

COMPARISON OF THE RATES OF ABSORPTION OF WATER BY CORN
KERNELS WITH AND WITHOUT DISSOLVED SO₂

by

HUAI-CHONG CHEN

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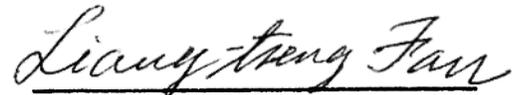
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Approved by:



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INTRODUCTION

"The Nation's Engineering Research Needs, 1965-85 (1)" states that "Engineers are learning that as they better understand nature's biological systems, they can develop new design principles for engineering components and systems based on analyses of the structure and function of biological components and systems."

The present work is a part of a long-range project concerning the diffusion processes of cereal grains conducted at Kansas State University (2) (3) (4). The main purpose of this work was to investigate the difference in absorption rates of water in aqueous SO₂ solution and in water by corn kernels during the steeping operation.

The present processes of manufacturing cornstarch involve steeping corn kernels in warm water of 110° to 160° F. containing about 0.25 to 0.35 per cent sulfur dioxide for about two days. The corn kernels are broken up and the germs are separated. The rest of the material is ground or milled and subjected to further separating operations with water, containing sulfurous acid, in reels and shaker sieves to remove the coarse bran and fiber. The slurry, containing starch and gluten, which passes through the silk sieves, is run over starch tables on which the starch settles and from which the water and gluten tails off. Then the starch on the tables is removed by flushing, filtered, washed and dried at low temperatures (5) (6).

According to Kerr (5) and Bartling (7), the major purposes

of a steeping process are:

1. To soften the kernel so that the various components of the grain, such as the hull and fiber, the germ, the gluten, and the starch, may be separated from each other with a high degree of efficiency.

2. To remove the protein components that are soluble in warm water.

3. To reduce or inhibit the activity of microorganisms on the grain that are brought into the mills.

4. To complete the cleaning of the grain.

5. To whiten the starch.

The function of SO_2 as a steeping agent has been investigated by Cox and MacMasters (8). These investigators showed that starch is embedded in and tightly held by a protein network. During steeping the network swells and tends to form tiny globules of hydrated protein. With time, the protein loses its birefringence and finally disperses. SO_2 greatly accelerates this process and hence increases starch recovery.

Long (9) has determined the effect of flow rate of steeping water on the diffusion rate in sorghum grains and has measured the extraction rates of water-solubles.

So far, however, a strictly quantitative comparison of the absorption rate of water by the grain kernels in sulfurous acid solution and in water has not been reported. Therefore, experiments to this effect were conducted on corn kernels to investigate the difference of the diffusion rates of water into corn kernels when they are steeped in water containing sulfurous acid solution

and in plain water and the effects of sulfur dioxide on the diffusion.

The diffusion equation which was derived by Becker (10) (11) and tested by other workers (2) (3) (4) was used here as the principal model for correlating the data.

THE WEIGHT INCREASE OF THE CORN GRAINS
DURING STEEPING

THEORY AND TREATMENT OF EXPERIMENTAL DATA

The object of this section is to outline a general equation for unsteady state diffusion and to examine methods for subsequent correlations of data. The detail of the derivations can be seen elsewhere (12).

The diffusion process is represented by Fick's Law (14) as:

$$D \left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2} \right) = \frac{\partial c}{\partial t} \quad (1)$$

where D is the diffusion coefficient, c is the concentration of diffusing substance at a point in a solid; x, y and z are Cartesian coordinates of the point under consideration, and t is the diffusion time. Becker (11) demonstrated that the integral of Equation (1) for a second order approximation of the particle of arbitrary shape under the assumption that the surface-to-volume ratio, $\frac{A}{V}$, remains constant is:

$$\bar{C} = 1 - \frac{2}{\sqrt{\pi}} X + BX^2 \quad (2)$$

where $\bar{C} = \frac{\bar{c} - c_s}{c_0 - c_s}$ in which \bar{c} is the average concentration, c_0 the initial concentration, and c_s the concentration at the bounding surface, $X = \frac{A}{V} \sqrt{Dt}$, and B = a dimensionless constant. If the concentration term is represented by the moisture content on a weight basis:

$$\bar{C} = \bar{M} = \frac{\bar{m} - m_s}{m_0 - m_s} \quad (3)$$

where \bar{m} is the average moisture content at the given absorption time, m_s is the effective surface moisture content, and m_0 is the

initial moisture content (moisture contents are expressed in gm./gm. dry basis). Equation (2) can be written as follows:

$$\bar{M} = 1 - \frac{2}{\sqrt{\pi}} X + BX^2 \quad (4)$$

For the first order approximation, or when X is small, Equation (4) is approximated by:

$$1 - \bar{M} = \frac{2}{\sqrt{\pi}} X \quad (5)$$

or, in terms of experimental variables:

$$\bar{m} - m_0 = K_1 \sqrt{t} \quad (6)$$

$$\text{where } K_1 = \frac{2}{\sqrt{\pi}} (m_s - m_0) \frac{A}{V} \sqrt{D}$$

Equation (6) shows that, if this mathematical model is applicable, there would be a linear relationship between $(\bar{m} - m_0)$ and \sqrt{t} .

A second procedure is to treat the data by a second order approximation. Equation (4) can be expressed in terms of the experimentally measurable variables as:

$$K = K_0 - b \sqrt{t} \quad (7)$$

$$\text{where } K = \frac{\bar{m} - m_0}{\sqrt{t}}$$

$$K_0 = \frac{2}{\sqrt{\pi}} \left(\frac{A}{V} \right) \sqrt{D} (m_s - m_0)$$

$$b = B \left(\frac{A}{V} \right)^2 D (m_s - m_0)$$

Equation (7) means that there should be a linear relation between k and \sqrt{t} , if the mathematical model is applicable.

The diffusivity, D, can be evaluated from either of these approximations. According to the first order approximation, the

diffusivity can be obtained from

$$D = \left[\frac{K_1}{\frac{2}{\sqrt{\pi}} \left(\frac{A}{V} \right) (m_s - m_o)} \right]^2 \quad (8)$$

using experimentally determined values of K_1 , $\left(\frac{A}{V} \right)$, and $(m_s - m_o)$.

According to the second order approximation the diffusivity can be obtained from

$$D = \left[\frac{K_o}{\frac{2}{\sqrt{\pi}} \left(\frac{A}{V} \right) (m_s - m_o)} \right]^2 \quad (9)$$

MATERIAL

The materials used in this work were K-4 hybrid popcorn, Gold Rash sweet corn, DeKalb 3xl dent corn, and K1830 hybrid dent corn.

The moisture contents shown in Table I were determined by heating at 110° C. for 4 hours under a vacuum of 29 inches water (14).

Distilled water was used for the steeping and the aqueous SO_2 solution was prepared by bubbling SO_2 gas through distilled water, as described in detail in the next section.

METHODS

Experiments were carried out with temperatures ranging from 50° F. to 160° F. and for immersion periods from several minutes to 10 hours. For each run, two weighed samples with accuracy to a thousandth of a gram were placed in 500-ml. flasks. One contained

Table 1. Characteristics of the material investigated.

	Gold Rash sweet corn %	K-4 hybrid popcorn %	DeKalb 3xl dent corn %	K1830 hybrid yellow dent corn %
Protein	10.88	10.69	8.31	8.06
Ether extract	8.18	3.69	3.90	3.94
Crude fiber	1.99	3.25	1.74	2.09
Moisture	10.10	9.78	11.46	10.12
Ash	1.83	1.45	1.18	1.40
N-free extract	67.02	72.14	73.41	74.39
Carbohydrates	69.01	74.39	75.15	76.48
Average initial surface area per grain, cm. ²	2.334	1.0655	2.1196	2.0830
Average initial volume per grain, cm. ³	0.1874	0.1038	0.2441	0.2291
Density, g./cm. ³	1.3228	1.3333	1.2500	1.2490

aqueous SO_2 solution and was sealed to prevent the escape of SO_2 gas, and the other contained distilled water. Both were immersed in a stirred water bath controlled within 0.1° F. of the set temperature. At the end of each immersion, both samples were quickly removed from the water bath and superficially dried on a large filter paper. After the surface water on the kernels was removed, the samples were weighed. The moisture gain was calculated from the weight of the water absorbed by the samples.

Initial Moisture Content

An air-oven method was used to measure initial moisture content. In order to overcome the moisture loss in grinding the grain, a two-state drying method was employed (15) (16).

Initial Moisture Gain

Several studies of the rate of uptake of liquid water by grain have indicated a very rapid initial rate followed by a much slower uptake at long times (3) (10) (11). According to Becker, the short initial period represents the saturation of the outer layers of the kernel with water by capillary imbibition. The time required for the moisture pick-up, or initial moisture gain, was assumed to be as short as 5 seconds and the initial moisture gain was measured for each sample at several temperature levels.

The Surface-Volume Ratio-- A/V

The surface area-to-volume ratio, $\frac{A}{V}$, was determined from the sphericity of the material tested. The sphericity is defined as

the ratio of the surface area of a sphere having a volume equal to that of the particle to the surface area of the solid particles.

It may be written as:

$$\psi = \frac{\frac{(A)}{V} \text{ sphere}}{\frac{(A)}{V} \text{ solid}} \quad (10)$$

Equation (10) can be reduced to (12):

$$\frac{(A)}{V} \text{ solid} = \frac{4.83}{\psi V^{\frac{1}{3}}} \quad (11)$$

Equation (11) shows that the ratio $\frac{(A)}{V}$ of the solid particles can be evaluated provided both the sphericity ψ and the particle volume are known. It can be assumed that the sphericity of a swelling solid is constant unless the swelling is unusually anisotropic.

Since the dimensions of the solid were assumed to be constant at times near zero the diffusion model was based on the initial period, and the initial value of the ratio $\frac{(A)}{V}$ was used for the latter correlations.

The sphericity is related to the bed porosity of the grains. In Figure 1,* the sphericity is plotted as a function of porosity as given by Brown et al. (17).

The porosity is defined as the ratio of the volume of the void space to the total volume of the bed. It is measured by discharging the grains into a 1000-ml. graduated column of known volume of toluene. The porosity was calculated by dividing the void volume, which is equal to the difference of the bulk volume of the

*All figures are in the Appendix.

grain bed and the displacement of the liquid, by the bulk volume of the grain.

The Effective Surface Moisture Content

For the moisture increase in diffusion, Equations (4) and (5) can be written in the form as:

$$\bar{m} - m_0 = K_A(m_S - m_0) \quad (12)$$

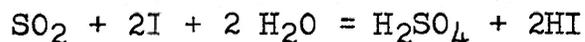
$$\bar{m} - m_0 = K_B(m_S - m_0) \quad (13)$$

Both Equations (12) and (13) show that if the weight increase $(m - m_0)$ is plotted as a function of the initial moisture content, a linear relationship will result and since when $\bar{m} - m_0 = 0$, $m_0 = m_S$, the intersection of the line with the m_0 -axis will give the value of m_S . Thus the quantity m_S can be determined experimentally.

Preparation of Aqueous SO₂ Solution

The aqueous SO₂ solution used in this work was prepared by bubbling SO₂ gas through water. The concentration of SO₂ in the solution was then determined by titration. Since the concentration of SO₂ in the steeping solutions used in the milling industry generally ranges from 0.25 to 0.35 weight per cent, 0.3% SO₂ solution was used throughout the work except in a sequence of experiments designed to investigate the effects of concentration.

Sulfurous acid was titrated with iodine solution. These react according to the following reaction:



The titration was accomplished by adding the solution of sulfurous

acid from a buret to the iodine solution. The solubility of iodine in water is small but it dissolves readily in ethyl alcohol. The standard solution for titration, therefore, was prepared by dissolving solid iodine in aqueous alcohol solution. The end point could be recognized without an indicator, but the addition of a few drops of starch solution was helpful. 100 c.c. of $\frac{N}{10}$ iodine solution will oxidize 0.3203 gm. of SO_2 , or 106.8 ccc. of 0.3% SO_2 solution.

RESULTS, CORRELATION AND DISCUSSION OF RESULTS

In Figures 2, 3 and 4, the weight of Gold Rash sweet corn, K-4 hybrid popcorn and DeKalb dent corn at each absorption time are plotted as a function of absorption time. The experimental data are tabulated in Table 2 in the Appendix.

Some Observations

After about thirty minutes of steeping, the corn kernels in aqueous SO_2 solution gradually turned pale yellow. This reduction was obviously caused by the sulfurous acid. On the other hand, no bleaching effect was observed for the kernels in water. The grain remained brownish yellow. The difference in whiteness at various steeping times was, thereafter, negligible. After about twelve hours of steeping, the corn kernels were softened and appeared smashed. It was especially so for the samples in SO_2 solution.

The aqueous SO_2 solution was prepared at room temperature and heated up to the desired temperature in a temperature-controlled

bath. There was an apparent increase of pressure in the steeping beaker. To prevent SO_2 from escaping to the gas phase from the liquid phase only a negligible gas space in the steeping beaker was left. To determine the reduction in concentration of SO_2 after heating to 120°F the solution was cooled and titrated. There was only a 5% loss in the concentration of SO_2 . This reduction would not affect the experimental data because, as will be described in a later chapter, the effects of the concentration of SO_2 on the absorption rates of water were negligible in this range of concentration.

The loss in water-soluble and acid-soluble materials from grain was disregarded in this work. According to the data of Long for sorghum grain (9), the loss of water-soluble material is around 0.005 gm. for 8 hours of steeping at room temperature. Since the grain size of corn is much larger than that of sorghum, and the steeping time in this work is less than 7 hours, the solubles extracted should be negligible.

The Difference in Rate of Moisture Increase

The difference in rate of moisture increase of the corn kernels in water and in aqueous SO_2 solution was plotted as a function of the steeping time for sweet corn, popcorn and dent corn, as shown in Figures 5, 6 and 7. The data for the plots are tabulated in Table 3 in Appendix.

It has been intuitively accepted that corn kernels absorb water faster in aqueous SO_2 solutions than in water. However, these results show that this assumption is not always true. For

Gold Rash sweet corn, the kernels absorb water in aqueous SO_2 solutions slower than in water in the initial period, at any particular temperature; but, as the duration of steeping was prolonged, such differences in the rates of moisture gain first increased and then reversed their trend and, eventually, they changed sign. The higher the temperature, the sooner this change took place. For instance, it took approximately 30 minutes at 160°F , 100 minutes at 140°F , 130 minutes at 120°F , while at 50°F it did not occur in 10 hours of steeping. After such change took place, the difference in moisture increased with increasing temperature. At 160°F the difference reached the maximum at approximately 110 minutes after immersion and then decreased and diminished again. This phenomenon might be due to the fact that both samples were completely swollen because of denaturization and gelatinization.

For K-4 hybrid popcorn the initial effect of SO_2 retarding the absorption rate was not so obvious as for Gold Rash sweet corn. When the temperature was low, however, such an effect of SO_2 was still quite appreciable. For instance, the reversion from retardation to acceleration took place at 80 minutes at 50°F . However, at room temperature or higher, the absorption rate was always higher in SO_2 solution; the higher the temperature the greater the difference in the rate of moisture gain. In most cases, the difference decreased again when the steeping was extended to several hours. Again this was probably due to the near saturation of the corn kernels by water and at high temperature, to gelatinization in the corn kernels.

For DeKalb 3xl dent corn, however, no detectable retarding effect of SO_2 on the absorption rate could be seen. If there was any, it must have disappeared very quickly. The absorption rate of water in SO_2 solution was always higher than that in plain water. The difference in the rate of moisture increases for dent corn was about twice as much as that for sweet corn and popcorn. It was surprising to see that the moisture increase in SO_2 solution was 25% higher than that in pure water after 7 hours of steeping at 120°F and that the isothermal curves did not appear to reverse themselves in the time range of the experiments, except the 140°F line for which the moisture difference reached its maximum after 2 hours and disappeared completely after 7 hours of steeping. This occurrence was again due to the saturation and gelatinization in the corn kernels.

The Initial Moisture Gain-- m_1

The quantity m_1 was measured for each of the three different samples at temperature levels from 50°F to 160°F , assuming five seconds as the time needed for these samples to complete the capillary action. There was essentially no difference between the m_1 in water and that in SO_2 solution. The values obtained are listed in Table 4.

The Effective Surface Moisture Content-- m_s

A number of samples which had been rewetted to different initial moisture contents, m_0 , and dried mildly in air were steeped in water and SO_2 solution for fifteen minutes to measure their

Table 4. Values of m_i , m_o , and m_s (in gm./gm.).

	Gold Rash sweet corn	K-4 hybrid popcorn	DeKalb dent corn
	m_i 0.0208	0.0216	0.0113
	m_o 0.1028	0.1300	0.1331
50°F	m_s 0.730	0.515	0.710
77°F	0.730	0.515	0.675
100°F	0.730	0.515	0.560
120°F	0.730	0.515	0.550
140°F	0.730	0.515	0.500
160°F	0.730		

Table 5. Values of $\frac{A}{V}$ (in cm.²/cm.³).

Gold Rash sweet corn	K-4 hybrid popcorn	DeKalb dent corn
12.9843	10.2766	8.6835

weight gains. A linear relationship was obtained by plotting $(\bar{m} - m_0)$ as a function of m_0 . The values of m_s were evaluated by extrapolating the straight line to the intercept with the abscissa, where $(\bar{m} - m_0)$ was equal to zero. The difference between the values in water and in SO_2 solution was negligible. The data are also listed in Table 4.

The Surface Area-to-Volume Ratio-- $\frac{A}{V}$

In deriving the diffusion model, the surface area-to-volume ratio was assumed constant. Therefore, the initial value of $(\frac{A}{V})$ was employed. The sphericity is related to the bed porosity of the grain as shown in Figure 1. The values of the porosity were 0.5205 for sweet corn, 0.3647 for popcorn and 0.4100 for dent corn. The corresponding sphericities were 0.650, 0.999 and 0.890, respectively. The results are listed in Table 5.

The Linear Relation Between $(\bar{m} - m_0)$ and \sqrt{t}

As shown in Equation (6), the moisture increase should be proportional to the square root of the absorption time if the diffusion model is applicable. Hence, for each of the samples the experimental data $(\bar{m} - m_0)$ were plotted as a function of \sqrt{t} at all the temperature levels shown in Figures 8, 9, and 10. Data for the plots are tabulated in Table 6 in the Appendix. The average slopes of the lines in the figures were determined by the method of least squares, using all the data included in the figures. The data of average slopes obtained are listed in Table 7 in Appendix.

The plots of the $(\bar{m} - m_0)$ vs. \sqrt{t} for sweet corn show that the linear relationship held approximately up to six hours for all temperature levels in both plain water and SO_2 solution. The differences in slope are always small, but the over-all slopes are always lower in water for temperature levels below 120°F .

Figure 9 shows that the relationship between $(\bar{m} - m_0)$ and \sqrt{t} for popcorn is essentially linear in the neighborhood of $t = 0$. At 50°F , it holds for about 45 minutes; at higher temperatures the relation holds in water, but the deviation from linearity is considerable in SO_2 solution at 140°F because popcorn absorbed water very fast and swelled up quickly. An examination of the over-all average slopes shows that the differences between the values in water and in SO_2 solution increase with increasing temperature but decrease again when the temperature becomes very high.

It can be seen from Figure 10 that the linearity in $(\bar{m} - m_0)$ vs. \sqrt{t} plots for dent corn is excellent at all temperature levels in both water and SO_2 solution except at 140°F where the curve bends downward after about 150 minutes of steeping and appears in a bow shape. The difference in slope in both the steeping solutions is relatively large. As with other samples, the differences in slopes for the samples in water and in SO_2 solution increase as temperature increases, but decrease again when they reach the gelatinization temperature.

The Effect of the Concentration of SO_2 on the Absorption Rates

In the industrial process the concentration of SO_2 in the

Table 8. Diffusivities of water in corn kernels.

Gold Rash Sweet Corn

Temp., °F		D X 10 ⁸ , cm./sec. ²	
		In Water	In SO ₂ Solution
50	Initial	5.2676	3.2602
	Average	4.1422	3.4762
77	Initial	10.3333	7.3919
	Average	10.1848	9.0945
100	Initial	15.578	14.925
	Average	20.005	19.862
120	Initial	30.117	25.903
	Average	32.136	31.546
140	Initial	46.593	44.684
	Average	52.771	58.347
160	Initial	65.713	68.271
	Average	73.701	78.902

K-4 Popcorn

Temp., °F		D X 10 ⁸ , cm./sec. ²	
		In Water	In SO ₂ Solution
50	Initial	20.054	20.228
	Average	9.492	10.487
77	Initial	32.675	33.510
	Average	17.466	21.678
100	Initial	46.269	50.906
	Average	26.118	32.181
120	Initial	57.018	71.442
	Average	37.645	42.302
140	Initial	71.329	106.63
	Average	43.508	48.045

Table 8 (cont'd)

		DeKalb 3xl Dent Corn	
Temp., °F		D X 10 ⁸ , cm./sec. ²	
		In Water	In SO ₂ Solution
50	Initial	4.941	4.896
	Average	4.502	4.967
77	Initial	11.121	12.638
	Average	11.543	14.884
100	Initial	33.722	42.886
	Average	19.725	27.618
120	Initial	48.321	66.174
	Average	40.471	62.550
140	Initial	89.681	141.23
	Average	89.275	109.682

steeping solution ranges from 0.25 to 0.35 per cent. In order to see the effects of various concentration levels of SO_2 on the absorption rate of water by the corn kernels, a sequence of experiments was conducted, using Kl830 yellow dent corn produced in Kansas in 1962. Its composition is listed in the section on MATERIAL. Steeping was carried out at 120°F in solutions of four different concentration levels, namely, 0%, 0.1%, 0.2%, and 0.4%. The moisture increase of the corn kernels was plotted as a function of the square root of steeping time between the moisture increases in water and those in SO_2 solution, as shown in Figure 11. The difference in moisture increase was as high as 20% after 8 hours of steeping. However, there was only a slight increase in the rate of moisture gain with an increase of concentration levels from 0.1 to 0.4%, although in many cases the moisture increase in 0.4% SO_2 solution showed slightly higher values than those at the lower concentration levels.

The Difference in Diffusivities--D

The diffusivities can be evaluated from Equation (8) with the known quantities of $(\frac{A}{V})$, $(m_s - m_o)$, and K_1 , as stated previously. As indicated by this equation, the diffusivities are proportional to the square root of the slopes of $(\bar{m} - m_o)$ vs. \sqrt{t} plot. From Figures 8, 9, and 10, it is seen that, in general, the plot of $(\bar{m} - m_o)$ vs. \sqrt{t} is linear at the initial period, and the slopes decrease when t increases. This implies that the calculated values of diffusivities are high and practically constant at the initial period but then gradually decrease. To show such a trend, values

of the diffusivities were calculated from both the initial slope and the average slope including all the data shown in Figures 8, 9, and 10. They are listed in Table 8. The linearity of $(\bar{m} - m_0)$ vs. \sqrt{t} plots is fairly good in the first forty-five minutes for the sweet corn and popcorn, and in the first 120 minutes for the dent corn. Those periods were considered as the initial periods of steeping.

The data for sweet corn show that, when the temperature was as low as 50°F, the diffusivity in SO₂ solution was lower than that in water. When the steeping time was prolonged, the diffusivities in water decreased, but the diffusivity of SO₂ solution increased. The reason was that the effect of SO₂ appeared gradually as time went on and increased the absorption rate. The same behavior was observed at 140°F. At this temperature, the initial diffusivity in SO₂ solution was lower than that in water, but the average values show that the order of magnitude had been reversed. The diffusivity in SO₂ solution became larger than that in water when absorption time increased. As the temperature increased again to 160°F, the accelerating effect of SO₂ on absorption appeared so rapidly that the diffusivity was greater in SO₂ solution almost from the beginning of steeping. This implied that the higher the temperature the sooner the difference between diffusivities in water and in SO₂ solution changed the sign.

For K-4 popcorn, the accelerating effect of SO₂ on the absorption rate was greater than its retarding effect even though at low temperature some retarding effect was seen in a very short initial

period of time. All the calculated values of diffusivity obtained in SO_2 solutions were higher than those obtained in water. The difference between them was more appreciable than that for sweet corn, and the higher the temperature the greater was the difference. The ratios of the initial diffusivities in SO_2 solution to those of water at 50°F , 77°F , 100°F , 120°F and 140°F were 1.01, 1.023, 1.10, 1.25, 1.50, respectively, but the ratio of average diffusivities at each temperature was 1.105, 1.24, 1.23, 1.12, 1.10, respectively. The increase in the ratio at low temperatures indicates that the accelerating effect of SO_2 played a significant role at low temperatures only after some time of absorption, but at higher temperatures the effect came sooner and decelerated again because of saturation and gelatinization.

Dent corn was characteristically similar in diffusion rate to popcorn. The only difference which could be observed was that the accelerating effect of SO_2 was much more pronounced and no retarding effect was seen in the data obtained. The ratios of diffusivities in SO_2 solution to those in water at 50°F , 77°F , 100°F , 120°F and 140°F were 0.99, 1.136, 1.28, 1.37 and 1.58 at the initial, 1.1, 1.29, 1.40, 1.54 and 1.23 in average.

The average diffusivities for all three varieties were plotted versus the reciprocal of the absolute temperatures on a semilogarithmic scale in Figures 12, 13, and 14. The results show that the relation between the diffusivity and the absolute temperature followed the Arrhenius-type equation:

$$D = D_0 \exp \left(- \frac{E}{RT} \right)$$

where E is the activation energy, R is the universal gas constant,

and T is the absolute temperature. The constant D_0 , and the slopes ($-\frac{E}{R}$) of the linear regression lines of the Arrhenius relation were estimated by the method of modified least squares, and the activation energy E was then evaluated. The data obtained are listed in Table 9 and also shown in Figures 12, 13, and 14.

A comparison of the data shows that for popcorn and dent corn there was no appreciable difference between the activation energy of the diffusion process in water and that in SO_2 solution. This is also seen in Figures 13 and 14 where the two lines of $\ln D$ vs. $1/T$ plot are nearly parallel to each other.

Because of the peculiar characteristics of sweet corn, the two lines on the $\ln D$ vs. $1/T$ plot cross each other; therefore, the value of activation energy obtained was higher in SO_2 solution than that in water.

The data obtained were compared with those of Becker (11), Chung (3) and Chu (12). It was shown that regardless of the varieties, almost all the cereal grains had diffusivities of the same order of magnitude, 10^{-7} cm.²/sec. in the temperature range from 32°F to 212°F. This would be expected because of the similarity in physical and chemical characteristics of cereal grains. Two varieties of corn identical to those used by Chu (12) were used in this work, namely, Gold Rash sweet corn and K-4 hybrid popcorn. The data obtained in this work had consistently lower values than those of Chu, but the order of magnitude was similar. The difference was, in addition to the personal errors, caused by the change

Table 9. Experimental data of D_o and E .

	Gold Rash sweet corn	K-4 hybrid popcorn	DeKalb dent corn
D_o in water	0.5547	0.00329	10.656
D_o in SO_2 so- lution	2.1508	0.00328	42.030
E in water	9.208	5.857	10.893
E in SO_2 so- lution	10.069	5.765	11.573

D_o in $cm.^2/sec.$, E in Kcal/mole

in bulk structure of the corn kernels resulting from an additional year of storage.

Some of the values of the activation energy for various cereal grains are listed here according to previous investigators (3) (12).

	E, Kcal/mole
K-4 hybrid popcorn	6.853
K1859 dent corn	7.578
Gold Rash sweet corn	8.167
White kafir sorghum	8.339
Atlas sorgo	8.424
Ponca sorghum	11.231

The values obtained in this work for K-4 hybrid popcorn and Gold Rash sweet corn were 5.857 and 9.208 Kcal/mole, respectively. It is apparent from the table that the magnitudes of the activation energy are fairly close to each other. This was also expected from the similarity in chemical and physical characteristics of cereal grains.

General Correlation

If the diffusion model used in this work is valid for the water-cereal grain diffusion, there should be a linear relationship between the dimensionless weight gain $(1 - \bar{M})$ and the new variable X with a slope of $\frac{2}{\sqrt{\pi}}$. In order to test this relation, the data of $(1 - \bar{M})$ and X were plotted in Figures 15, 16, and 17 and also tabulated in Table 10. The figures show that all the data fit the equation excellently.

CONCLUSION AND FUTURE WORK

The results obtained in these experiments show that the absorption rate of water in SO_2 solution, as well as in water, by corn kernels follows approximately the diffusion equation based on Fick's law.

The addition of SO_2 to steeping water has two extreme effects on the absorption rate, i.e., a retarding effect and an accelerating effect. For Gold Rash sweet corn the retarding effect is appreciable, for popcorn it is small, but for dent corn it is negligible. On the other hand, the accelerating effect on the absorption rate is small for Gold Rash sweet corn but considerable for K-4 popcorn and DeKalb 3xl dent corn. In general, the absorption rate is slower in SO_2 solution than in water at the onset of steeping, but this is reversed when the absorption time increases at any particular temperature. The higher the steeping temperature the sooner the reversion takes place. The accelerating effect of SO_2 rate increases with increasing temperature; but, at a certain high temperature, the difference decreases after a certain period of absorption because of the saturation of corn kernels by water and because of the gelatinization of starch in corn kernels.

The effect of the concentration levels of SO_2 on the absorption rate is negligible in the range of these experiments.

The accelerating effect of SO_2 on the absorption rate is probably due to the disintegration of the protein network as described in the work of Cox and MacMasters (8). The disintegration of the protein network will soften the grain and provide easy

paths for penetration. A microscopic observation also showed that the pericarp of the grain was eroded by the action of SO_2 . The erosion is obviously of some help in accelerating the absorption of liquid.

The retarding effect, however, was not reported by any previous investigators and its nature is not well understood.

Therefore, the following work on this project is proposed for the future:

(1) Explore the causes for such effects of SO_2 as retardation and acceleration of the diffusion rate by means of microscopic and chemical examination.

(2) Investigate the effect or effects of SO_2 on the absorption rate of water by other varieties of corn and grain.

(3) Extend the diffusion periods further to see if the difference in moisture gain, which occurs when corn kernels are steeped in water and in SO_2 solution, will eventually diminish for all temperature levels.

(4) Measure the initial diffusion rate more accurately than has been done to see if the retarding effect of SO_2 exists for dent corn and other varieties of corn at lower temperature levels.

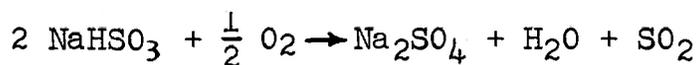
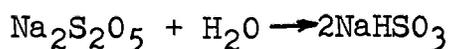
(5) Establish equations which will provide precise prediction of absorption rate of water in SO_2 solution.

TREATMENT OF WET CORN WITH
SODIUM METABISULFITE

TREATMENT OF WET CORN WITH SODIUM METABISULFITE

Preservation of wet grain has often been complicated by rapid spoilage caused by microorganisms, insects and self-heating. Therefore, several methods have been used to counteract such spoilage and the growth of molds (15). Some of these methods are drying the grains immediately after harvest so that there will be insufficient water available for the growth of the undesirable microorganisms, storing the grain in air-tight bins, and shutting off the supply of oxygen to the grain. However, the operating cost, the high equipment investment, and the time required for operation are limitations of drying as a preservation practice of the grain. Air-tight storage also has many shortcomings (15). For instance, fermentation occurs in grain with high moisture content after several months of storage.

Among several chemicals investigated by G. W. Isaac (18) for preserving wet grain, sodium metabisulfite ($\text{Na}_2\text{S}_2\text{O}_5$) was reported to be the most effective for wet shelled corn. Probably sodium metabisulfite affects the grain quite similarly to sulfur dioxide since, in the presence of moisture and air, sodium metabisulfite undergoes the following reactions:



The starch produced from corn treated with sodium metabisulfite is as good as ordinarily processed starch except that, according to the American Corn Federation (19), there is approxi-

mately 50% less thiamine (Vitamin B₁) in treated corn. However, this reduction in thiamine does not significantly affect the production of industrial materials such as dextrose, dextrin and others produced in large quantities from starch.

G. W. Isaac (18) compared the rate of exposed layer drying for both the treated and untreated corn and found a considerable increase in the drying rate with treated corn. For instance, the drying constant of the untreated shelled corn investigated was 0.245 hour⁻¹ at 140°F while that of treated corn was 0.336 hour⁻¹ at the same conditions. Drying constant is defined as the constant in the exponential function of drying.

It was proposed (19) that the effects of and mechanism of the sodium metabisulfite on the corn in increasing the drying rate may be similar to those of sulfurous acid to the corn in increasing diffusion rate. Some experiments, therefore, were conducted to confirm this proposition.

Material and Storage

DeKalb 3x1 dent corn rewetted to moisture content of 0.200 gm./gm. was sealed in three plastic containers, one containing no sodium metabisulfite and the others containing 0.4% and 2.0% of sodium metabisulfite by weight-wet basis. Another set of samples of dry corn (0.1331 gm./gm. moisture) was also sealed in separate containers with the same proportions of sodium metabisulfite as the rewetted corn samples.

After several days of storage, the odor of sulfur dioxide was detected from the wet corn samples with the agent. The grain was

whitened gradually and the surface of the grain in the sample with 2.0% agent became wet, while the untreated grain remained unchanged. On the other hand, no apparent changes could be detected for all the dry samples.

Comparison of Diffusion Rate

After one month of storage at room temperature, approximately 80°F, experiments were conducted for comparing the diffusion rate of treated corn and untreated corn. For each run of the experiment, three samples sealed with 0%, 0.4% and 2.0% of sodium metabisulfite were weighed and steeped.

The previously described procedure was followed except that all the samples were steeped in distilled water. Some of the results obtained are listed in Tables 11 and 12.

It can be seen that the diffusion rates of water into the corn kernels were definitely increased by preserving them with sodium metabisulfite. Further examination of the data indicates that the moisture increases of the samples treated with 0.4% and 2.0% sodium metabisulfite were very close to each other, especially when the steeping time was long. Hence it may be supposed that the optimal weight of sodium metabisulfite to be added to a storage container may be around 0.4% or less from the standpoint of increasing the diffusion rate. Application at greater rates will not materially increase the diffusion rate.

After forty days of storage the untreated wet corn appeared considerably fermented and a layer of mold was observed while the treated wet corn remained clean and white.

Table 11. Comparison of moisture increase of treated corn and untreated corn in water (I).

Temperature 120°F $m_0 = 0.2606$ D.B. Storage time = 30 days

Steeping time (min.)	Moisture increase (m - m_0) gm./gm.		
	No $\text{Na}_2\text{S}_2\text{O}_5$	0.4% $\text{Na}_2\text{S}_2\text{O}_5$	2% $\text{Na}_2\text{S}_2\text{O}_5$
15	0.0787	0.0949	0.1025
30	0.1031	0.1309	0.1421
60	0.1434	0.1686	0.1881
120	0.1876	0.2385	0.2562
180	0.2209	0.2967	0.2957
240	0.2614	0.3359	0.3368

Table 12. Comparison of moisture increase of treated corn and untreated corn in water (II).

Temperature 140°F $m_0 = 0.220$ D.B. Storage time = 10 days

Steeping time (min.)	Moisture increase (m - m_0)		
	No $\text{Na}_2\text{S}_2\text{O}_5$	0.4% $\text{Na}_2\text{S}_2\text{O}_5$	2% $\text{Na}_2\text{S}_2\text{O}_5$
5	0.0630	0.0811	0.0884
15	0.0936	0.1034	0.1228
60	0.1916	0.2174	0.2289
90	0.2220	0.2533	0.2598
120	0.2467	0.2872	0.3374
180	0.3027	0.3507	0.3416
240	0.3498	0.3996	0.4033

After two months of storage, the untreated dry corn thrived with insects and the treated dry corn appeared undamaged.

DISCUSSION AND PROPOSED FUTURE WORK

The functions of SO_2 as a steeping agent are, as indicated previously, to soften the kernels, to prevent fermentation, and to whiten the starch. Such functions of SO_2 are all attainable if the corn is treated with sodium metabisulfite. Therefore, it is reasonable to consider the possibility of replacing the traditional method of steeping corn in sulfurous acid with preserving the corn with sodium metabisulfite before steeping in water. And since this preservative prevents and retards mold growth in corn for three to six months, drying prior to storage may be avoided provided the corn is processed within three to six months of harvest. If the application rate of the sodium metabisulfite is 0.4%, the cost of treatment, including the cost of the preservative, labor, feeder and feeder power, will average $1\frac{1}{2}$ cents to 2 cents per bushel of corn (20) (21). Thus, the over-all cost of storage and processing of corn could be greatly reduced.

Should the pretreatment with sodium metabisulfite be insufficient for steeping in water for further processing, this compound may also be dissolved in the water as a steeping agent in place of SO_2 gas. The amount of the compound to be used must be less than the usual steeping solution, sulfurous acid, in equivalent SO_2 . The amount to be used will determine whether it is preferable. The solubility of sodium metabisulfite in water is 31.23 gm./l. at 25°C .

If the traditional way of steeping must be used, there is still a possibility that the steeping time may be considerably reduced if the corn is pretreated with sodium metabisulfite.

To confirm all these propositions, much more data should be accumulated and further experiments must be conducted. For instance, some experiments should be done to obtain complete data on the yield of starch manufactured from corn after different degrees of pretreatment resulting from the different application rates of the preservative, different times of storage and different periods of steeping time, and different concentrations of sodium metabisulfite in steeping water.

A study of the effects of sodium metabisulfite on corn kernels may also provide much information concerning the function of SO_2 on corn kernels during steeping in sulfurous acid. Some facts have already been found in this work. For instance, the apparent increases in diffusion rate as well as drying rate and the microscopic observation of treated corn indicate that the pericarp of the corn is eroded by SO_2 during storage with sodium metabisulfite. This explains why the diffusion rate, in most cases after the initial period, increases if the corn is steeped in sulfurous acid, as compared with that in water. The reason for the initial decrease in the diffusion rate caused by the presence of SO_2 in water may be related to the increased surface tension or some other physical and chemical interaction between the steeping and the grain. However, further systematic investigation is necessary in order to confirm these speculations.

ACKNOWLEDGMENTS

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NOMENCLATURE

A	= effective surface area of a solid, cm.^2
c	= concentration of diffusion substance at a point in a solid, gm./cm.^3
c_0	= initial, uniform concentration, gm./cm.^3
c_s	= concentration at the bounding surface, gm./cm.^3
\bar{c}	= average concentration, gm./cm.^3
D	= diffusivity, $\text{cm.}^2/\text{sec.}$
D_0	= constant in Arrhenius equation, $\text{cm.}^2/\text{sec.}$
E	= energy of activation, KCal./mole.
f	= function
f', f''	= first and second, derivatives of f.
F	= diffusion current (i.e., the specific rate of mass transfer), $\text{gm./}(\text{cm.}^2)(\text{sec.})$.
m_0	= initial moisture content, dry basis, gm./gm.
m_s	= moisture content at the bounding surface, dry basis, gm./gm.
\bar{m}	= average moisture content, dry basis, gm./gm.
$\bar{m} - m_0$	= average moisture gain, dry basis, gm./gm.
m_i	= initial moisture gain, dry basis, gm./gm.
R	= gas constant, $\text{cal./mol.}^\circ\text{K.}$
T	= absolute temperature, $^\circ\text{K.}$
t	= time, sec.
V	= volume of a solid, cm.^3
t, y, z	= cartesian coordinates, cm.
	= sphericity.
	= porosity.

Dimensionless Factors in Diffusion Equation

$$\bar{C} = \frac{c_s - \bar{c}}{c_s - c_0}$$

$$M = \frac{m_s - \bar{m}}{m_s - m_0}$$

$$X = \frac{A}{V} \int \bar{D}t$$

$$Y = \frac{l - \bar{C}}{X}$$

APPENDIX

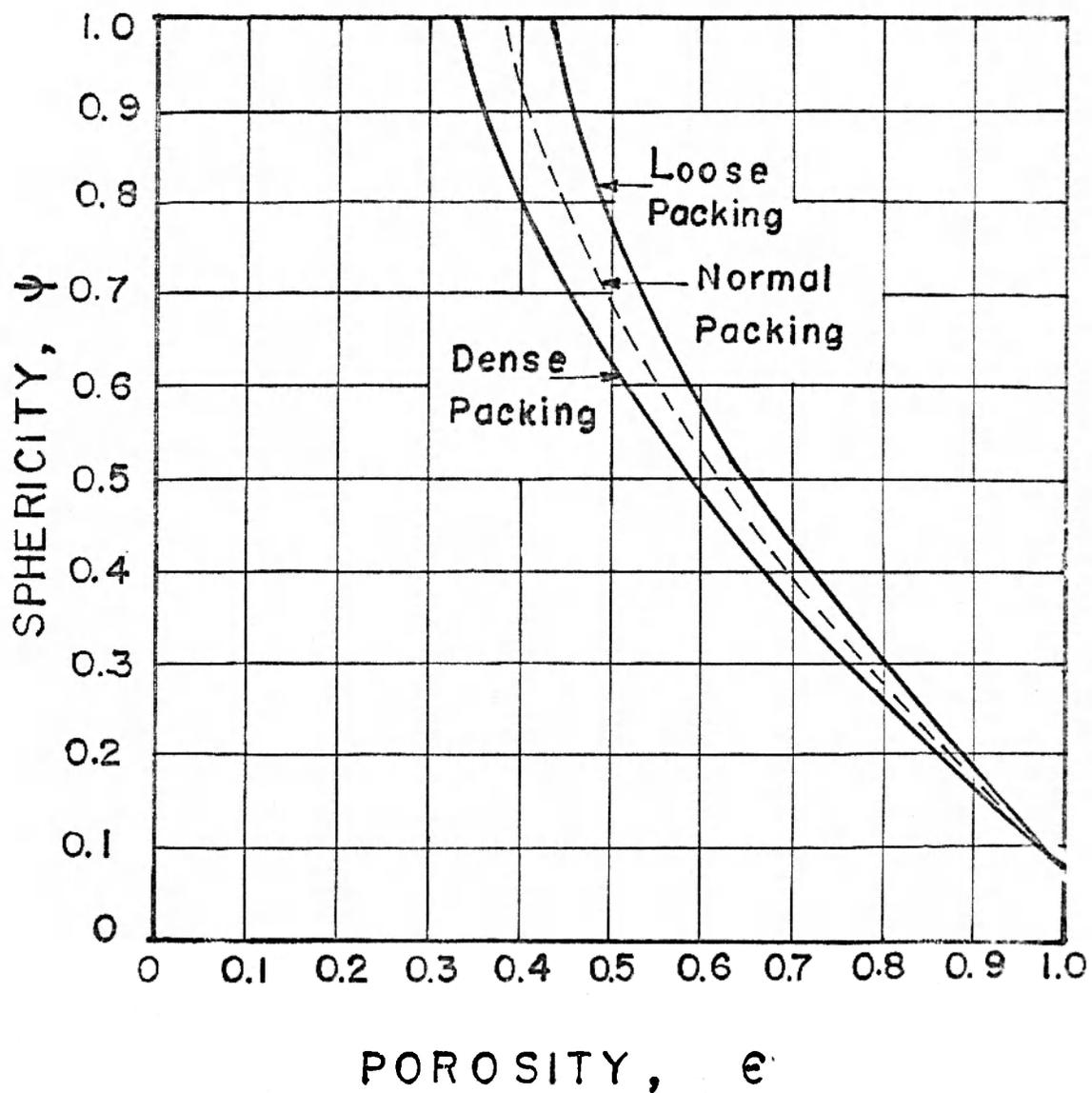


Fig.1. Sphericity as a function of porosity for random-packed beds of uniform-sized particles.

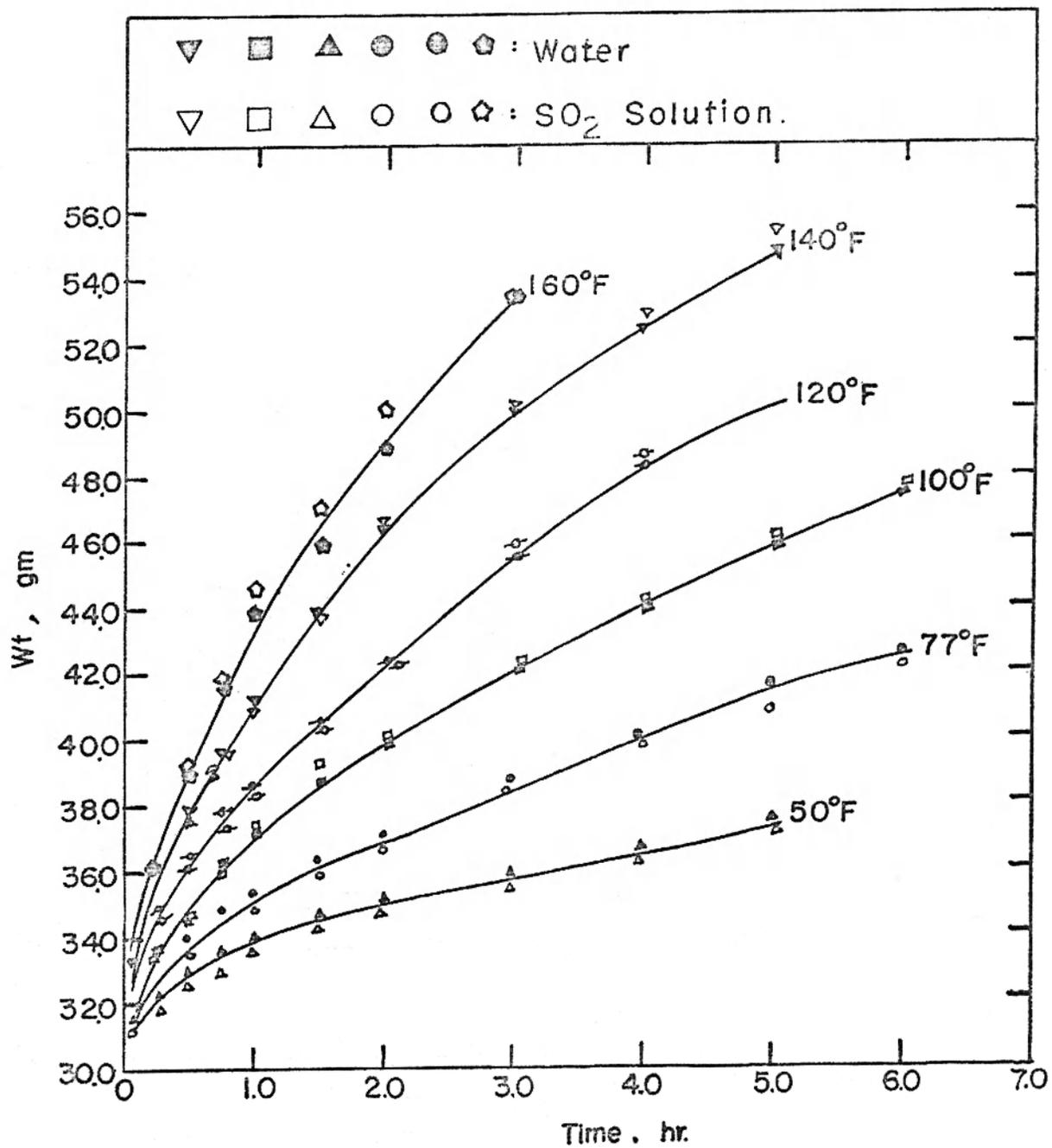


Fig.2. weight of Gold Rash sweet corn as a function of absorption time.

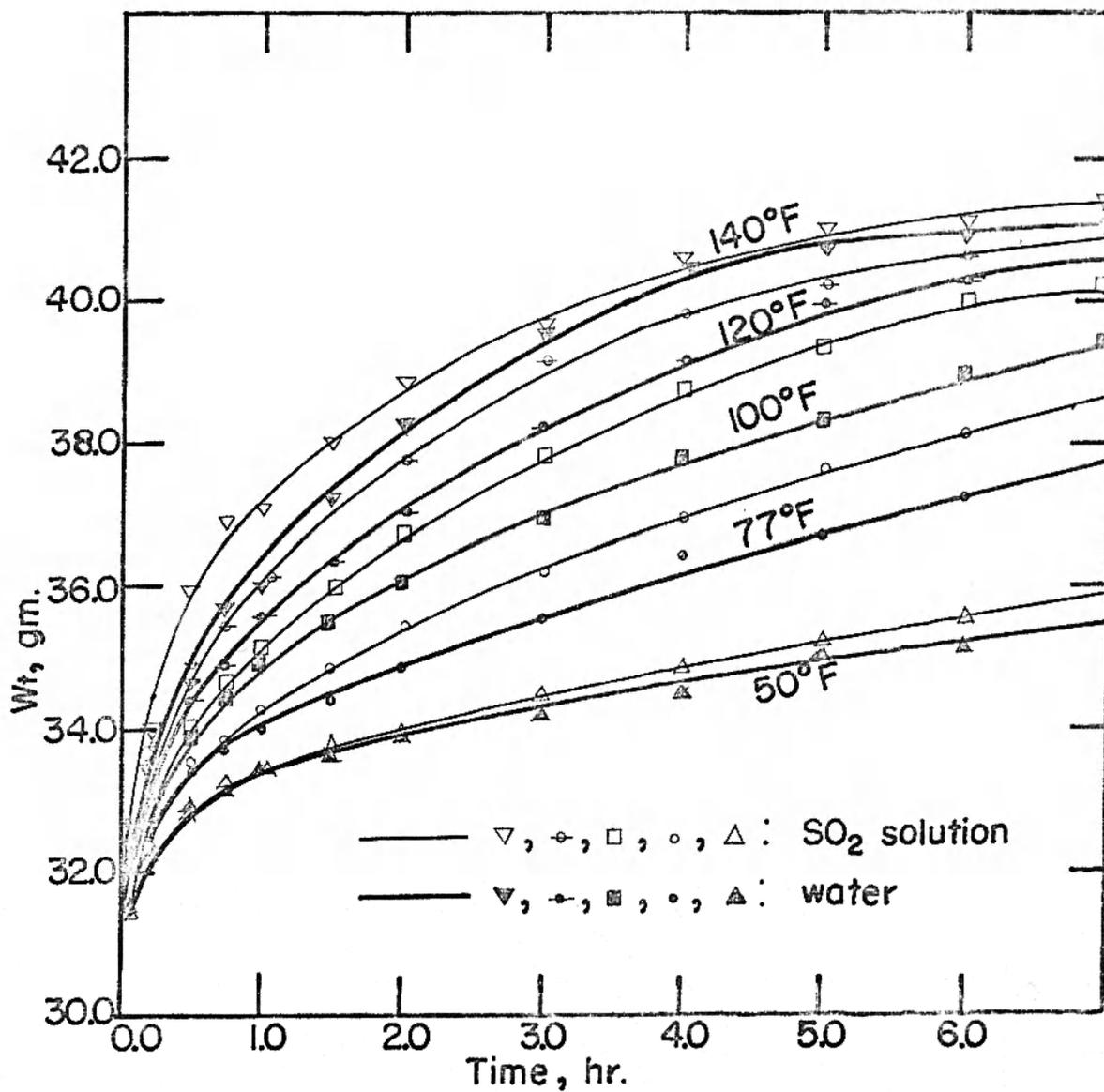


Fig.3. Weight of the K-4 hybrid popcorn as a function of absorption time.

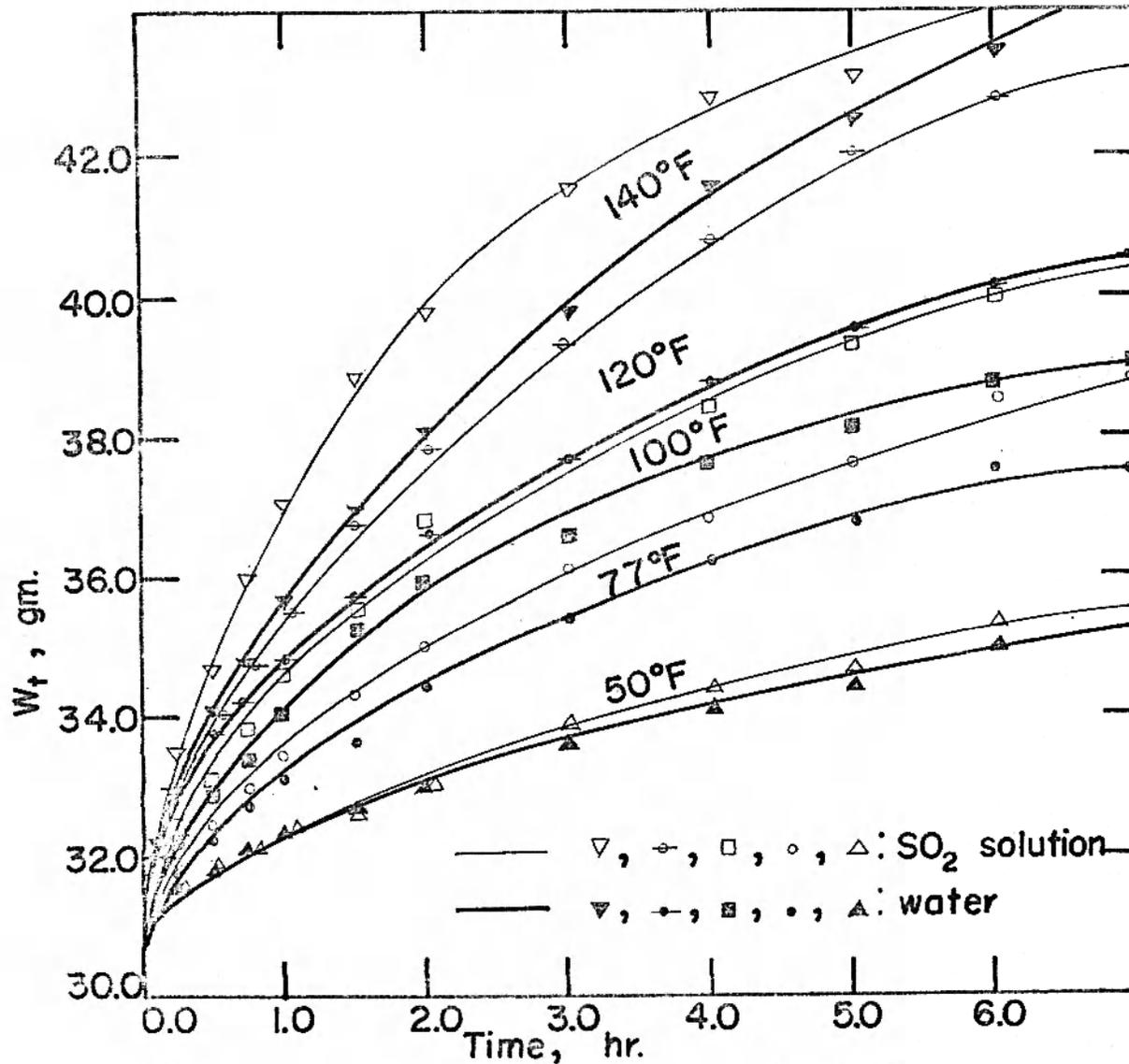


Fig. 4. Weight of the De Kalb 3x1 dent corn as a function of steeping time.

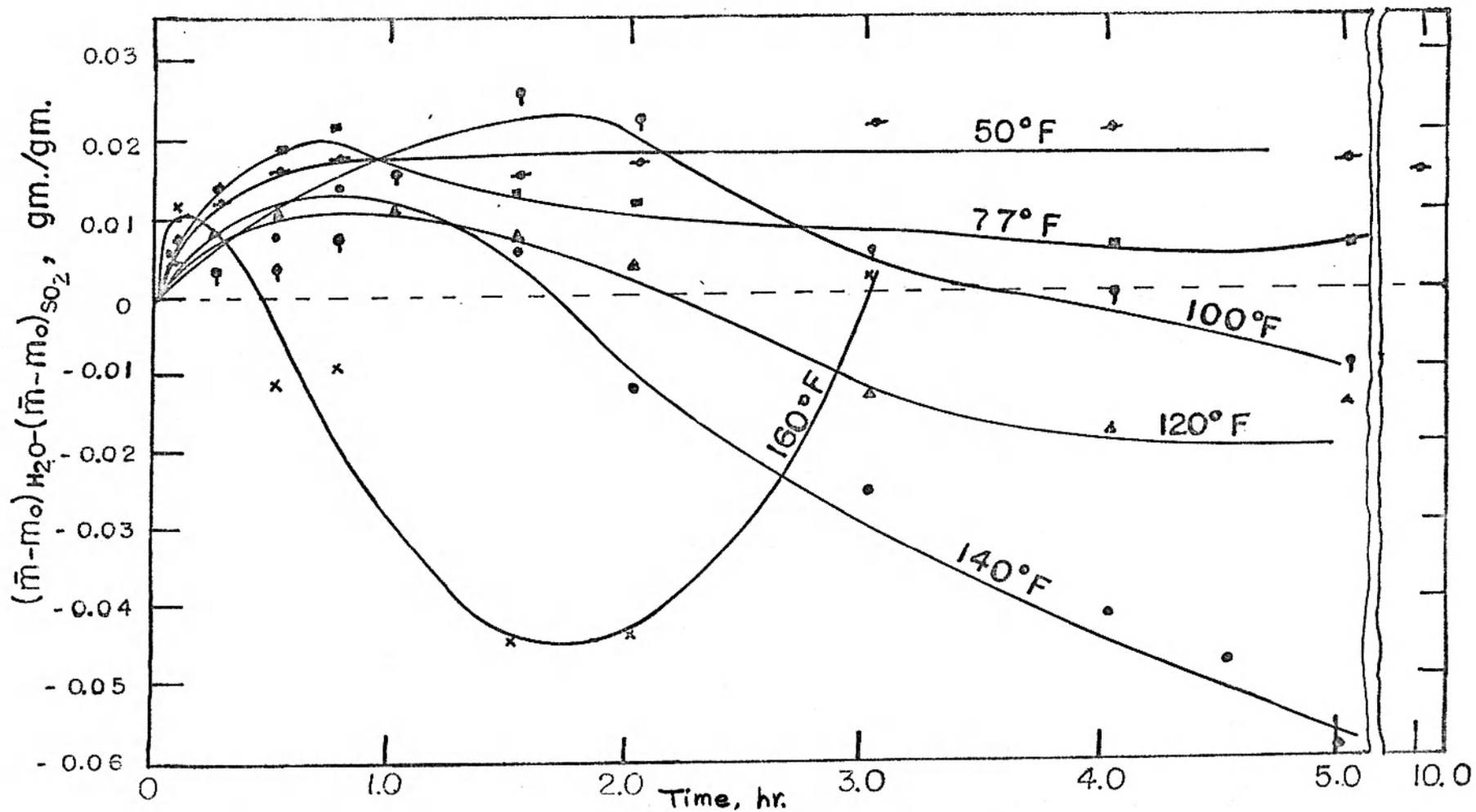


Fig.5. The difference in moisture increase as a function of the absorption time for Gold Rash sweet corn in water and aqueous SO_2 solution.

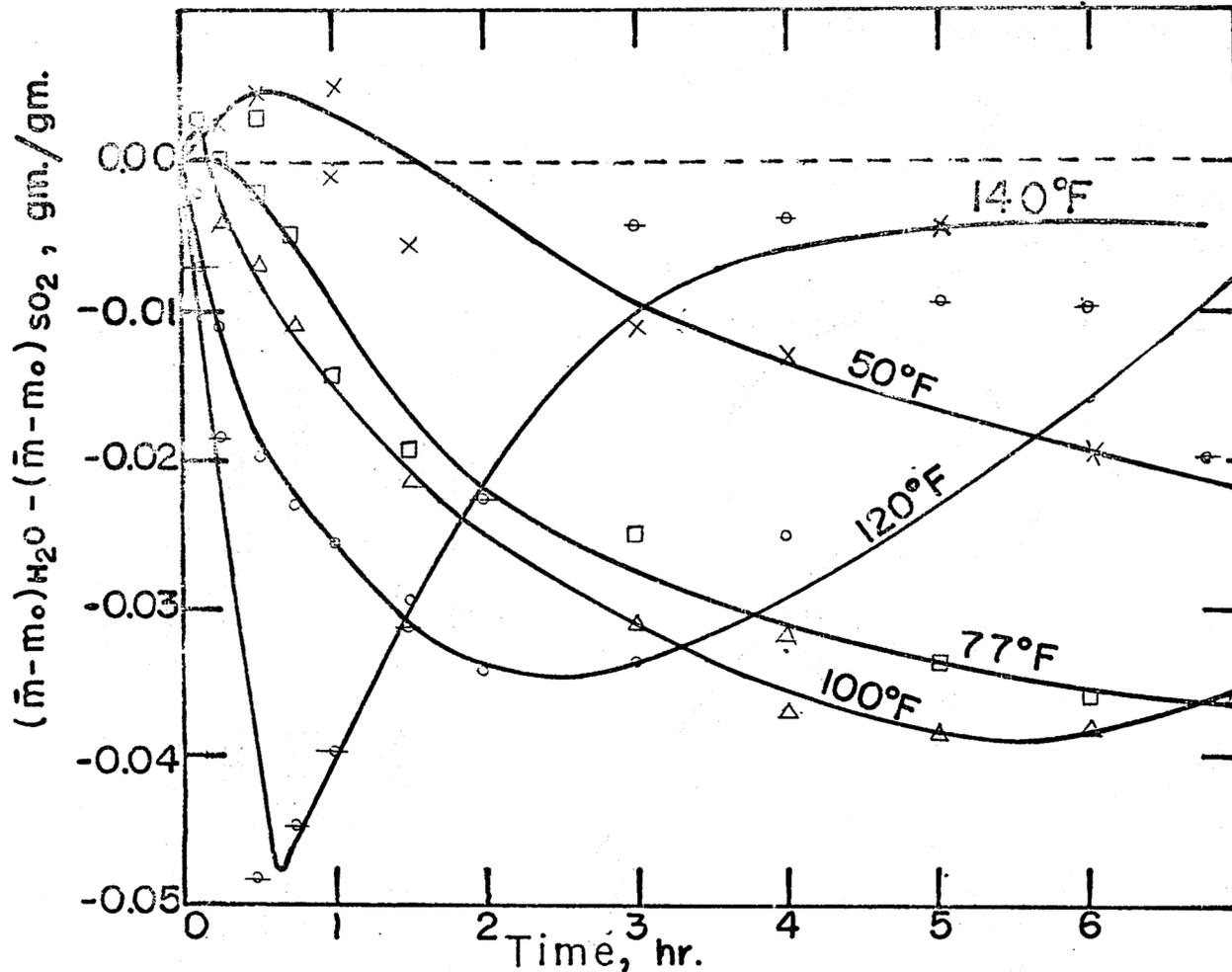


Fig. 6. The difference in moisture increase as a function of the absorption time for K-4 hybrid popcorn in water and in aqueous SO_2 solution.

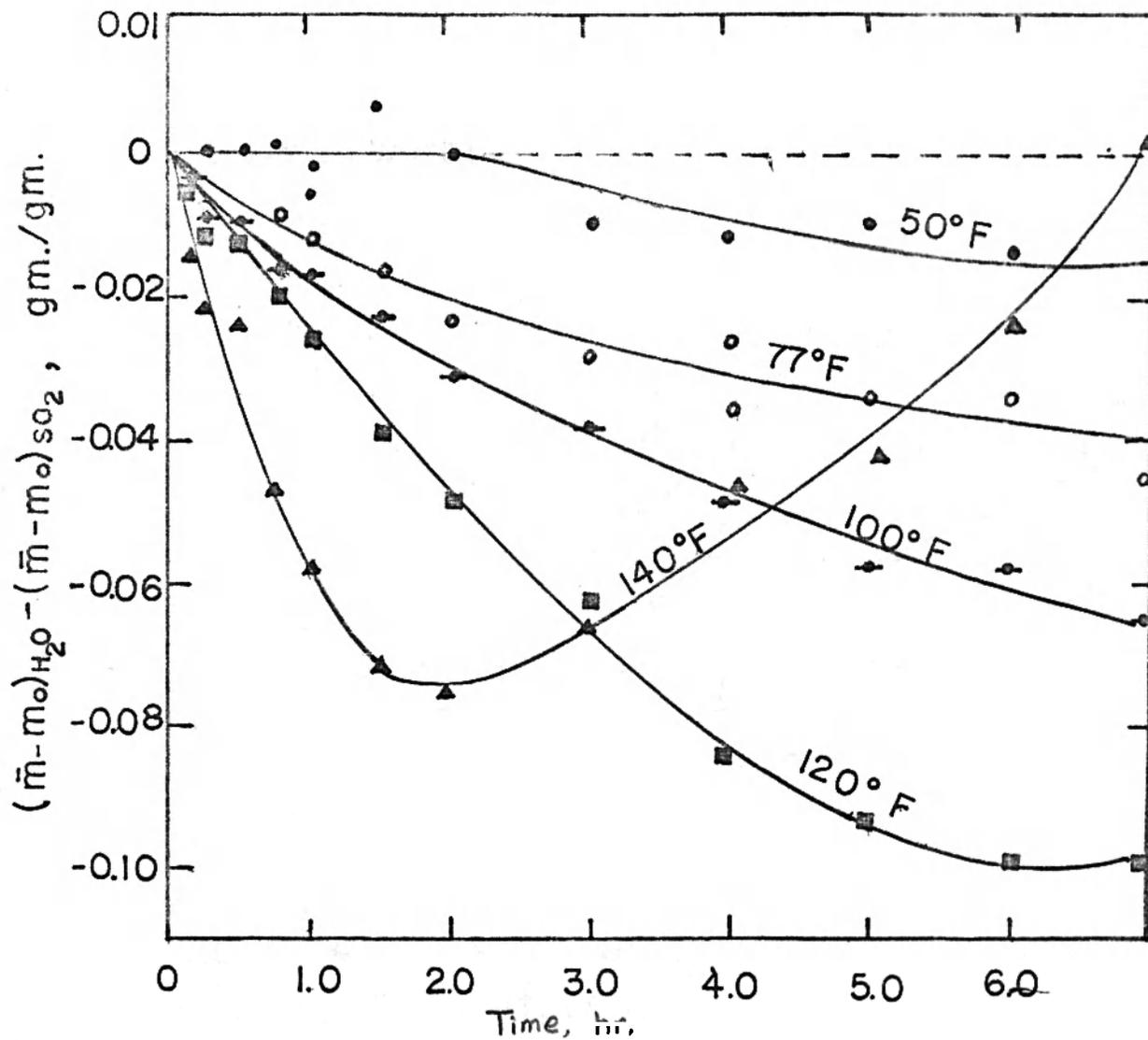


Fig. 7. The difference in moisture increase as a function of the absorption time for De Kalb 3x1 dent corn in water and aqueous SO₂ solution.

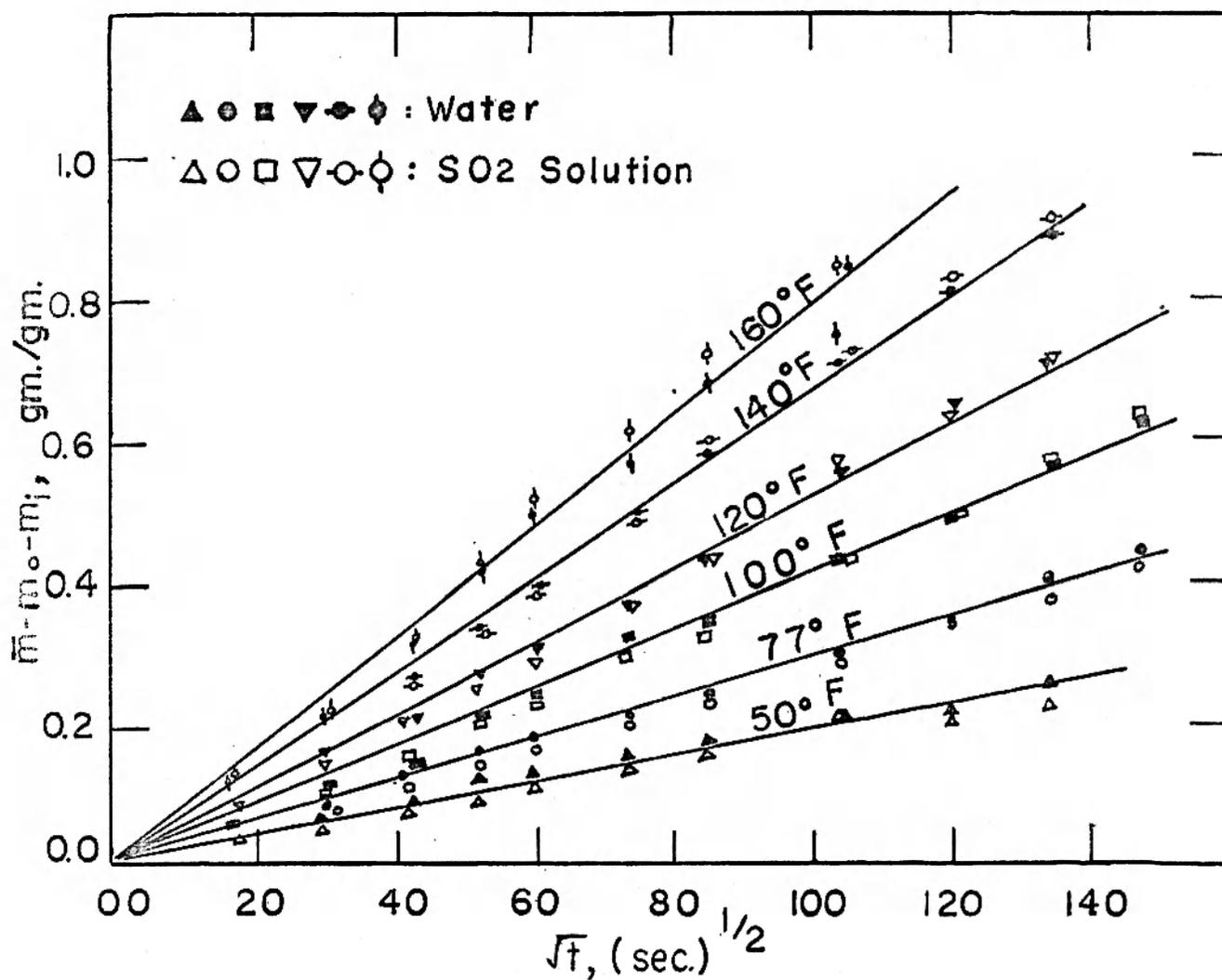


Fig. 8. The linear relation between the moisture gain and the square root of the absorption time for Gold Rash sweet corn.

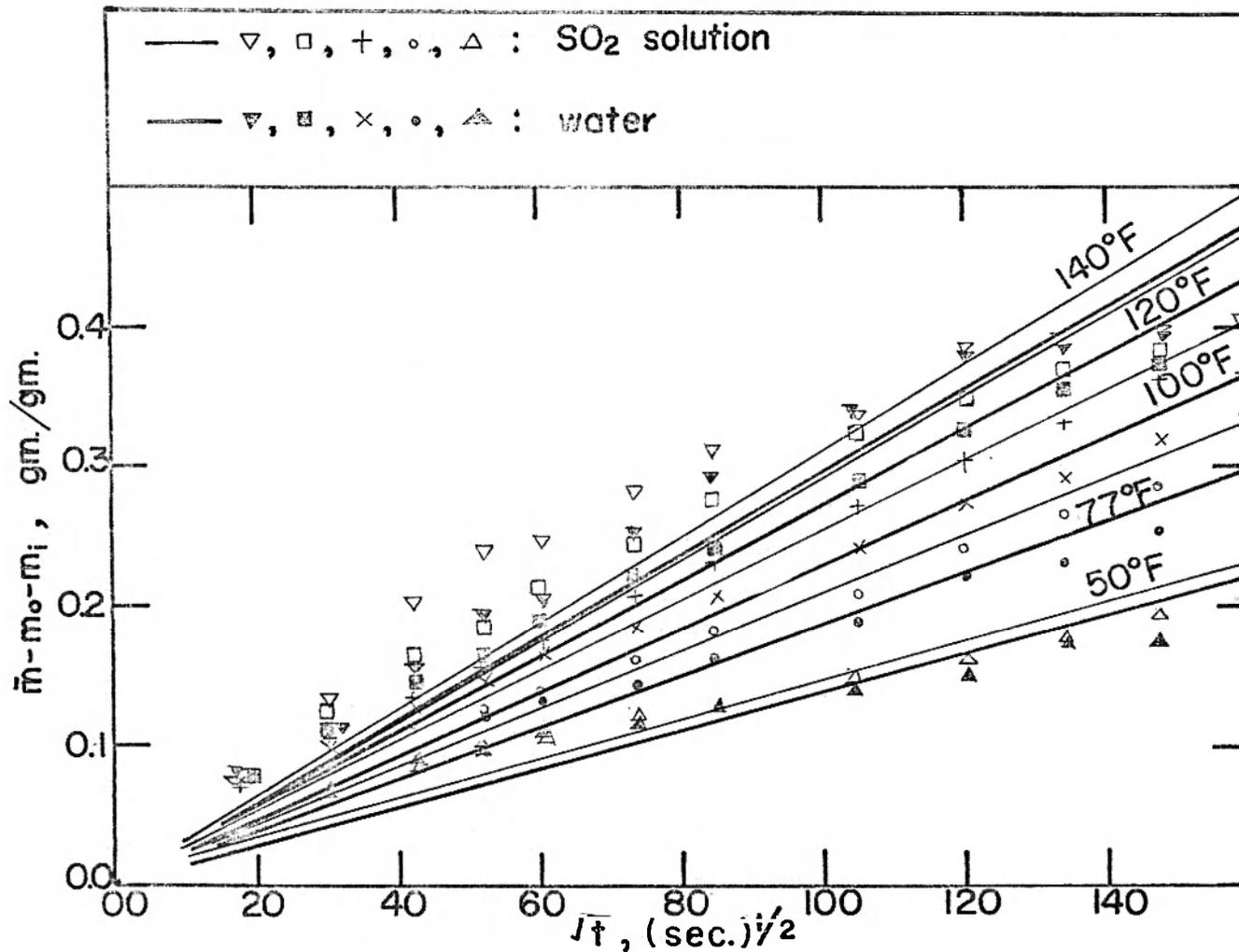


Fig. 9. The linear relation between the moisture gain and the square root of the absorption time for K-4 hybrid popcorn.

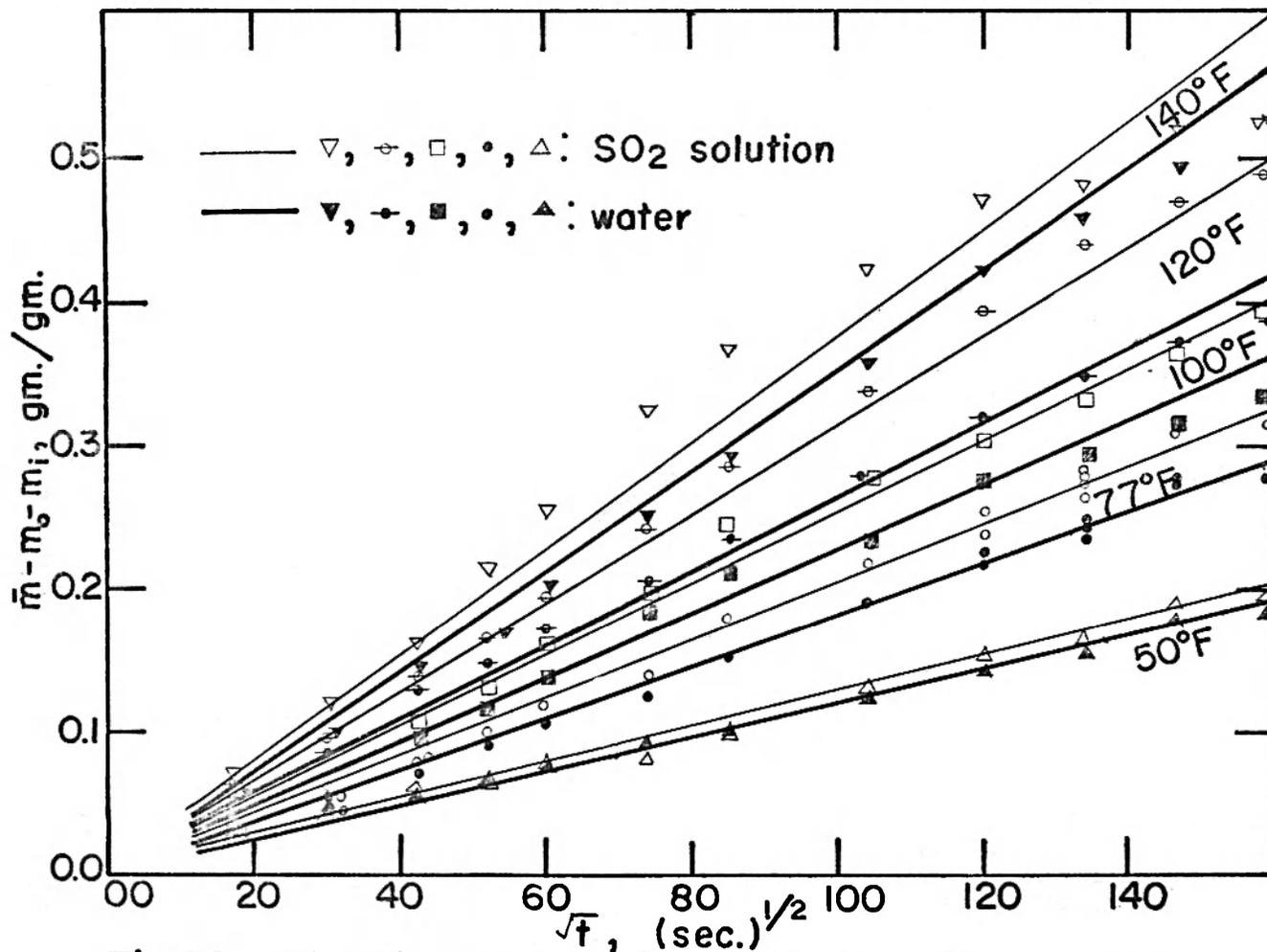


Fig.10. The linear relation between the moisture gain and the square root of the absorption time for De Kalb 3X1 dent corn.

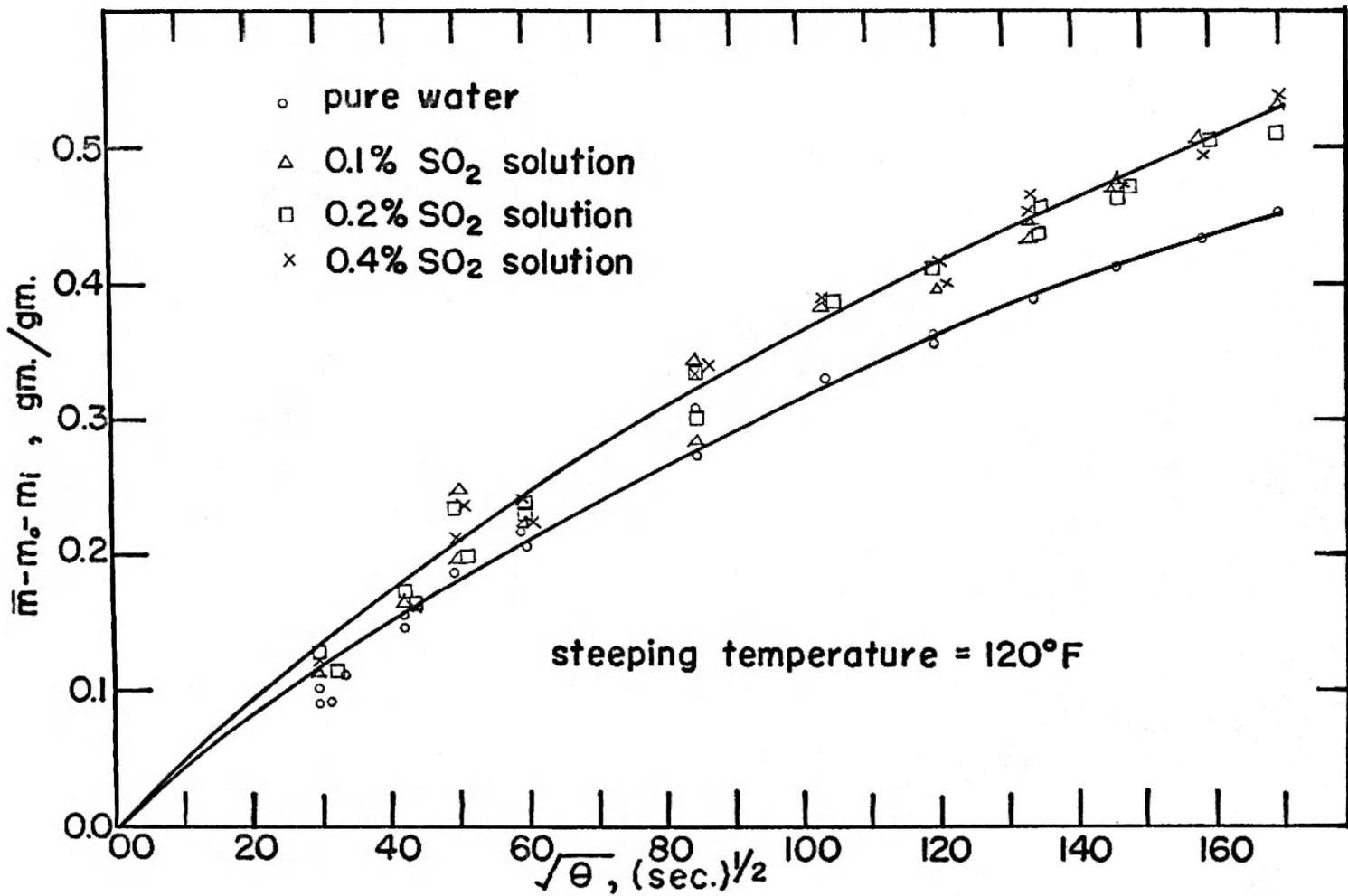


Fig.11. The effect of concentration of SO₂ on the moisture increase for K 1830 hybrid yellow dent corn.

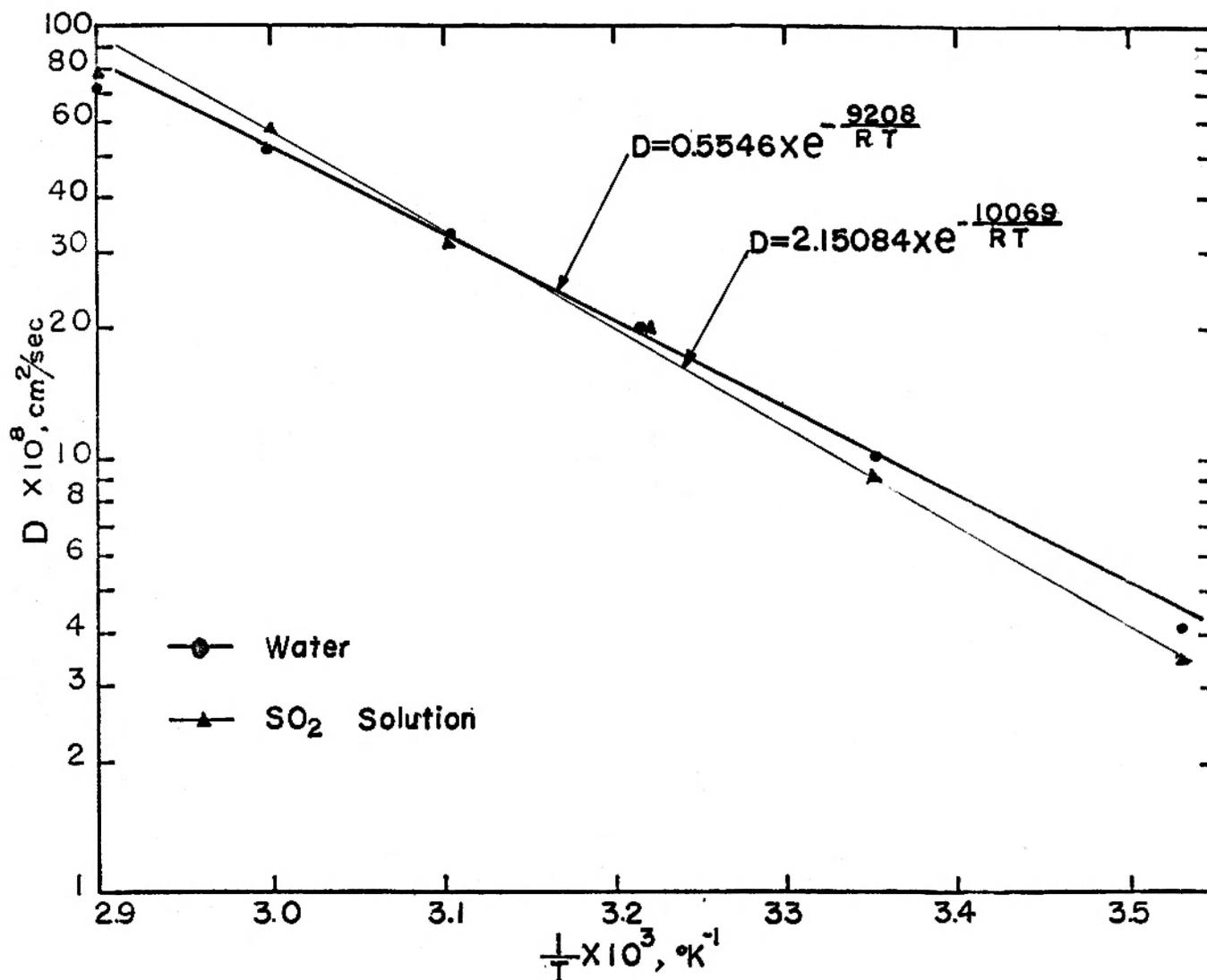


Fig.12. The diffusion coefficient calculated from equation (14), as a function of reciprocal of temperature for Gold Rash sweet corn.

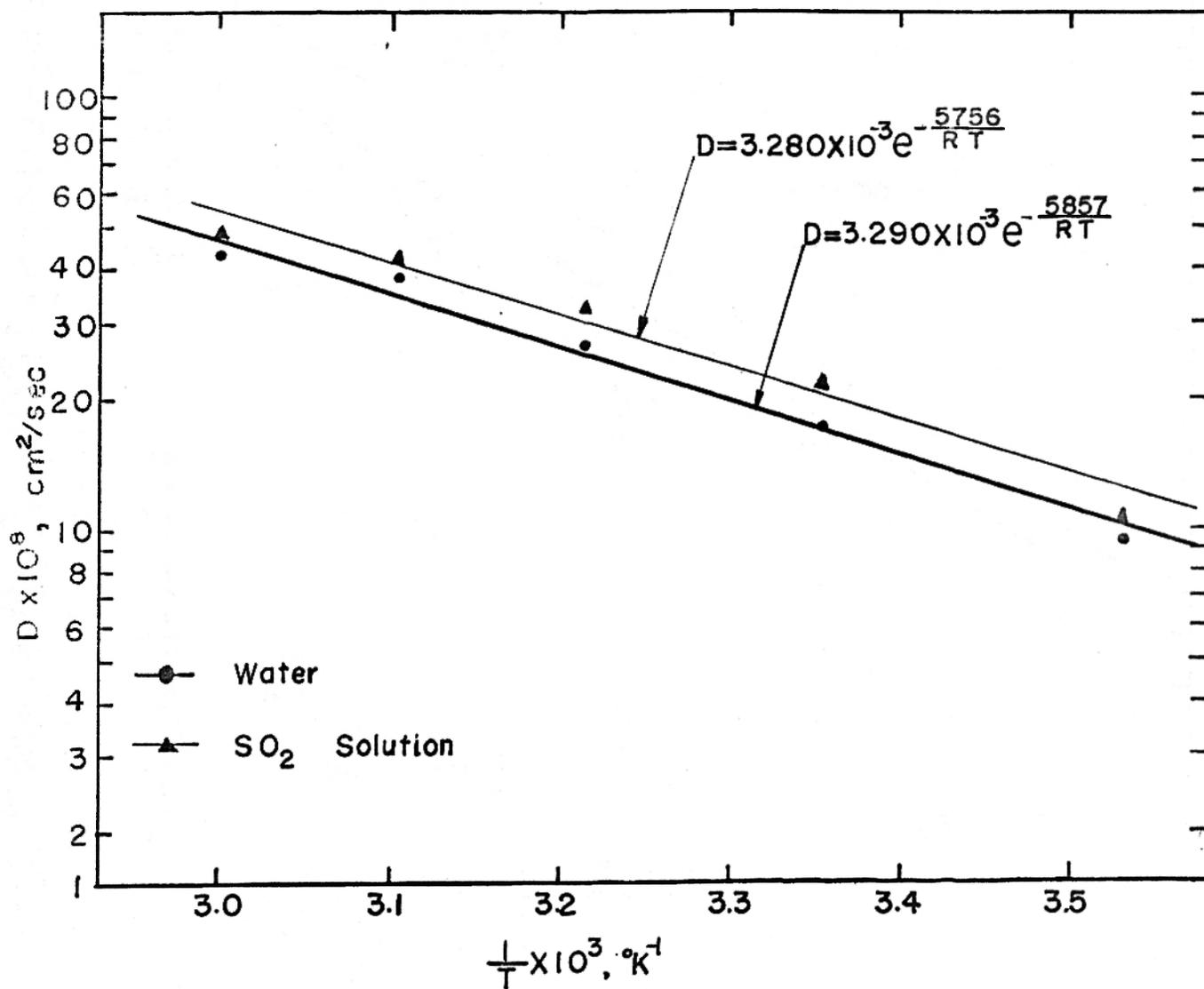


Fig.13. The diffusion coefficient calculated from equation (14), as a function of reciprocal of temperature for K-4 hybrid popcorn.

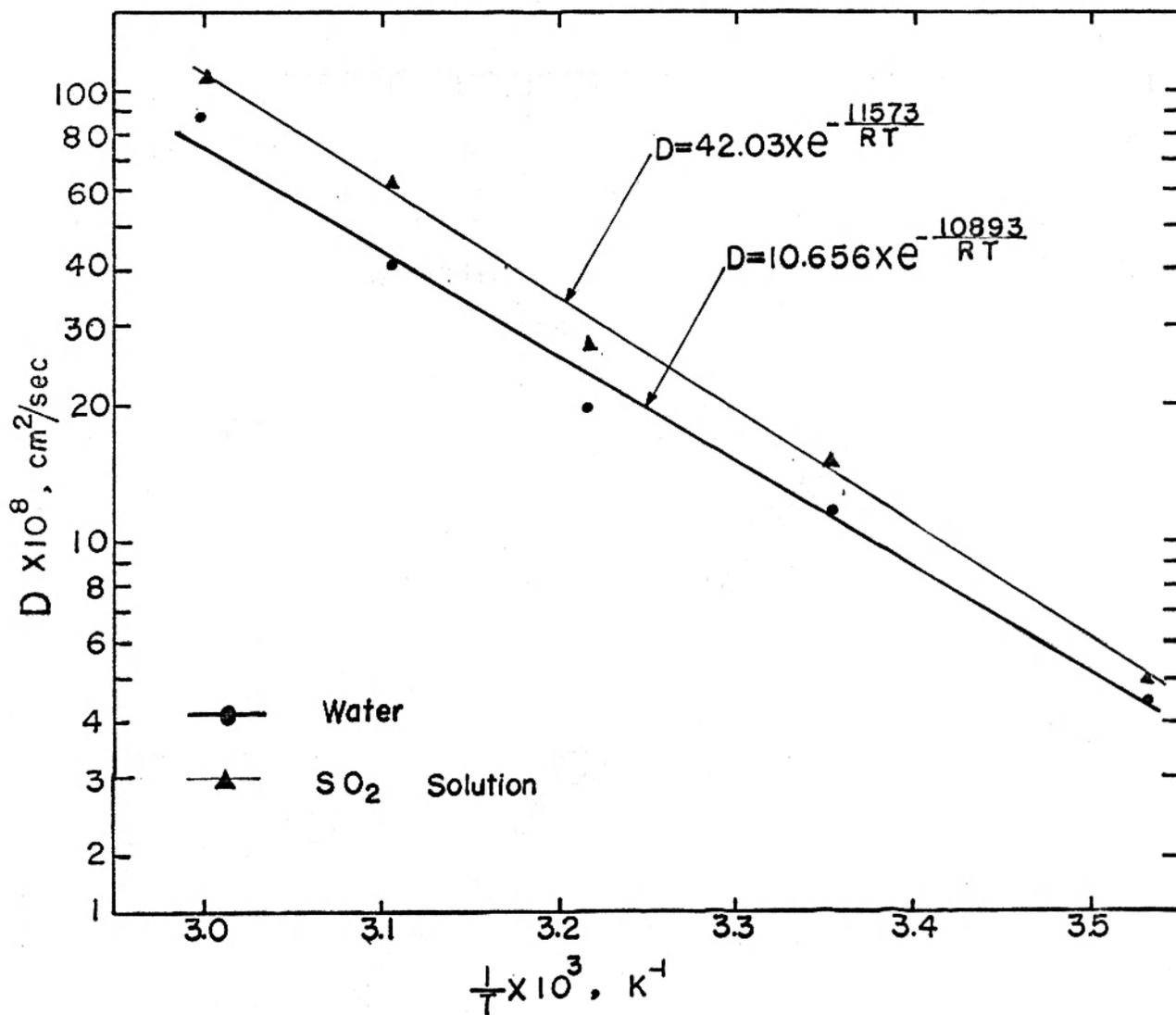


Fig.14. The diffusion coefficient calculated from equation (14), as a function of reciprocal of temperature for De Kalb dent corn.

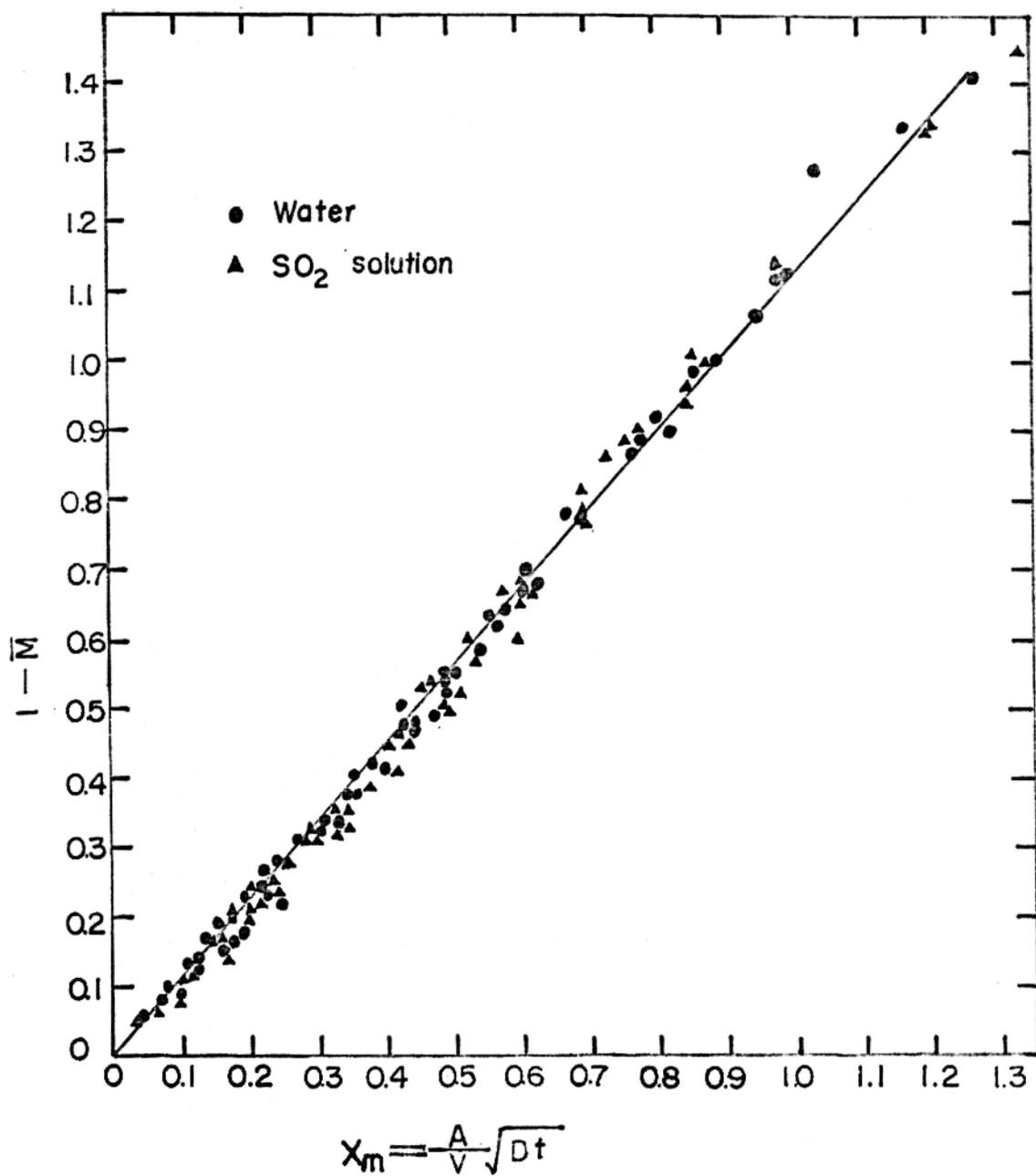


Fig.15. Dimensionless correlation for the weight gain data of Gold Rash sweet corn according to the first order approximation to diffusion equation.

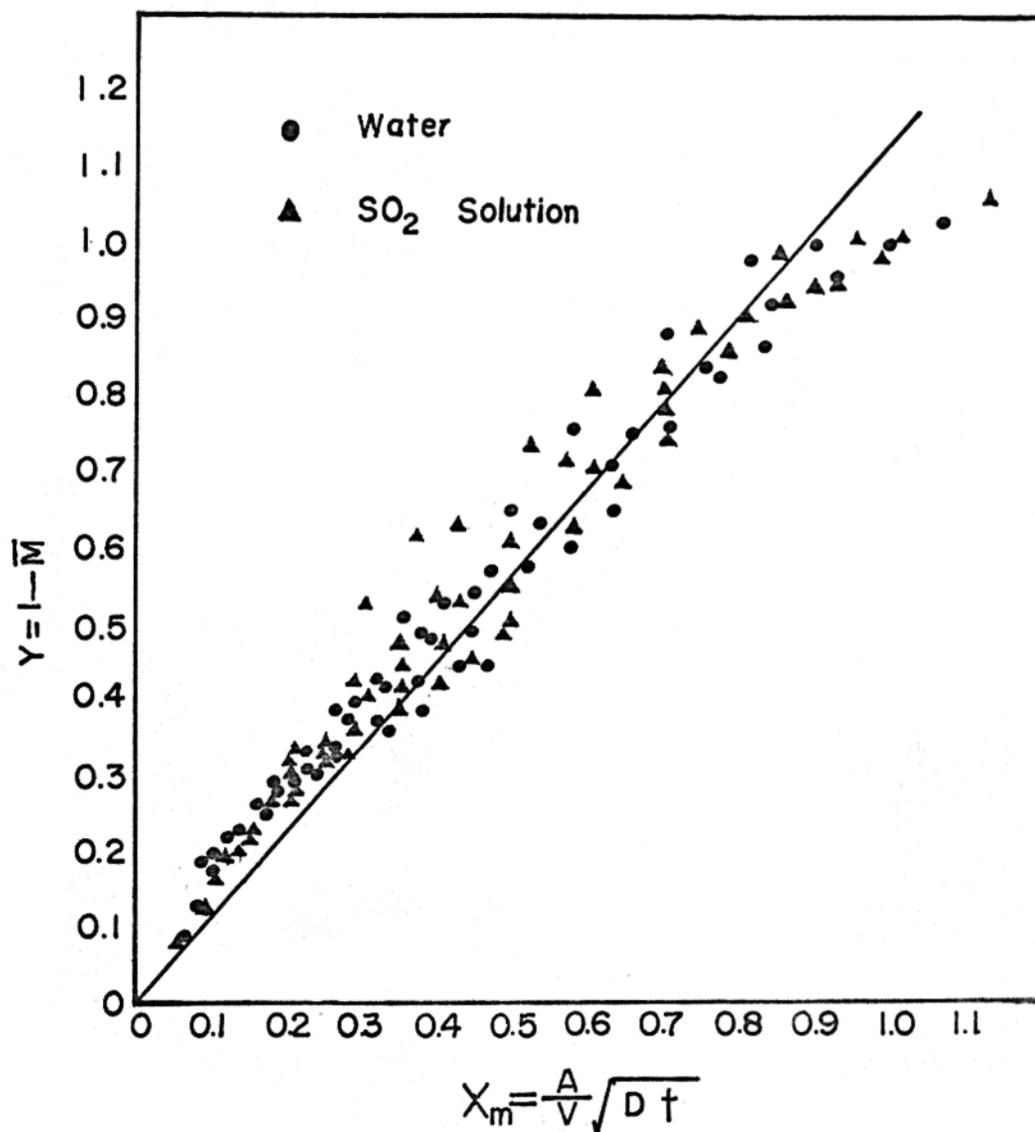


Fig.16. Dimensionless correlation for the weight gain data of the K-4 hybrid popcorn according to the first order approximation to diffusion equation.

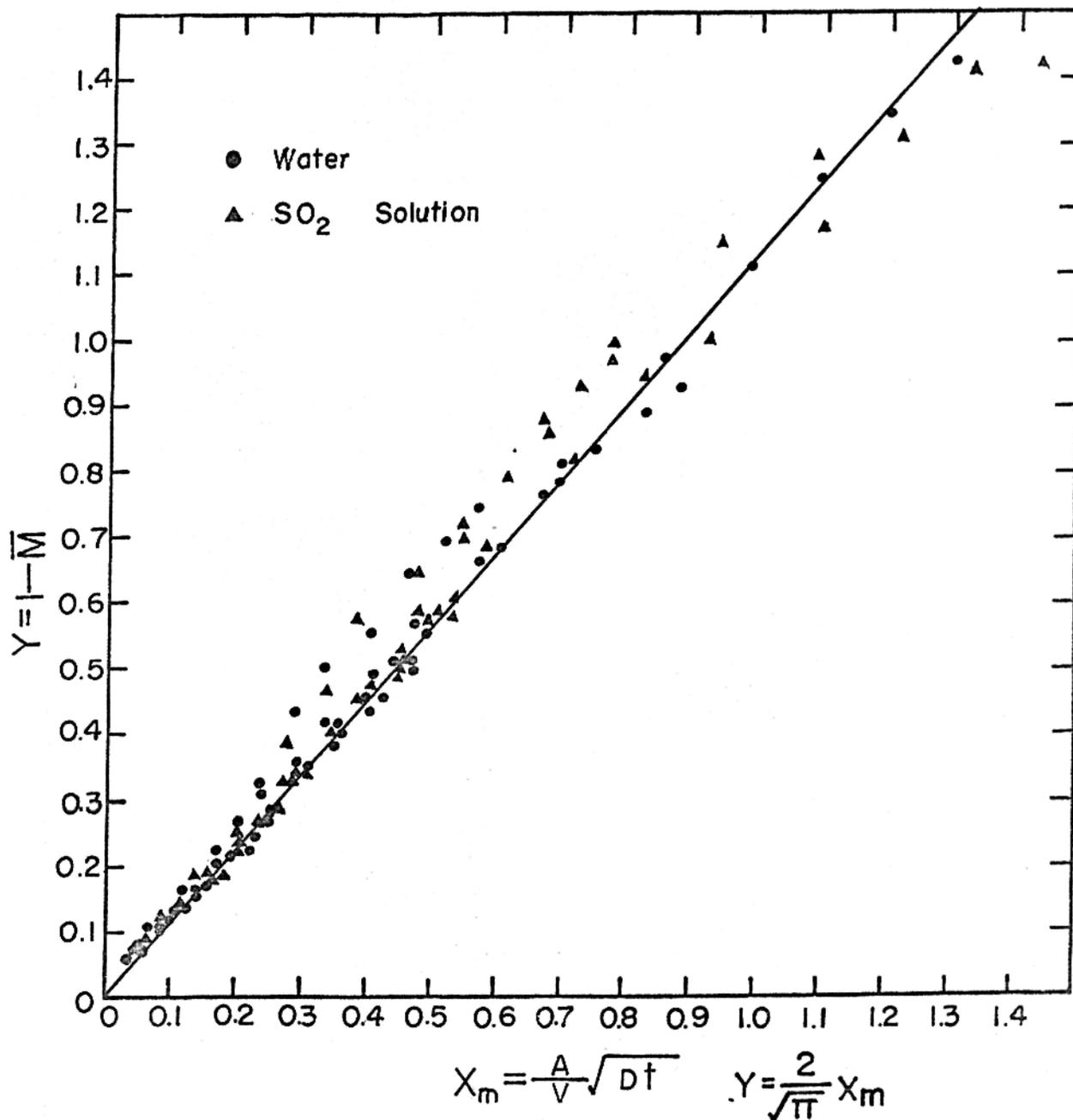


Fig.17. Dimensionless correlation for the weight gain data of the De Kalb 3X1 dent corn according to the first order approximation to diffusion equation.

TABLE 2
 Experimental data on weight increase
 during steeping

GOLD RASH SWEET CORN

t min.	wt (water) gm.	wt (SO ₂ soln) gm.
TEMP.=50F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31650E+02	.31518E+02
.15000E+02	.32320E+02	.31888E+02
.30000E+02	.32962E+02	.32522E+02
.45000E+02	.33529E+02	.32824E+02
.60000E+02	.33880E+02	.33486E+02
.90000E+02	.34554E+02	.34126E+02
.12000E+03	.35198E+02	.34700E+02
.18000E+03	.35915E+02	.35354E+02
.24000E+03	.36454E+02	.36128E+02
.30000E+03	.37478E+02	.36656E+02
.48000E+03	.38862E+02	.38182E+02
.60000E+03	.40048E+02	.39713E+02
TEMP.=77F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31914E+02	.31671E+02
.15000E+02	.32920E+02	.32518E+02
.30000E+02	.33992E+02	.33460E+02
.45000E+02	.34775E+02	.34163E+02
.60000E+02	.35290E+02	.34870E+02
.90000E+02	.36313E+02	.35939E+02
.12000E+03	.37005E+02	.36673E+02
.18000E+03	.38716E+02	.38274E+02
.24000E+03	.39939E+02	.39769E+02
.30000E+03	.41521E+02	.40827E+02
.36000E+03	.42575E+02	.42100E+02
TEMP.=100F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.32126E+02	.31914E+02
.15000E+02	.33429E+02	.33250E+02
.30000E+02	.34319E+02	.34583E+02
.45000E+02	.36152E+02	.35881E+02
.60000E+02	.37047E+02	.36626E+02
.90000E+02	.39296E+02	.38590E+02
.12000E+03	.39830E+02	.39169E+02
.18000E+03	.42001E+02	.42209E+02
.18000E+03	.42081E+02	.42138E+02
.24000E+03	.43931E+02	.43907E+02
.24000E+03	.43975E+02	.43988E+02
.30000E+03	.45833E+02	.46012E+02
.36000E+03	.47481E+02	.47823E+02

TABLE 2 (CONTINUED)

TEMP.=120F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.32728E+02	.32604E+02
.15000E+02	.34656E+02	.34281E+02
.30000E+02	.36337E+02	.36025E+02
.45000E+02	.37821E+02	.37241E+02
.60000E+02	.38596E+02	.38284E+02
.90000E+02	.40580E+02	.40371E+02
.12000E+03	.42266E+02	.42142E+02
.18000E+03	.45465E+02	.45813E+02
.24000E+03	.48135E+02	.47657E+02
.30000E+03	.49768E+02	.50047E+02

TEMP.=140F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.33235E+02	.33046E+02
.30000E+02	.37719E+02	.37507E+02
.45000E+02	.39598E+02	.39508E+02
.60000E+02	.41232E+02	.40835E+02
.90000E+02	.43868E+02	.43680E+02
.12000E+03	.46343E+02	.46647E+02
.18000E+03	.49956E+02	.50047E+02
.24000E+03	.52412E+02	.52996E+02
.30000E+03	.54764E+02	.55345E+02

TEMP.=160F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.33584E+02	.33930E+02
.15000E+02	.36406E+02	.36146E+02
.30000E+02	.38974E+02	.39266E+02
.45000E+02	.41552E+02	.41777E+02
.60000E+02	.43924E+02	.44540E+02
.90000E+02	.45884E+02	.47062E+02
.12000E+03	.48887E+02	.50064E+02
.18000E+03	.53475E+02	.53453E+02

K-4 HYBRID POPCORN

t	wt (water)	wt (SG, soln)
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TEMP.=50F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31492E+02	.31420E+02
.15000E+02	.32358E+02	.32291E+02
.30000E+02	.32939E+02	.32835E+02
.45000E+02	.33128E+02	.33301E+02
.60000E+02	.33455E+02	.33473E+02
.60000E+02	.33442E+02	.33333E+02
.90000E+02	.33642E+02	.33818E+02
.12000E+03	.33886E+02	.33952E+02

TABLE 2 (CONTINUED)

.18000E+03	.34238E+02	.34521E+02
.24000E+03	.34524E+02	.34865E+02
.30000E+03	.35110E+02	.35232E+02
.36000E+03	.35199E+02	.35658E+02
TEMP.=77°F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31906E+02	.31839E+02
.15000E+02	.32877E+02	.32876E+02
.30000E+02	.33491E+02	.33414E+02
.30000E+02	.33555E+02	.33642E+02
.45000E+02	.33762E+02	.33901E+02
.60000E+02	.34034E+02	.34283E+02
.90000E+02	.34379E+02	.34876E+02
.12000E+03	.34855E+02	.35456E+02
.18000E+03	.35554E+02	.36206E+02
.24000E+03	.36461E+02	.36980E+02
.30000E+03	.36708E+02	.37613E+02
.36000E+03	.37227E+02	.38178E+02
TEMP.=100°F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.32599E+02	.32526E+02
.15000E+02	.33269E+02	.33328E+02
.30000E+02	.33931E+02	.34096E+02
.45000E+02	.34445E+02	.34733E+02
.60000E+02	.34984E+02	.35190E+02
.90000E+02	.35481E+02	.36028E+02
.12000E+03	.36073E+02	.36775E+02
.18000E+03	.36954E+02	.37786E+02
.24000E+03	.37834E+02	.38813E+02
.24000E+03	.37865E+02	.38581E+02
.30000E+03	.38336E+02	.39358E+02
.36000E+03	.39023E+02	.40028E+02
.42000E+03	.39432E+02	.40266E+02
TEMP.=120°F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.32611E+02	.32594E+02
.15000E+02	.33547E+02	.33835E+02
.30000E+02	.34427E+02	.34921E+02
.45000E+02	.34849E+02	.35457E+02
.60000E+02	.35574E+02	.36126E+02
.90000E+02	.36358E+02	.35731E+02
.12000E+03	.37011E+02	.37875E+02
.18000E+03	.38262E+02	.39132E+02
.24000E+03	.39170E+02	.39814E+02
.30000E+03	.39991E+02	.40236E+02
.36000E+03	.40299E+02	.40686E+02

TABLE 2 (CONTINUED)

TEMP. = 140°F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.32793E+02	.32616E+02
.15000E+02	.33524E+02	.34021E+02
.30000E+02	.34672E+02	.35958E+02
.45000E+02	.35765E+02	.36932E+02
.60000E+02	.36016E+02	.37069E+02
.90000E+02	.37252E+02	.38101E+02
.12000E+03	.38299E+02	.38880E+02
.18000E+03	.39579E+02	.39698E+02
.24000E+03	.40579E+02	.40672E+02
.30000E+03	.40754E+02	.41004E+02
.36000E+03	.40974E+02	.41204E+02
.42000E+03	.41118E+02	.41446E+02

DE KALB DENT CORN

t	wt (water)	wt (SO ₂ soln)
TEMP. = 50°F		
.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31196E+02	.31114E+02
.15000E+02	.31512E+02	.31518E+02
.30000E+02	.31760E+02	.31936E+02
.45000E+02	.32074E+02	.32037E+02
.60000E+02	.32311E+02	.32364E+02
.90000E+02	.32718E+02	.32566E+02
.12000E+03	.32938E+02	.32943E+02
.18000E+03	.33573E+02	.33855E+02
.24000E+03	.34063E+02	.34364E+02
.30000E+03	.34396E+02	.34673E+02
.36000E+03	.34980E+02	.35354E+02
.42000E+03	.35307E+02	.35466E+02

TEMP. = 77°F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31423E+02	.31510E+02
.15000E+02	.31737E+02	.31932E+02
.30000E+02	.32224E+02	.32371E+02
.45000E+02	.32719E+02	.32955E+02
.60000E+02	.33110E+02	.33423E+02
.90000E+02	.33580E+02	.33186E+02
.12000E+03	.34388E+02	.35002E+02
.18000E+03	.35343E+02	.36095E+02
.24000E+03	.36071E+02	.37028E+02
.24000E+03	.36322E+02	.36628E+02
.30000E+03	.36535E+02	.37690E+02
.30000E+03	.36826E+02	.37256E+02
.30000E+03	.36929E+02	.37512E+02
.30000E+03	.36543E+02	.37915E+02
.36000E+03	.37518E+02	.38608E+02
.36000E+03	.37624E+02	.38463E+02
.42000E+03	.37413E+02	.38643E+02
.42000E+03	.37695E+02	.38955E+02

TABLE 2 (CONTINUED)

TEMP.=100°F

.00000E-99	.30000E+02	.30000E+02
.20000E+01	.31101E+02	.31156E+02
.50000E+01	.31553E+02	.31640E+02
.15000E+02	.32164E+02	.32402E+02
.30000E+02	.32835E+02	.33094E+02
.45000E+02	.33361E+02	.33786E+02
.60000E+02	.33990E+02	.34657E+02
.90000E+02	.35219E+02	.35590E+02
.12000E+03	.35956E+02	.36796E+02
.18000E+03	.36575E+02	.37597E+02
.24000E+03	.37596E+02	.38400E+02
.30000E+03	.38099E+02	.39277E+02
.36000E+03	.38703E+02	.39976E+02
.42000E+03	.39096E+02	.40800E+02
.13200E+04	.41755E+02	.44616E+02

TEMP.=120°F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31663E+02	.31802E+02
.15000E+02	.32554E+02	.32877E+02
.30000E+02	.33762E+02	.34043E+02
.45000E+02	.34223E+02	.34751E+02
.60000E+02	.34859E+02	.35549E+02
.90000E+02	.35708E+02	.36758E+02
.12000E+03	.36584E+02	.37884E+02
.18000E+03	.37659E+02	.39320E+02
.24000E+03	.38797E+02	.40778E+02
.30000E+03	.39524E+02	.42000E+02
.36000E+03	.40101E+02	.42744E+02
.42000E+03	.40552E+02	.43217E+02

TEMP.=140°F

.00000E-99	.30000E+02	.30000E+02
.50000E+01	.31792E+02	.32173E+02
.15000E+02	.32917E+02	.33480E+02
.30000E+02	.34074E+02	.34687E+02
.45000E+02	.34734E+02	.35985E+02
.60000E+02	.35682E+02	.37048E+02
.90000E+02	.36947E+02	.38854E+02
.12000E+03	.38194E+02	.39761E+02
.12000E+03	.37919E+02	.40265E+02
.18000E+03	.39769E+02	.41520E+02
.24000E+03	.41524E+02	.42769E+02
.30000E+03	.42461E+02	.43058E+02
.36000E+03	.43382E+02	.44002E+02
.42000E+03	.44171E+02	.44108E+02

TABLE 3

Difference of $(\bar{m}-m_0)$ in water
and in SO_2 solution
GOLD RASH SWEET CORN

t min.	$(\bar{m}-m_0)_{\text{H}_2\text{O}}$ gm./gm.	$(\bar{m}-m_0)_{\text{SO}_2}$ gm./gm.
TEMP.=50° F		
.00000E-99	.00000E-99	
.50000E+01	.48530E-02	
.15000E+02	.15881E-01	
.30000E+02	.16175E-01	
.45000E+02	.25910E-01	
.60000E+02	.14480E-01	
.90000E+02	.15730E-01	
.12000E+03	.18300E-01	
.18000E+03	.20620E-01	
.24000E+03	.11980E-01	
.30000E+03	.30220E-01	
.48000E+03	.24990E-01	
.60000E+03	.12320E-01	
TEMP.=77° F		
.00000E-99	.00000E-99	
.50000E+01	.89330E-02	
.15000E+02	.14778E-01	
.30000E+02	.19560E-01	
.45000E+02	.22490E-01	
.60000E+02	.15440E-01	
.90000E+02	.13750E-01	
.12000E+03	.12210E-01	
.18000E+03	.16250E-01	
.24000E+03	.62500E-02	
.30000E+03	.25510E-01	
.36000E+03	.17460E-01	
TEMP.=100° F		
.00000E-99	.00000E-99	
.50000E+01	.77930E-02	
.15000E+02	.65800E-02	
.30000E+02	.97100E-02	
.45000E+02	.99600E-02	
.60000E+02	.15470E-01	
.90000E+02	.25960E-01	
.12000E+03	.24300E-01	
.18000E+03	.76500E-02	
.18000E+03	.21000E-02	
.24000E+03	.88000E-03	
.24000E+03	.47000E-03	
.30000E+03	.65800E-02	
.36000E+03	.12570E-01	

TABLE 3 (CONTINUED)

TEMP.=120°F

.00000E-99	.00000E-99
.50000E+01	.45580E-02
.15000E+02	.13790E-01
.30000E+02	.11470E-01
.45000E+02	.21320E-01
.60000E+02	.11470E-01
.90000E+02	.76900E-02
.12000E+03	.45600E-02
.18000E+03	.12790E-01
.24000E+03	.17570E-01
.30000E+03	.10250E-01

TEMP.=140°F

.00000E-99	.00000E-99
.50000E+01	.69480E-02
.30000E+02	.78000E-02
.45000E+02	.33100E-02
.60000E+02	.14590E-01
.90000E+02	.69100E-02
.12000E+03	.11180E-01
.18000E+03	.33400E-02
.24000E+03	.21470E-01
.30000E+03	.21360E-01

TEMP.=160°F

.00000E-99	.00000E-99
.50000E+01	.12720E-01
.15000E+02	.95600E-02
.30000E+02	.10730E-01
.45000E+02	.82700E-02
.60000E+02	.22650E-01
.90000E+02	.43300E-01
.12000E+03	.43270E-01
.18000E+03	.81000E-03

K-4 HYBRID POPCORN

$$t \quad (\bar{m}-m_0)H_2O - (\bar{m}-m_0)SO_2$$

TEMP.=50°F

.00000E-99	.20330E-00
.00000E-99	.00000E-99
.50000E+01	.27120E-02
.15000E+02	.25240E-02
.30000E+02	.39170E-02
.45000E+02	.65090E-02
.60000E+02	.68000E-03
.60000E+02	.41000E-02
.90000E+02	.66300E-02

TABLE 3 (CONTINUED)

TEMP.=140°F

.00000E-99	.00000E-99
.50000E+01	.66670E-02
.15000E+02	.18720E-01
.30000E+02	.48440E-01
.45000E+02	.43960E-01
.60000E+02	.39660E-01
.90000E+02	.31980E-01
.12000E+03	.21890E-01
.18000E+03	.44900E-02
.24000E+03	.35000E-02
.30000E+03	.94200E-02
.36000E+03	.86600E-02
.42000E+03	.12360E-01

DE KALB DENT CORN

$$t \quad (\bar{m}-m_0)H_2O - (\bar{m}-m_0)SO_2$$

TEMP.=50°F

.00000E-99	.00000E-99
.50000E+01	.30970E-02
.15000E+02	.22600E-03
.30000E+02	.66470E-02
.45000E+02	.13970E-02
.60000E+02	.20020E-02
.90000E+02	.57410E-02
.12000E+03	.18900E-03
.18000E+03	.10650E-01
.24000E+03	.11370E-01
.30000E+03	.10460E-01
.36000E+03	.14130E-01
.42000E+03	.60100E-02

TEMP.=77°F

.00000E-99	.00000E-99
.50000E+01	.32860E-02
.15000E+02	.73650E-02
.30000E+02	.55520E-02
.45000E+02	.89140E-02
.60000E+02	.11820E-01
.90000E+02	.14880E-01
.12000E+03	.23190E-01
.18000E+03	.28400E-01
.24000E+03	.36140E-01
.24000E+03	.11550E-01
.30000E+03	.43630E-01
.30000E+03	.16240E-01
.30000E+03	.22020E-01
.30000E+03	.51820E-01
.36000E+03	.41170E-01
.36000E+03	.31690E-01
.42000E+03	.46460E-01
.42000E+03	.47590E-01

TABLE 3 (CONTINUED)

.12000E+03-.24800E-02
 .18000E+03-.10660E-01
 .24000E+03-.12840E-01
 .30000E+03-.46000E-02

TEMP.=77°F

.36000E+03-.17290E-01
 .00000E-99 .00000E-99
 .50000E+01 .25230E-02
 .15000E+02 .38000E-04
 .30000E+02 .29000E-02
 .30000E+02-.32800E-02
 .45000E+02-.52300E-02
 .60000E+02-.93800E-02
 .90000E+02-.18720E-01
 .12000E+03-.22630E-01
 .18000E+03-.24550E-01
 .24000E+03-.19550E-01
 .30000E+03-.34090E-01
 .36000E+03-.35820E-01

TEMP.=100°F

.00000E-99 .00000E-99
 .50000E+01 .27490E-02
 .15000E+02-.22200E-02
 .30000E+02-.62200E-02
 .45000E+02-.10850E-01
 .60000E+02-.77600E-02
 .90000E+02-.20600E-01
 .12000E+03-.26450E-01
 .18000E+03-.31340E-01
 .24000E+03-.36870E-01
 .24000E+03-.26970E-01
 .30000E+03-.38500E-01
 .36000E+03-.37860E-01
 .42000E+03-.31410E-01

TEMP.=120°F

.00000E-99 .00000E-99
 .50000E+01 .64000E-03
 .15000E+02-.10850E-01
 .30000E+02-.18600E-01
 .45000E+02-.22900E-01
 .60000E+02-.20790E-01
 .90000E+02 .23620E-01
 .12000E+03-.32540E-01
 .18000E+03-.32770E-01
 .24000E+03-.24260E-01
 .30000E+03-.92300E-02
 .36000E+03-.14580E-01

TABLE 3 (CONTINUED)

TEMP.=100°F

.00000E-99	.00000E-99
.20000E+01-	.20780E-02
.50000E+01-	.32860E-02
.15000E+02-	.89890E-02
.30000E+02-	.97830E-02
.45000E+02-	.16050E-01
.60000E+02-	.25190E-01
.90000E+02-	.14010E-01
.12000E+03-	.31730E-01
.18000E+03-	.38600E-01
.24000E+03-	.30360E-01
.30000E+03-	.44500E-01
.36000E+03-	.48080E-01
.42000E+03-	.64360E-01
.13200E+04-	.10806E-00

TEMP.=120°F

.00000E-99	.00000E-99
.50000E+01-	.52500E-02
.15000E+02-	.12200E-01
.30000E+02-	.10610E-01
.45000E+02-	.19940E-01
.60000E+02-	.26060E-01
.90000E+02-	.39650E-01
.12000E+03-	.49100E-01
.18000E+03-	.62730E-01
.24000E+03-	.74820E-01
.30000E+03-	.93520E-01
.36000E+03-	.99830E-01
.42000E+03-	.10066E-00

TEMP.=140°F

.00000E-99	.00000E-99
.50000E+01-	.14391E-01
.15000E+02-	.21255E-01
.30000E+02-	.23150E-01
.45000E+02-	.47250E-01
.60000E+02-	.51600E-01
.90000E+02-	.72030E-01
.12000E+03-	.59190E-01
.12000E+03-	.88600E-01
.18000E+03-	.66140E-01
.24000E+03-	.47020E-01
.30000E+03-	.22550E-01
.36000E+03-	.23420E-01
.42000E+03	.23800E-02

TABLE 6

Values of $(\bar{m}-m)$ versus t and \sqrt{t}

GOLD RASH SWEET CORN			
t min.	\sqrt{t} (sec.) ^{1/2}	$(\bar{m}-m)_{H_2O}$ gm./gm.	$(\bar{m}-m)_{SO_2}$ gm./gm.
TEMP=50F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.39854E-01	.35001E-01
.15000E+02	.30000E+02	.64483E-01	.48602E-01
.30000E+02	.42426E+02	.88083E-01	.71908E-01
.45000E+02	.51961E+02	.10892E-00	.83010E-01
.60000E+02	.60000E+02	.12182E-00	.10734E-00
.90000E+02	.73484E+02	.14660E-00	.13087E-00
.12000E+03	.84852E+02	.17027E-00	.15197E-00
.18000E+03	.10392E+03	.19663E-00	.17601E-00
.24000E+03	.12000E+03	.21644E-00	.20446E-00
.30000E+03	.13416E+03	.25409E-00	.22387E-00
.48000E+03	.16970E+03	.30496E-00	.27997E-00
.60000E+03	.18973E+03	.34856E-00	.33624E-00
TEMP=77F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.49558E-01	.40625E-01
.15000E+02	.30000E+02	.86539E-01	.71761E-01
.30000E+02	.42426E+02	.12594E-00	.10638E-00
.45000E+02	.51961E+02	.15472E-00	.13223E-00
.60000E+02	.60000E+02	.17366E-00	.15822E-00
.90000E+02	.73484E+02	.21126E-00	.19751E-00
.12000E+03	.84852E+02	.23670E-00	.22449E-00
.18000E+03	.10392E+03	.29960E-00	.28335E-00
.24000E+03	.12000E+03	.34455E-00	.33830E-00
.30000E+03	.13416E+03	.40271E-00	.37720E-00
.36000E+03	.14696E+03	.44145E-00	.42399E-00
TEMP=100F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.57351E-01	.49558E-01
.15000E+02	.30000E+02	.10525E-00	.98670E-01
.30000E+02	.42426E+02	.13796E-00	.14767E-00
.45000E+02	.51961E+02	.20534E-00	.19538E-00
.60000E+02	.60000E+02	.23824E-00	.22277E-00
.90000E+02	.73484E+02	.32092E-00	.29496E-00
.12000E+03	.84852E+02	.34055E-00	.31625E-00
.18000E+03	.10392E+03	.42035E-00	.42800E-00
.18000E+03	.10392E+03	.42329E-00	.42539E-00
.24000E+03	.12000E+03	.49130E-00	.49042E-00
.24000E+03	.12000E+03	.49292E-00	.49339E-00
.30000E+03	.13416E+03	.56122E-00	.56780E-00
.36000E+03	.14696E+03	.62180E-00	.63437E-00

TABLE 6 (CONTINUED)

.18000E+03	.10392E+03	.13803E-00	.14869E-00
.24000E+03	.12000E+03	.14880E-00	.16164E-00
.30000E+03	.13416E+03	.17087E-00	.17547E-00
.36000E+03	.14696E+03	.17422E-00	.19151E-00

TEMP=77F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.50192E-01	.47669E-01
.15000E+02	.30000E+02	.86767E-01	.86729E-01
.30000E+02	.42426E+02	.10989E-00	.10699E-00
.30000E+02	.42426E+02	.11230E-00	.11558E-00
.45000E+02	.51961E+02	.12010E-00	.12533E-00
.60000E+02	.60000E+02	.13034E-00	.13972E-00
.90000E+02	.73484E+02	.14334E-00	.16206E-00
.12000E+03	.84852E+02	.16127E-00	.18390E-00
.18000E+03	.10392E+03	.18760E-00	.21215E-00
.24000E+03	.12000E+03	.22176E-00	.24131E-00
.30000E+03	.13416E+03	.23106E-00	.26515E-00
.36000E+03	.14696E+03	.25061E-00	.28643E-00

TEMP=100F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.76295E-01	.73546E-01
.15000E+02	.30000E+02	.10153E-00	.10375E-00
.30000E+02	.42426E+02	.12646E-00	.13268E-00
.45000E+02	.51961E+02	.14582E-00	.15667E-00
.60000E+02	.60000E+02	.16613E-00	.17389E-00
.90000E+02	.73484E+02	.18485E-00	.20545E-00
.12000E+03	.84852E+02	.20714E-00	.23359E-00
.18000E+03	.10392E+03	.24033E-00	.27167E-00
.24000E+03	.12000E+03	.27348E-00	.31035E-00
.24000E+03	.12000E+03	.27464E-00	.30161E-00
.30000E+03	.13416E+03	.29238E-00	.33088E-00
.36000E+03	.14696E+03	.31826E-00	.35612E-00
.42000E+03	.15874E+03	.33367E-00	.36508E-00

TEMP=120F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.76747E-01	.76107E-01
.15000E+02	.30000E+02	.11200E-00	.12285E-00
.30000E+02	.42426E+02	.14515E-00	.16375E-00
.45000E+02	.51961E+02	.16104E-00	.18394E-00
.60000E+02	.60000E+02	.18835E-00	.20914E-00
.90000E+02	.73484E+02	.21788E-00	.19426E-00
.12000E+03	.84852E+02	.24248E-00	.27502E-00
.18000E+03	.10392E+03	.28960E-00	.32237E-00
.24000E+03	.12000E+03	.32380E-00	.34806E-00
.30000E+03	.13416E+03	.35472E-00	.36395E-00
.36000E+03	.14696E+03	.36632E-00	.38090E-00

TABLE 6 (CONTINUED)

TEMP=120°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.79481E-01	.74923E-01
.15000E+02	.30000E+02	.15035E-00	.13656E-00
.30000E+02	.42426E+02	.21214E-00	.20067E-00
.45000E+02	.51961E+02	.26669E-00	.24537E-00
.60000E+02	.60000E+02	.29518E-00	.28371E-00
.90000E+02	.73484E+02	.36812E-00	.36043E-00
.12000E+03	.84852E+02	.43009E-00	.42553E-00
.18000E+03	.10392E+03	.54769E-00	.56048E-00
.24000E+03	.12000E+03	.64584E-00	.62827E-00
.30000E+03	.13416E+03	.70587E-00	.71612E-00

TEMP=140°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.98118E-01	.91170E-01
.30000E+02	.42426E+02	.26295E-00	.25515E-00
.45000E+02	.51961E+02	.33202E-00	.32871E-00
.60000E+02	.60000E+02	.39208E-00	.37749E-00
.90000E+02	.73484E+02	.48898E-00	.48207E-00
.12000E+03	.84852E+02	.57996E-00	.59114E-00
.18000E+03	.10392E+03	.71278E-00	.71612E-00
.24000E+03	.12000E+03	.80306E-00	.82453E-00
.30000E+03	.13416E+03	.88952E-00	.91088E-00

TEMP=160°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.11094E-00	.12366E-00
.15000E+02	.30000E+02	.21468E-00	.20512E-00
.30000E+02	.42426E+02	.30908E-00	.31981E-00
.45000E+02	.51961E+02	.40385E-00	.41212E-00
.60000E+02	.60000E+02	.49104E-00	.51369E-00
.90000E+02	.73484E+02	.56309E-00	.60639E-00
.12000E+03	.84852E+02	.67348E-00	.71675E-00
.18000E+03	.10392E+03	.84214E-00	.84133E-00

K-4 HYBRID POPCORN

t	\sqrt{t}	$(\bar{m}-m)_{H_2O}$	$(\bar{m}-m)_{SO_2}$
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TEMP=50°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.34598E-01	.31886E-01
.15000E+02	.30000E+02	.67218E-01	.64694E-01
.30000E+02	.42426E+02	.89102E-01	.85185E-01
.45000E+02	.51961E+02	.96221E-01	.10273E-00
.60000E+02	.60000E+02	.10853E-00	.10921E-00
.60000E+02	.60000E+02	.10804E-00	.10394E-00
.90000E+02	.73484E+02	.11558E-00	.12221E-00
.12000E+03	.84852E+02	.12477E-00	.12725E-00

TEMP=140F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.83603E-01	.76936E-01
.15000E+02	.30000E+02	.11113E-00	.12985E-00
.30000E+02	.42426E+02	.15437E-00	.20281E-00
.45000E+02	.51961E+02	.19554E-00	.23950E-00
.60000E+02	.60000E+02	.20500E-00	.24466E-00
.90000E+02	.73484E+02	.25155E-00	.28353E-00
.12000E+03	.84852E+02	.29099E-00	.31288E-00
.18000E+03	.10392E+03	.33920E-00	.34369E-00
.24000E+03	.12000E+03	.37687E-00	.38037E-00
.30000E+03	.13416E+03	.38346E-00	.39288E-00
.36000E+03	.14696E+03	.39175E-00	.40041E-00
.42000E+03	.15874E+03	.39717E-00	.40953E-00

DE KALE DENT CORN

t	Jt	(m-m _o) _{H₂O}	(m-m _o) _{SO₂}
TEMP=50F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.33872E-01	.30775E-01
.15000E+02	.30000E+02	.45808E-01	.46034E-01
.30000E+02	.42426E+02	.55175E-01	.61822E-01
.45000E+02	.51961E+02	.67034E-01	.65637E-01
.60000E+02	.60000E+02	.75986E-01	.77988E-01
.90000E+02	.73484E+02	.91358E-01	.85617E-01
.12000E+03	.84852E+02	.99668E-01	.99857E-01
.18000E+03	.10392E+03	.12365E-00	.13430E-00
.24000E+03	.12000E+03	.14215E-00	.15352E-00
.30000E+03	.13416E+03	.15473E-00	.16519E-00
.36000E+03	.14696E+03	.17679E-00	.19092E-00
.42000E+03	.15874E+03	.18914E-00	.19515E-00

TEMP=77F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.42446E-01	.45732E-01
.15000E+02	.30000E+02	.54306E-01	.61671E-01
.30000E+02	.42426E+02	.72700E-01	.78252E-01
.45000E+02	.51961E+02	.91396E-01	.10031E-00
.60000E+02	.60000E+02	.10616E-00	.11798E-00
.90000E+02	.73484E+02	.12391E-00	.10903E-00
.12000E+03	.84852E+02	.15443E-00	.17762E-00
.18000E+03	.10392E+03	.19050E-00	.21890E-00
.24000E+03	.12000E+03	.21800E-00	.25414E-00
.24000E+03	.12000E+03	.22748E-00	.23903E-00
.30000E+03	.13416E+03	.23552E-00	.27915E-00
.30000E+03	.13416E+03	.24651E-00	.26275E-00
.30000E+03	.13416E+03	.25040E-00	.27242E-00
.30000E+03	.13416E+03	.23582E-00	.28764E-00
.36000E+03	.14696E+03	.27265E-00	.31382E-00
.36000E+03	.14696E+03	.27665E-00	.30834E-00
.42000E+03	.15874E+03	.26868E-00	.31514E-00
.42000E+03	.15874E+03	.27934E-00	.32693E-00

TABLE 6 (CONTINUED)

TEMP=100°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.20000E+01	.10954E+02	.30284E-01	.32362E-01
.50000E+01	.17320E+02	.47356E-01	.50642E-01
.15000E+02	.30000E+02	.70434E-01	.79423E-01
.30000E+02	.42426E+02	.95777E-01	.10556E-00
.45000E+02	.51961E+02	.11564E-00	.13169E-00
.60000E+02	.60000E+02	.13940E-00	.16459E-00
.90000E+02	.73484E+02	.18582E-00	.19983E-00
.12000E+03	.84852E+02	.21365E-00	.24538E-00
.18000E+03	.10392E+03	.23703E-00	.27563E-00
.24000E+03	.12000E+03	.27560E-00	.30596E-00
.30000E+03	.13416E+03	.29459E-00	.33909E-00
.36000E+03	.14696E+03	.31741E-00	.36549E-00
.42000E+03	.15874E+03	.33225E-00	.39661E-00
.13200E+04	.28142E+03	.43268E-00	.54074E-00

TEMP=120°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.51511E-01	.56761E-01
.15000E+02	.30000E+02	.85164E-01	.97364E-01
.30000E+02	.42426E+02	.13079E-00	.14140E-00
.45000E+02	.51961E+02	.14820E-00	.16814E-00
.60000E+02	.60000E+02	.17222E-00	.19828E-00
.90000E+02	.73484E+02	.20429E-00	.24394E-00
.12000E+03	.84852E+02	.23737E-00	.28647E-00
.18000E+03	.10392E+03	.27798E-00	.34071E-00
.24000E+03	.12000E+03	.32096E-00	.39578E-00
.30000E+03	.13416E+03	.34842E-00	.44194E-00
.36000E+03	.14696E+03	.37021E-00	.47004E-00
.42000E+03	.15874E+03	.38724E-00	.48790E-00

TEMP=140°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.50000E+01	.17320E+02	.56383E-01	.70774E-01
.15000E+02	.30000E+02	.98875E-01	.12013E-00
.30000E+02	.42426E+02	.14257E-00	.16572E-00
.45000E+02	.51961E+02	.16750E-00	.21475E-00
.60000E+02	.60000E+02	.20330E-00	.25490E-00
.90000E+02	.73484E+02	.25108E-00	.32311E-00
.12000E+03	.84852E+02	.29818E-00	.35737E-00
.12000E+03	.84852E+02	.28780E-00	.37640E-00
.18000E+03	.10392E+03	.35767E-00	.42381E-00
.24000E+03	.12000E+03	.42396E-00	.47098E-00
.30000E+03	.13416E+03	.45935E-00	.48190E-00
.36000E+03	.14696E+03	.49413E-00	.51755E-00
.42000E+03	.15874E+03	.52393E-00	.52155E-00

TABLE 7

Slopes of (m-m₀) versus \sqrt{t} plots

A. AVERAGE VALUES

GOLD RASH SWEET CORN

temp.	in water	in SO ₂ soln
50 F	.21090E-02	.16541E-02
77 F	.29539E-02	.24983E-02
100 F	.36270E-02	.35501E-02
120 F	.50430E-02	.46768E-02
140 F	.62725E-02	.61426E-02
160 F	.74491E-02	.75927E-02

K-4 HYBRID POPCORN

50 F	.19992E-02	.20079E-02
77 F	.25519E-02	.25843E-02
100 F	.30368E-02	.31855E-02
120 F	.35711E-02	.37735E-02
140 F	.37705E-02	.46101E-02

DE KALB DENT CORN

50 F	.12563E-02	.12507E-02
77 F	.17706E-02	.16875E-02
100 F	.24289E-02	.27392E-02
120 F	.28394E-02	.33228E-02
140 F	.34043E-02	.42721E-02

B. INITIAL VALUES

GOLD RASH SWEET CORN

50 F	.18702E-02	.17133E-02
77 F	.29526E-02	.27712E-02
100 F	.41100E-02	.40954E-02
120 F	.52093E-02	.51612E-02
140 F	.66754E-02	.70192E-02
160 F	.78889E-02	.81625E-02

K-4 HYBRID POPCORN

50 F	.13755E-02	.14458E-02
77 F	.18658E-02	.20786E-02
100 F	.22816E-02	.25326E-02
120 F	.27392E-02	.29037E-02
140 F	.29448E-02	.30945E-02

DE KALB DENT CORN

50 F	.11992E-02	.12598E-02
77 F	.18039E-02	.20453E-02
100 F	.19448E-02	.23012E-02
120 F	.26114E-02	.32306E-02
140 F	.33966E-02	.37649E-02

TABLE 10

Values of (1-M) versus X for steeping samples

GOLD RASH SWEET CORN			
$X = \frac{A}{V} \sqrt{Dt}$	Y=1-M	$X = \frac{A}{V} \sqrt{DE}$	Y=1-M
in water		in SO ₂ soln	
TEMP.=50°F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.45769E-01	.63542E-01	.41929E-01	.55805E-01
.79278E-01	.10281E-00	.72625E-01	.77490E-01
.11211E-00	.14043E-00	.10270E-00	.11464E-00
.13731E-00	.17366E-00	.12578E-00	.13235E-00
.15855E-00	.19422E-00	.14525E-00	.17114E-00
.19418E-00	.23373E-00	.17789E-00	.20865E-00
.22423E-00	.27147E-00	.20541E-00	.24229E-00
.27461E-00	.31350E-00	.25157E-00	.28062E-00
.31711E-00	.34508E-00	.29050E-00	.32598E-00
.35453E-00	.40511E-00	.32478E-00	.35693E-00
.44844E-00	.48622E-00	.41081E-00	.44638E-00
.50138E-00	.55573E-00	.45930E-00	.53609E-00
TEMP.=77°F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.71769E-01	.79014E-01	.67819E-01	.64772E-01
.12431E-00	.13797E-00	.11747E-00	.11441E-00
.17580E-00	.20079E-00	.16612E-00	.16961E-00
.21531E-00	.24668E-00	.20346E-00	.21082E-00
.24862E-00	.27688E-00	.23494E-00	.25226E-00
.30450E-00	.33683E-00	.28773E-00	.31490E-00
.35160E-00	.37739E-00	.33225E-00	.35792E-00
.43061E-00	.47767E-00	.40691E-00	.45176E-00
.49725E-00	.54934E-00	.46988E-00	.53938E-00
.55592E-00	.64207E-00	.52532E-00	.60140E-00
.60896E-00	.70384E-00	.57544E-00	.67600E-00
TEMP.=100°F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.10058E-00	.91439E-01	.10022E-00	.79014E-01
.17422E-00	.16780E-00	.17360E-00	.15731E-00
.24638E-00	.21996E-00	.24550E-00	.23544E-00
.30175E-00	.32739E-00	.30068E-00	.31151E-00
.34844E-00	.37984E-00	.34720E-00	.35518E-00
.42675E-00	.51167E-00	.42522E-00	.47028E-00
.49277E-00	.54296E-00	.49101E-00	.50422E-00
.60350E-00	.67020E-00	.60135E-00	.68239E-00
.60350E-00	.67488E-00	.60135E-00	.67823E-00
.69689E-00	.78332E-00	.69440E-00	.78191E-00
.69689E-00	.78590E-00	.69440E-00	.78665E-00
.77912E-00	.89480E-00	.77634E-00	.90529E-00
.85345E-00	.99139E-00	.85041E-00	.10114E+01

TABLE 10 (CONTINUED)

.32902E-00	.35851E-00	.34584E-00	.38620E-00
.37993E-00	.38649E-00	.39935E-00	.41984E-00
.42477E-00	.44381E-00	.44648E-00	.45576E-00
.46529E-00	.45251E-00	.48908E-00	.49742E-00

TEMP.=77°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.74385E-01	.13036E-00	.82872E-01	.12381E-00
.12884E-00	.22536E-00	.14354E-00	.22527E-00
.18220E-00	.28542E-00	.20299E-00	.27789E-00
.18220E-00	.29168E-00	.20299E-00	.30020E-00
.22316E-00	.31194E-00	.24862E-00	.32553E-00
.25768E-00	.33854E-00	.28708E-00	.36290E-00
.31559E-00	.37231E-00	.35160E-00	.42093E-00
.36441E-00	.41888E-00	.40599E-00	.47766E-00
.44631E-00	.48727E-00	.49723E-00	.55103E-00
.51537E-00	.57600E-00	.57417E-00	.62677E-00
.57618E-00	.60015E-00	.64192E-00	.68870E-00
.63115E-00	.65093E-00	.70316E-00	.74397E-00

TEMP.=100°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.90963E-01	.19816E-00	.10097E-00	.19102E-00
.15755E-00	.26371E-00	.17489E-00	.26948E-00
.22281E-00	.32846E-00	.24733E-00	.34462E-00
.27289E-00	.37875E-00	.30291E-00	.40693E-00
.31511E-00	.43150E-00	.34978E-00	.45166E-00
.38593E-00	.48012E-00	.42838E-00	.53363E-00
.44563E-00	.53802E-00	.49466E-00	.60672E-00
.54577E-00	.62423E-00	.60582E-00	.70563E-00
.63022E-00	.71033E-00	.69956E-00	.80610E-00
.63022E-00	.71335E-00	.69956E-00	.78340E-00
.70459E-00	.75942E-00	.78211E-00	.85942E-00
.77182E-00	.82664E-00	.85673E-00	.92498E-00
.83368E-00	.86667E-00	.92540E-00	.94825E-00

TEMP.=120°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.10920E-00	.19934E-00	.11576E-00	.19768E-00
.18915E-00	.29090E-00	.20051E-00	.31909E-00
.26750E-00	.37701E-00	.28357E-00	.42532E-00
.32762E-00	.41828E-00	.34730E-00	.47776E-00
.37831E-00	.48922E-00	.40103E-00	.54322E-00
.46333E-00	.56592E-00	.49116E-00	.50457E-00
.53501E-00	.62981E-00	.56714E-00	.71433E-00
.65524E-00	.75220E-00	.69459E-00	.83732E-00
.75662E-00	.84105E-00	.80207E-00	.90405E-00
.84591E-00	.92135E-00	.89671E-00	.94532E-00
.92661E-00	.95148E-00	.98227E-00	.98935E-00

TABLE 10 (CONTINUED)

TEMP.=100°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.42244E-01	.70939E-01	.49985E-01	.75806E-01
.66794E-01	.11092E-00	.79035E-01	.11862E-00
.11569E-00	.16498E-00	.13689E-00	.18604E-00
.16361E-00	.22455E-00	.19360E-00	.24727E-00
.20038E-00	.27088E-00	.23711E-00	.30847E-00
.23139E-00	.32654E-00	.27379E-00	.38554E-00
.28339E-00	.43527E-00	.33532E-00	.46809E-00
.32723E-00	.50046E-00	.38720E-00	.57479E-00
.40076E-00	.55523E-00	.47421E-00	.64565E-00
.46278E-00	.64558E-00	.54758E-00	.71670E-00
.51738E-00	.69006E-00	.61220E-00	.79430E-00
.56675E-00	.74352E-00	.67061E-00	.85614E-00
.61218E-00	.77828E-00	.72436E-00	.92904E-00
.10852E+01	.10135E+01	.12841E+01	.12666E+01

TEMP.=120°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.96147E-01	.12355E-00	.11894E-00	.13615E-00
.16653E-00	.20427E-00	.20602E-00	.23354E-00
.23551E-00	.31372E-00	.29135E-00	.33917E-00
.28844E-00	.35548E-00	.35683E-00	.40331E-00
.33307E-00	.41309E-00	.41204E-00	.47560E-00
.40792E-00	.49002E-00	.50464E-00	.58512E-00
.47103E-00	.56936E-00	.58271E-00	.68714E-00
.57688E-00	.66677E-00	.71366E-00	.81724E-00
.66615E-00	.76987E-00	.82409E-00	.94934E-00
.74475E-00	.83573E-00	.92133E-00	.10600E+01
.81581E-00	.88800E-00	.10092E+01	.11274E+01
.88120E-00	.92885E-00	.10901E+01	.11703E+01

TEMP.=140°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.14209E-00	.15367E-00	.15750E-00	.19289E-00
.24613E-00	.26948E-00	.27281E-00	.32741E-00
.34807E-00	.38857E-00	.38581E-00	.45167E-00
.42630E-00	.45652E-00	.47252E-00	.58530E-00
.49226E-00	.55410E-00	.54563E-00	.69473E-00
.60288E-00	.68432E-00	.66825E-00	.88064E-00
.69615E+00	.81270E-00	.77163E-00	.97402E-00
.69615E-00	.78440E-00	.77163E-00	.10258E+01
.85259E-00	.97484E-00	.94503E-00	.11551E+01
.98452E-00	.11355E+01	.10912E+01	.12836E+01
.11006E+01	.12519E+01	.12200E+01	.13134E+01
.12057E+01	.13467E+01	.13364E+01	.14106E+01
.13023E+01	.14279E+01	.14435E+01	.14215E+01

TABLE 10 (CONTINUED)

TEMP. = 140°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.11740E-00	.21715E-00	.12337E-00	.19983E-00
.20335E-00	.28864E-00	.21369E-00	.33727E-00
.28758E-00	.40096E-00	.30220E-00	.52677E-00
.35221E-00	.50789E-00	.37012E-00	.62207E-00
.40670E-00	.53246E-00	.42739E-00	.63548E-00
.49811E-00	.65337E-00	.52343E-00	.73644E-00
.57516E-00	.75581E-00	.60441E-00	.81267E-00
.70442E-00	.88103E-00	.74024E-00	.89270E-00
.81341E-00	.97888E-00	.85478E-00	.98797E-00
.90940E-00	.99600E-00	.95564E-00	.10204E+01
.99616E-00	.10173E+01	.10468E+01	.10400E+01
.10760E+01	.10316E+01	.11307E+01	.10637E+01

DE KALB DENT CORN

$X = \frac{A}{V} \sqrt{Dt}$ ln water	$Y = 1 - \bar{M}$	$X = \frac{A}{V} \sqrt{Dt}$ ln SO ₂ soln	$Y = 1 - \bar{M}$
TEMP. = 50°F			
.00000E-99	.00000E-99	.00000E-99	.00000E-99
.31908E-01	.58713E-01	.33520E-01	.53345E-01
.55268E-01	.79403E-01	.58061E-01	.79795E-01
.78160E-01	.95640E-01	.82110E-01	.10716E-00
.95726E-01	.11619E-00	.10056E-00	.11377E-00
.11053E-00	.13171E-00	.11612E-00	.13518E-00
.13537E-00	.15838E-00	.14221E-00	.14840E-00
.15632E-00	.17276E-00	.16422E-00	.17309E-00
.19144E-00	.21433E-00	.20112E-00	.23279E-00
.22107E-00	.24640E-00	.23224E-00	.26611E-00
.24715E-00	.26820E-00	.25964E-00	.28634E-00
.27074E-00	.30644E-00	.28442E-00	.33094E-00
.29244E-00	.32785E-00	.30722E-00	.33827E-00

TEMP. = 77°F

.00000E-99	.00000E-99	.00000E-99	.00000E-99
.51096E-01	.78328E-01	.57933E-01	.84391E-01
.88504E-01	.10021E-00	.10034E-00	.11380E-00
.12516E-00	.13415E-00	.14190E-00	.14440E-00
.15329E-00	.16865E-00	.17380E-00	.18510E-00
.17700E-00	.19590E-00	.20069E-00	.21771E-00
.21678E-00	.22865E-00	.24579E-00	.20119E-00
.25032E-00	.28497E-00	.28381E-00	.32777E-00
.30657E-00	.35154E-00	.34759E-00	.40394E-00
.35401E-00	.40228E-00	.40138E-00	.46897E-00
.35401E-00	.41978E-00	.40138E-00	.44109E-00
.39579E-00	.43461E-00	.44874E-00	.51513E-00
.39579E-00	.45489E-00	.44874E-00	.48486E-00
.39579E-00	.46207E-00	.44874E-00	.50271E-00
.39579E-00	.43517E-00	.44874E-00	.53079E-00
.43355E-00	.50313E-00	.49156E-00	.57911E-00
.43355E-00	.51051E-00	.49156E-00	.56899E-00
.46830E-00	.49581E-00	.53096E-00	.58154E-00
.46830E-00	.51548E-00	.53096E-00	.60330E-00

COMPARISON OF THE RATES OF ABSORPTION OF WATER BY CORN
KERNELS WITH AND WITHOUT DISSOLVED SO₂

by

HEAI-CHONG CHEN

B. S., National Taiwan University, 1960

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Chemical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

Approved by:

Major Professor

Diffusion of water into kernels of three varieties of corn steeped in aqueous SO_2 solution and in water was investigated quantitatively. Experiments were carried out over a temperature range from 50°F to 160°F to compare the rates of moisture increase in corn kernels during steeping, in both solutions.

The results obtained in these experiments showed that the absorption rate of water in SO_2 solution, as well as in water, followed approximately the diffusion equation based on Fick's law:

$$1 - \bar{M} = \frac{2}{\pi} X$$

where $\bar{M} = \frac{m_s - \bar{m}}{m_s - m_0}$, and $X = \frac{A}{V} \sqrt{Dt}$

It was shown that an addition of SO_2 in water has two extreme effects on the absorption rate, retarding effect at the onset of steeping and accelerating effect which follows the retarding effect. For Gold Rash sweet corn the retarding effect was appreciable, for K-4 hybrid popcorn it was comparatively small, and for DeKalb dent corn it was negligible. On the other hand, the accelerating effect was small for Gold Rash sweet corn, but quite appreciable for K-4 hybrid popcorn and DeKalb dent corn. At any particular temperature, the absorption rate was slower in SO_2 solution than in water in the initial period of steeping but this was reversed as the absorption time increased. The higher the steeping temperature the sooner the reversion took place. The promoting effect in absorption rate increased with increasing temperature; but, at the vicinity of gelatinization temperature of starch, the difference decreased after a certain period of absorp-

tion because of the saturation of the corn kernels by water and gelatinization.

Preservation of wet corn with approximately 0.4% of sodium metabisulfite was shown experimentally to be of promoting effect on the absorption rate of water into corn kernels. But an increase in application rate of the compound would not materially increase the absorption rate.