a granary, as well as the hulled rice stored therein, by a desiccating material.

2) When it is required to desiccate hulled rice with a moisture content of 18, 17, 16, 15, and 14 per cent respectively to 13 per cent, then 7.9, 6.4, 4.9, 3.3, 1.7 L. of the water must be removed from one koku of the hulled rice.

3) From the experiment and calculation, it was found that, the addition of calcium chloride in the proportion of one kg. to one koku of the hulled rice is needed for the absorption of one per cent of the moisture of rice. In practice, however, it is necessary to add calcium chloride twice that amount, because the efficiency of the absorption of moisture of rice is only 50 to 60 per cent that of the absorption of the atmospheric moisture.

4) For the desiccation of a granary atmosphere of a relative humidity of 70 to 90 per cent at the temperature of 5 to 30°C., to the relative humidity of 60 per cent at the temperature of 20°C., or at a lower temperature, 0.068 to 1.668 L. of the water from 100 cubic meters of the atmosphere should be removed. For this only 0.04 to 0.93 kg of calcium chloride is needed.

5) For the desiccation of the atmosphere in a granary, as well as the rice therein, the moisture content in the atmosphere can be entirely ignored in the calculation, since the quantity is inconsiderable in comparison with that of the rice.

6) Calcium chloride absorbed a moisture of 1.8 L. from one hundred cubic meters in a laboratory atmosphere, during 52 days and 1.9 L. in a damp atmosphere.

7) Calcium oxide absorbs the atmospheric moisture only to one-third or one-quarter of the capacity of calcium chloride, but it absorbs it more rapidly than the latter.

8) The authors believe that, calcium oxide can be used for the desiccation of rice during storage, since it absorbs the moisture rapidly, is much cheaper than calcium chloride and is very convenient. It must be added, however, for the absorption of one per cent of the moisture of rice, in the proportion of 6 kgs. per one koku of the hulled rice, while three to four times that quantity of calcium chloride is needed.