# Effect of Heating Without Drying on The Brown Rice Kernel

# 溫差對糙米胴裂之影響

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## 摘要

稻米在碾白前之胴裂情形直接影響碾白及碎米之多寡：自成熟以至碾白整個過程中，稻米發生胴裂之機會甚多，其誘因在於周遭環境——溼度、溫度之變化。

1954 年，Henderson 氏發現稻米胴裂之發生始於米之內部，異於一般人之認定：卽稻米最外層因過乾而裂。他推定稻米胴裂之物理原因在於其外層受溫或吸濕膨脹，因此導致內部發生張力，如張力大於其張力強度，則生拉裂。

Kunze 和 Hall 二人在 1965, 1967 年由實驗證明 34°C 之溫差不致造成胴裂；Arora 阿洛拉等人在 1973 年據稻米之膨脹係數及拉力強力而計算，算得結果認爲：如溫差超過 53°C，將導致胴裂。

1975 年，Wraften 等人由實驗證明：相對溫度 1 %之差異對糙米容積膨脹之影響相當於 100°C 溫差之影響，1961 年，Desikachar 和 Subrahmanyan 氏將白米浸於 30°C 之溫水中，發現胴裂現象開始於浸水之後 3～4 分鐘。

本文之目的在盼經由實驗進一步確定或否定溫差對稻米胴裂之影響。

實驗分二項，第一項是置不同含水率之糙米於熱風中歷時四小時，加溫而不予乾燥，觀察其胴裂之有無，第二項是置已乾糙米於冷媒 (R-12) 中 10～30 秒鐘，再轉投入 66°C 之溫水中 10～60 秘鐘，觀察其胴裂效果，結果，二項實驗之胴裂效果皆爲否定。因而，本文證明：在田間或加工、貯運之環境中，溫差不是造成稻米胴裂的原因。

## Introduction

Unbroken rice kernels are preferred for the commercial market because their value generally is much greater than that of broken kernels. Therefore, the ways to increase maximum head yield or to reduce rice fissuring and cracking are of great interest to the rice industry.

Mechanical properties of the individual rice grain change with varying environmental conditions which involve mainly moisture and temperature. Rapid moisture adsorption or desorption due to environmental changes during harvesting, handling and processing are expected sources which may cause fissures in rice kernels.

In the drying operation, both moisture desorption and moisture adsorb moisture from the humid warm exhaust air before the grains begin to dry. During tempering, moisture in the humid warm air may condense on cooler grains or surfaces. Temperature gradients often exist in grains during different phases of the drying procedure. It has been believed that all of these conditions may contribute to fissuring of the rice grain.

Some researchers, Kunze, (1964), Wratten et al. (1975), believe that the moisture gradient has more influence on the fissuring of rice grains than does the temperature gradient. There are few studies where the temperature gradient effect on the fissuring of rice has been investigated experimentally without being entangled with simultaneous moisture changes. The objective of this study was to single out the effect of the temperature gradient on rice fissuring both with theoretical calculations and with simple experiments.

## Literature Review

Kondo and Okamura (1930) reported that 72 percent of rough rice at 12.6 percent moisture fissured when exposed to an ambient air from 8 a. m. one day to 8 a. m. of the next day. In case of brown rice, 100 percent fissured. The fissuring was due to moisture adsorption during the high relative humidity hours of the night. Henderson (1954) reported that checking result from a moisture of Temperature increase. When the outer portions of the kernel take on moisture or increase in temperature, they expand. Since the central portions are inelastic, internal pulling apart occurs and cracks or faults result. He also mentioned that checking fast drying must be due to the increase in temperature which produces fast drying rather than a decrease in moisture in the surface portions.

Ban (1971) found that the crack ratio increased when drying air temperature was increased. The crack ratio was defined as the number of grains that fissured compared to the total number of grains treated. The crack ratio reached a maximum at 80°C, and then, it dropped to practically zero at 130 C. The decreasing crack ratio above 80 C is probably attributable to the fact that the starch granules in high moisture rice were beino gelatinized.

Kunze and Hall (1965, 1967) found that a thermal gradient of 34 C did not produce fissures in rice as long as the grain was maintained at a constant moisture content. They concluded that thermal stresses were small compared to moisture stresses.

Arora et al. (1973) studied thermal and mechanical properties of the rice grain and concluded that rice kernels exhibit an increased rate of thermal expansion above 53 C. A temperature difference larger than 43 C between the drying air and the rice kernels was calculated to be sufficient to cause kernel damage.

Wratten, et al. (1975) found that the coefficient of cubical thermal expansion of brown rice could be expressed by the formula

$\partial r \times 10^5 = 9.36 + 1.09M^2 + 0.0329\ M^3$

And, the coefficient of cubical hygroscopic expansion of brown rice was found to be

$\beta r = 0.0106 + 0.000059\ T$

where

$\partial r$=coefficient of cubical thermal expansion, $mm^3/mm^3$-°C

$\beta r$=coefficient of cubical hygroscopic expansion, $mm^3/mm^9$ -%M

M =moisture content, % dry basis

T =temperature,°C

They concluded that volumetric expansion of brown rice for a 1 percent change in moisture is about 100 times that for a 1°C change in temperature. Stresses due to moisture gradients therefore may be the major cause for cracking the drying process.

Kunze and Choudhury (1972) made a hypothetical stress analysis for the rice kernel and reported that kernel failure could occur if the compressive stresses at the surface layers developed to the extent that the resultant stresses at the center exceeded the tensile strength of the central portions of the grain.

Hogan and Larkin (1954) applied X-ray and photomicrography technigues to examine the structure of rice kernel and found that the physical properties of the rice kernel depend largely on the properties of the bricklike-shaped starchy endosperm cells. They concluded that the radial arrangement of the endosperm cells is generally responsible for the checks and breaks which develope across the kernel.

Desikachar and Subrahmanyan (1961) found that milled raw or parboiled rice developed transverse lines of cracks when soaked in water. It took a longer time for the cracks to develop in parboiled rice than in raw rice. Formation of cracks was accelerated by temperature in the case of parboiled rice; whereas a retarding effect was observed above 70°C in raw raw rice. At ordinary temperature (30°C), a certain time (about 3-4 minutes in the case of raw rice and about 20 minutes for parboiled rice) elapsed before the cracking started.

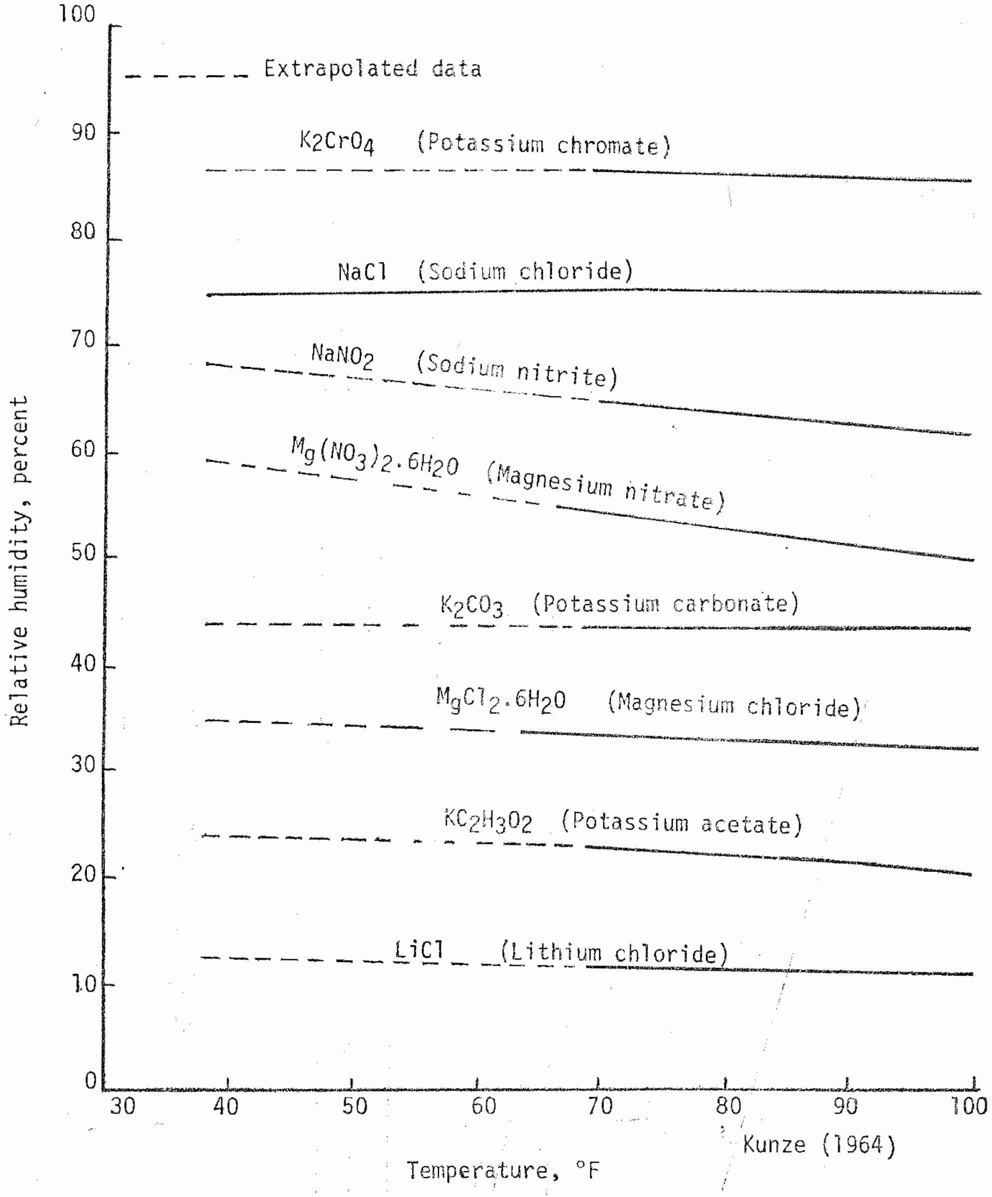
## Method and Procedure

Two appronches were used for this study. In the first, hot air was used to heat the rice and to produce a temperature gradient in the grain. In the second, rice was first submersed in liguid refrigerant (R-12) for a given time interval before the same grains were submersed in hot water to produce the temperature gradient.

### A. First Approaeh:

Brown rice (Labelle) hervested in Texas during 1977, was used in this study. The grains were hulled with a Satake Grain Testing Mill. Only sound and unfissured kernels were selected for the experiments.

The selected brown rice kernels then were divided into three equal portions. Each portion was placed in a sealed plastic container and equilibrated with a specific salt solution. All containers were put into an environment controlled chamber with a temperature of 25°C. The satl solutions were sodium chloride ($NaCl$), potassium carbonate ($K_2Co_3$) and lithium chloride ($LiCl$). The expected relative humidities which these saturated salt solutions produced at the 25°C temperature are shown in Fig. 1. The kernels equilibrated with $NaCl$, $K_3Co_3$ and $LiCl$ would



Kunze (1964)

Fig. 1. The relative humidities which the respective saturated salt solutions will produce in enclosed containers at the indicated temperatures.

then have final moisture contents of 14.87, 10.53 and 4.86 percent respectively, at 25°C. The experimental set-up was composed of two water baths with heat exchangers' a saturated vapor collector, an inspection chamber, thermometerf and insulated connecting tubes, (Fig. 2). A battery operated pen flashlght was used to inspect grains for fissures.

Air was forced in through coils of copper tubing in the lower temperature water bath (LTWB). Then, it was bubbled through the water to saturation and collected by the the higher temperature water bath varpor collector before being sent to the higher temperature water bath (HTWB). The air was then moved through coils of copper tubing in the HTWB and conditioned to the desired temperature

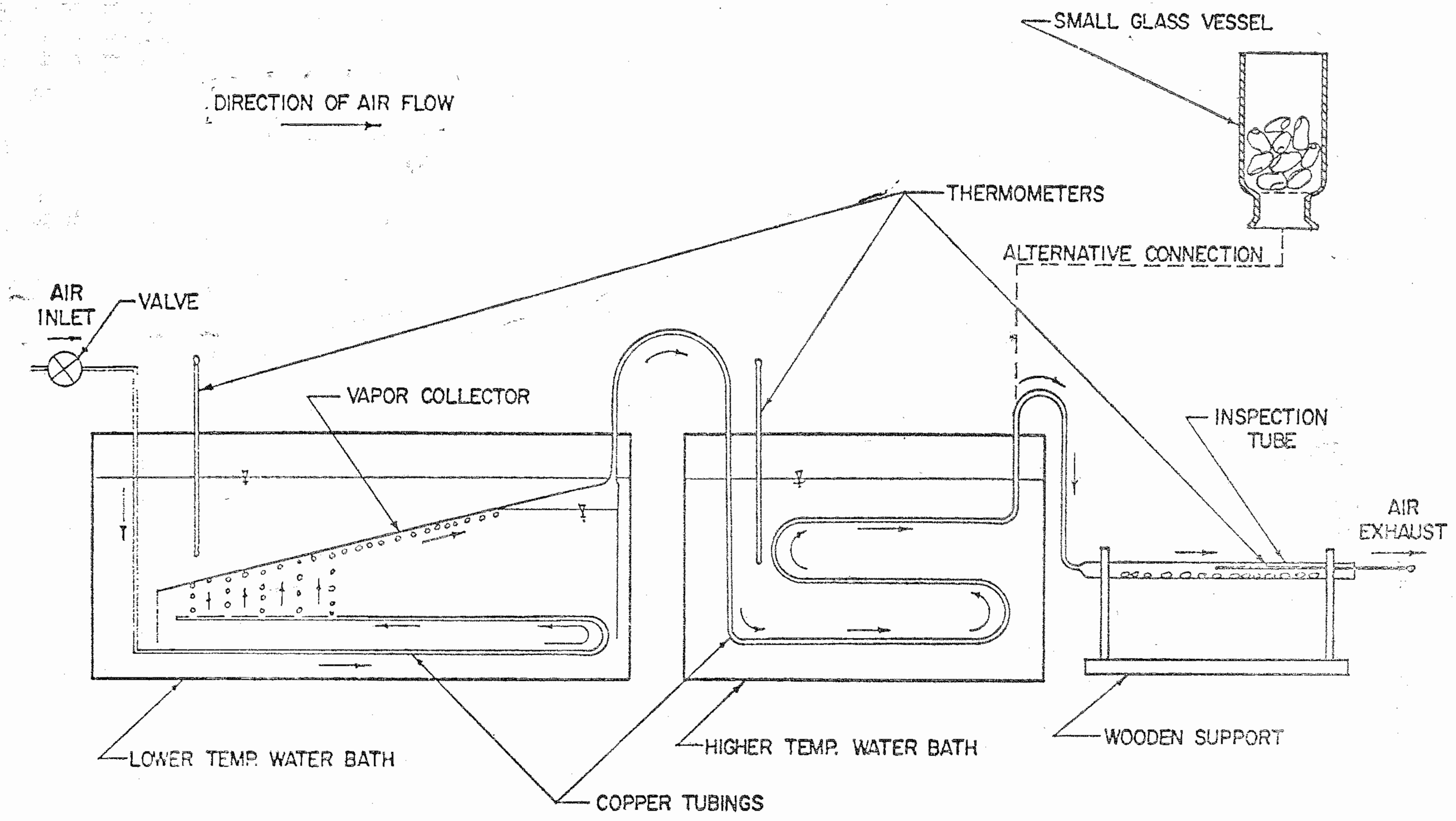


Fig. 2. Apparatus used to produce a thermal gradient in the rice grains with little or no change in moisture content. Air was conditioned to the appropriate temperature and relative humidity.

and relative humidity. The copper tubes served as a heat exchanger.

The conditioned air then was exhausted into the heating chamber where the rice kernels were placed and heaced and heated for 4 hours during each treatment. Before and after each treatment, the kernels were inspected for fissures and were weighed with a precision balance to determine if there was a gain or loss in moisture. At higher relative humidities, a small glass vessel was used to replace the long inspection chamber to avoid moisture condensation.

In order to achieve the goal of heating the grain without changing its moisture content, the relative humidity of the heated air must be exactly the same as the equilibrium relative humidity of the grain at the elevated temperature. Since needed specific information was not available, data for making an estimate were obtained from the literature.

Equilibrium moisture contents for undermilled rice at 25°C were obtained from Karon and Adams (1949).

Ebuilibrium moisture contents (wb) at 25°C for undermilled rice

| Relative Humidity % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 90 | 90 |
| 4.6 | 7.0 | 8.6 | 10.0 | 11.4 | 12.8 | 14.2 | 15.4 | 18.4 |

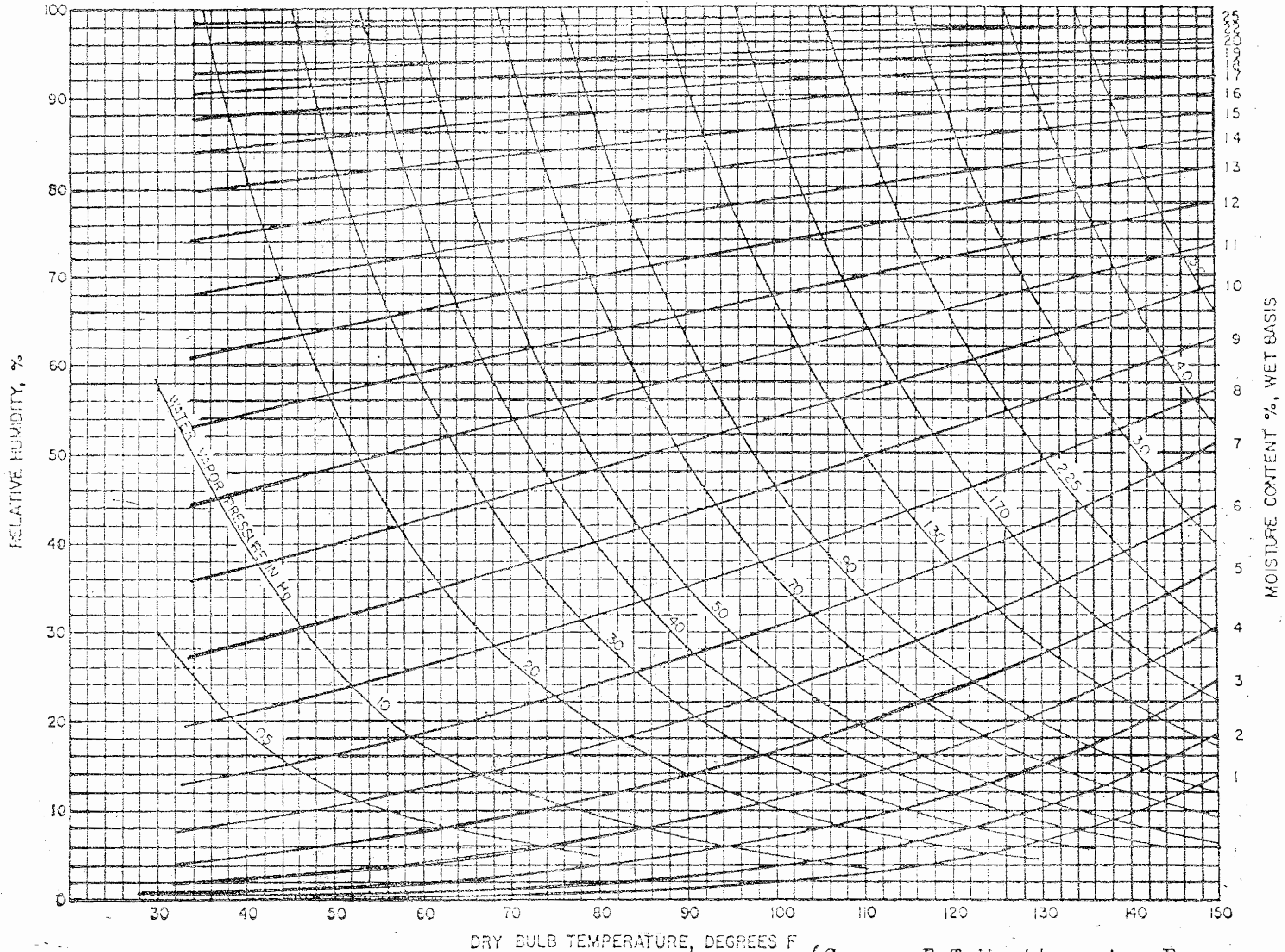
By means of interpolation, the equilibrium relative humidities of undermilled rice of 4.86, 10.53 and 14.87 percent moisture contents at 25°C were found to be 11.1, 43.8 and 75.6 percent, respectively.

The hygroscopic ebuilibrium chart for rough rice (Fig. 3), developed by F. T. Wratten, was used to extrapolate the following:

| M. C. (% wb) | Equilibrium Relative Humidities | | |
|---|---|---|---|
| | 25°C | 43°C | 66°C |
| 4.86 | 10.5 (11.2)* | 19.0 | 37.0 |
| 10.53 | 51.5 (43.8)* | 60.5 | 09.5 |
| 14.87 | 79.5 (75.6)* | 83.5 | 88.0 |

* Date in parentheses were obtained by extrapolating from Karon and Adams (1949).

Finally, the equilibrium relative humidities (ERH) for brown rice at 43 and 66°C were estimated by proportioning. For example, the estimated ERH for brown rice having 4.86 percent M. C. at 43°C equals to 19.0×(11.1%10.5)=20.3 percent, thus producing Table 1.



(Source:F.T.Wratten, Ag. Eng. Dept.,L.S.U.)

Fig.3. Hygroscopic equilibrium of rough rice at different temperatures.

Table 1. Equilibrium relative humidities in percent for brown rice at the temperature and moisture contents indicated

| M. C. (% wb) | 43°C | 66°C |
|---|---|---|
| 4.86 | 20.3 | 39.5 |
| 10.53 | 51.5 | 60.8 |
| 14.87 | 79.4 | 83.7 |

A psychrometric chart was used to find the dew points for conditioned air at 20.3, 51.5 and 79.4 percent R. H. at 43°C. The respective dew points are 16, 31 and 39 C. The dew points for conditioned air at 39.5, 60.8 and 83.7 percent at 66°C are 46, 54 and 62°C, respectively.

Therefore, the temperature of the LTWB was so set that the temperature of the saturated vapor leaving the LTWB was expected to be at the dew point in each case. After heating in the HTWB. the relative humidity of the heated air approximated the ERH listed in Table 1.

The rate of air flow was roughly measured to be 100 c. c. per second.

**B. Second Approach:**

Brown rice (Lbelle) harvested in Texas during 1978 was equilibrated in the laboratory ambient air at an average temperature of 22°C and 58 percent relative humidity. The brown rice grains were divided into groups of 25 kernels. The samples were first submersed in liquid refrigerant R-12 (Dichlorodlfluromethane) for a short time to cool the grain to the saturation temperature of the refrigerant at atmospheric pressure. After that, the grains were immediately submersed in water at 66°C for another short period of time. Thereafter, the grains were removed from the water and inspedted for fissures.

The time periods for which the grains were submersed were 10, 30 and 60 seconds in the refrigerant, and 10, 20, 30 and 60 seconds in the water. Three replications of each treatment were run.

## Results and Discussion

Brown rice (sample size 25 or 50 kernels) conditioned to three levels of moisture content at 25°C, when exposed for 4 hours to heated air at 43°C and 66°C, respectively, without drying or wetting of the grains, showed no fissures, Table 2.

Table 2. Heating brown rice with conditioned air (Moisture contents on wet basis)

| No. | Sample Conditions | Heating-air Conditions | Grain* Weight, % | Fissures |
|---|---|---|---|---|
| 1 | 25 C, 4.86 % M. C. | 43 C, 20.3% RH | -0.01 | None |
| 2 | 〃 〃 | 66 C, 39.5% RH | 1.30 | None |
| 3 | 25 C, 10.53 % M. C. | 43 C, 51.5% RH | -0.07 | None |
| 4 | 〃 〃 | 66 C, 60.8% RH | -0.46 | None |

| | | | | |
|---|---|---|---|---|
| 5 | 25 C, 14.87 % M. C. | 43 C, 79.4% RH | -1.30 | None |
| 6 | 〃 〃 | 66 C, 83.7% RH | 1.50 | None |
| 7 | 〃 〃 | 66 C, 83.7% RH | -2.20 | None |

* Sample calculations are shewn in Table 3.

Due to temperature meaeuring errors or/and errors introduced in the estimating process, the relative humidities of the heated air were not exactly as desired. Therefore, some sample weights changed a little during the heating process. However, neither positive nor negative change in weight resulted in kernel fissures. But, even with a small gain in weight, resulted in kernel fissures. But, even with a small gain in weight, which was not sufficient to cause the kernels to fissure, the addition of the temperature gradient in the grain still did not cause kernel failure. The grain did not fissure because of the thermal gradient even when a small moisture gradient was helping to produce fissures. Kernel fissres would occur if the compressive stresses at the surface layers of the grain were such that the resulting tensile stresses at the center exceeded the strength of the central portion of the grain.

Table 3. Weighs records before and after heating

| Sample | 25 C | 25 C | 25 C | 25 C | 25 C | 25 C | 25 C |
|---|---|---|---|---|---|---|---|
| | 4.86% M.C. | 4.86% M.C. | 10.53%M.C. | 10.53%M.C. | 14.87%M.C. | 14.87%M.C. | 14.87%M.C. |
| | 50 Kernels | 50 Kernels | 50 Kernels | 25 Kernels | 25 Kernels | 25 Kernels | 25 Kernels |
| Heating Air | 43 C | 66 C | 43 C | 66 C | 43 C | 66 C | 66 C |
| | 20.3% RH | 39.5% RH | 51.5% RH | 60.8% RH | 79.4% RH | 83.7% RH | 83.7% RH |
| Initial Sample (gr) Weight | 0.7952 | 0.7835 | 0,8299 | 0.4175 | 0.4453 | 0.4505 | 0.4442 |
| Final Sample (gr) Weight | 0.7951 | 0.7940 | 0.8293 | 0.4156 | 0.4396 | 0.4574 | 0.4342 |
| Gain of Weight (%) | -0.01 | 1.3 | -0.07 | -0.46 | -1.3 | 1.5 | -2.3 |

If the above-mentioned compressive stresses were caused by surface expansion of the grain due to the temperature gradient, how much temperature rise would be necessary to cause a tensile failure at the center of the grain? Atora etal. (1973) suggested that a temperature difference larger than 43°C (110 F) between drying air and rice kernels may result in serious cracking. Their calculation were based on the following data:

Tensile strength: 117.84 $kg/cm^2$ at 12 % M. C. (wb)

Modulus of elasticity of rice kernel:

$2.448 \times 10^4$ $kg/cm^2$ at 12 % M. C. (wb)

Coefficient of cubical thermal expansion of rice kernel:

$2.403 \times 10^{-4}/C$ at temperature $<$ 53°C

$3.364 \times 10^{-4}/C$ at temperature $>$ 53°C

Rutture strain: $4.813\times10^{-3}$cm/cm

Lee (1971) worked on the mechanical properties of brown rice and found different values for ths modulus of elasticity. For example, he reported the following for Bluebelle brown rice at 27°C and 11.7 percent moisture content:

Modulus of elasticity: 1337 kg/cm$^2$

Tensile strength: 59.29 kg/cm$^2$

Ultimate tensile strain: (within the elastic range) $4.4\times10^{-2}$cm/cm.

If Lee's data for tensile strain are used with a coefficient of cubical thermal expansion of $2.403\times10^{-4}$/C, then the critical temperature difference which could cause internal failure would be:

$$T=er/(ck/3)=4.4\times10^{-2}/(2.403\times10^{-4}/3)=549°C$$

where:

ck is the coefficient of cubical thermal expansion

er is the tensile strain.

Hence, there should be little prospect for a rice kernel to fissure from a temperature gradient alone in a normal drying operation. However, since the composition of the surface layer and that of the central portions of a rice grain are somewhat different (the former contains more protein and is more elastic, whereas the latter contains mostly starch, which is less elastic), the use of an average modulus of elasticity for the above calculation may not be appropriate.

When a rice kernel is first submersed in refrigerant R-12 before it is submersed in 66 C water, the grain is subjected to a temperature change of 96°C. Even with this temperature change, the grains developed essentially no fissures, Table 4.

Table 4. Fissured brown rice grains observed after kernels were cooled in liquid refrigerant-12 for the indicated time before Being submersed in 66 C water for the time periods shown (Sample Size-25 Kernels)

| Liquid R-12 (sec)<br>Water, 66 C (sec) | 10 | 20 | 30 |
|---|---|---|---|
| 10 | None | None | None |
| 20 | — | None | None |
| 30 | None | None | None |
| 60 | Noen | None | None |

If the grains would be submerged in the 66°C water for an extended period of time, they should fissure within several minutes. According to Desikachar and Snbrahmanyan (1961), milled rice, when soaked in warm water, will start to fissure with less than 2 minutes of submergence time.

## Conclusions

1. The experimental results indicate that brown rice grains, when subjected to air temperature differentials ranging from 18 to 41°C without a substantial change in moisture, did not fissure when the grains were initially conditioned to moisture contents of 4.86, 10.53 and 14.87 percent (wb) at a temperature of 25°C.
2. There is littie if any indication that temperature gradients as large 96°C in brown rice will produce fissures in the grain

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