NOTE

Sulfur Dioxide Treatment to Extend Corn Drying Time[1]

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Low-temperature drying in conjunction with a suitable preservative is an energy-efficient and cost-effective way to control microbial growth during slow drying of high-moisture corn (Eckhoff et al 1983, 1984). SO_2 at 0.05–0.1% of wet weight controlled microbial growth during ambient air drying of cleaned 25–30% moisture corn, provided several treatments were used. Successive treatments were required because SO_2 was desorbed or formed inactive products (Eckhoff 1983). Subsequent treatments of SO_2 were needed to control the microorganisms introduced into the corn mass by fans as well as any survivors of previous treatments. If sufficient SO_2 was not maintained within the corn, the ensuing microbial growth was rapid and extensive. A small-bin study demonstrated this with a single-dose treatment (Eckhoff et al 1984). Near pure culture growth occurred and the amount of mold-damaged corn was greater than occurred in an untreated control.

The present test was designed to study radial distribution of SO_2 in unclean corn and its effectiveness in a slow-drying system using a down-flow treatment that released the gas from a simple device above the grain. Favorable drying conditions and the low initial moisture content of the corn (24.8%) caused us to delay the usual time for the second treatment of the corn. This note details the adverse effects of this decision. The inability of SO_2 to stop deterioration in heating grain is also discussed.

Procedures

Corn at 24.7% mc was harvested and placed in a 5.48-m diameter bin 3.96 m high with a perforated drying floor. A total of 66.0 t (2,600 bushels) was augered into the bin and distributed with a grain spreader. SO_2 was applied at the top of the bin through a simple device made of 9.1-mm i.d. pipe 50 cm long, with four short 8.9-cm lateral open-ended pipes arranged in different directions and heights off the main pipe. It was suspended vertically, with the bottom approximately 60 cm above the grain. SO_2 gas was metered from a standard 68-kg compressed-gas tank through a rotameter into the applicator. The gas was drawn into the downward airflow induced by the fan. SO_2 was applied one, 56, and 138 days after the bin was filled; dosages were 0.13, 0.05, and 0.05% (weight SO_2/wet weight corn), respectively. The fan was turned off for 24 hr after the one- and 138-day treatments and for 72 hr after the 56-day treatment, and then reversed. Airflow was 0.89 $m^3/min \cdot t$ (0.8 cfm/bu) in an upward flow during drying, a rate considered inadequate for low-temperature drying of corn of this moisture.

Temperature was monitored weekly using thermocouples at the center and 91 cm from the wall located at 60-cm intervals down in the corn. Airflow at the surface of the corn was measured using a 25-to-1 reducing funnel and a hot-wire anemometer. Probe samples were taken 30.5 cm from the radial center of the bin and 0.9 m from the wall near the entrance hatch at depth intervals of 60 cm at eight times during storage. Sampling was done with a Probe-A-Vac sampling device (Cargill Grain Co.). These and additional samples were analyzed for moisture, water-extractable SO_2 (WE-SO_2), seed germination, percentage of kernels infected, and numbers and kinds of fungi. Moisture was determined using the 72-hr, 103°C oven-moisture method. Water-extractable SO_2 was determined using the procedure of Eckhoff and Okos (1983). Selected bin unload and in-bin samples were analyzed for aflatoxin and zearalenone using the CB (AOAC 1980a) and Eppley methods (AOAC 1980b), respectively.

Fungi were determined by plating 50 disinfected seeds (one minute in 1% NaClO, Clorox brand) on malt-salt agar (6% NaCl) or modified potato-dextrose agar (100 ppm Tergitol NPX, Union Carbide, and 30 ppm chlortetracycline) and by culturing dilutions of comminuted kernels on the same media.

RESULTS AND DISCUSSION

Initial kernel infection averaged 64%, with *Nigrospora oryzae*, *Fusarium moniliforme*, and *Cephalosporium acremonium* predominating. Lower infections (<10%) of *Alternaria*, *Cladosporium*, *Gibberella zeae*, *Penicillium*, and *Rhizoctonia* were also found. The initial treatment of SO_2 (0.13%) decreased all fungi below detectable limits in 13 of 16 samples from the top two-thirds (2.7 m from surface) of the bin. Three samples had a trace of one of the following as determined by plating: *Aspergillus glaucus*, *F. moniliforme*, *N. oryzae*, or *Chaetomium* sp. No fungi were found on dilution plates (10^{-3}). Sampling after six weeks revealed no mold activity except at a depth of 2.1 m, where some *Penicillium* spp. and *F. moniliforme* had grown. Germination was eliminated in kernels to a depth of 2.1 m, but at 2.7 m over half the seed was alive.

The distribution device gave a reasonably good radial distribution of SO_2 in the bin. WE-SO_2 levels at the center of the bin went from a maximum of 686 ppm at the top to 637, 487, 288, 150, 46, 36, and 29 ppm at depths of 0.3, 0.9, 1.5, 2.1, 2.7, 3.3, and

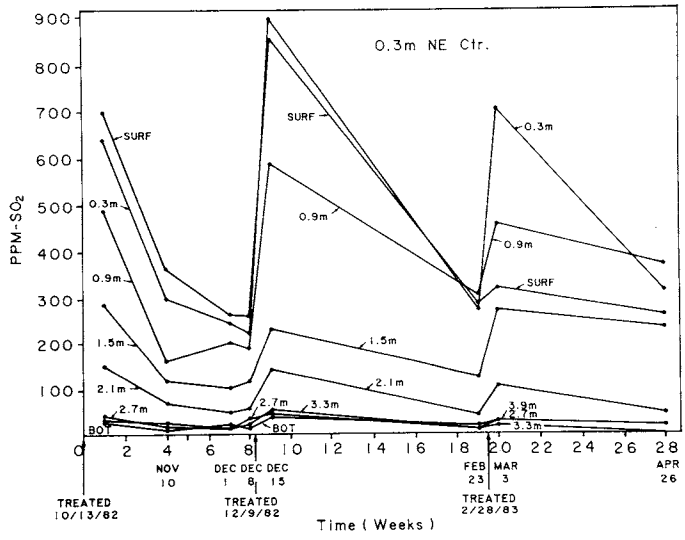

Fig. 1. Water-extractable SO_2 amounts in corn kernels at 0.3 m northeast of the center of various depths.

[1]Journal Paper no. 10,570 of the Purdue Agricultural Experiment Station. This research was partially supported by a USDA research project.

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3.9 m, respectively (Fig. 1). Amounts near the hatch entrance were 627, 615, 536, 399, 235, 108, 36, and 23 ppm for similar depths (Fig. 2). Thus, the downflow resulted in higher amounts of WE-SO_2 at the top than the bottom, an advantage in a slow-drying system with upward airflow. The lower maximum levels reported here in comparison with previous work (Eckhoff et al 1984) resulted from a more dilute concentration of SO_2 in the air being pulled down through the bin. SO_2-to-air mass ratios for the three treatments were 1:359, 1:772, and 1:574 respectively; the previously cited work used a ratio of 1:146. Distributions of the SO_2 after the 56- and 138-day treatments were similar, with the exception that nonuniform moisture distribution as a result of mold development and nonuniform airflow caused differences in WE-SO_2 levels. In general, areas with higher moistures had higher WE-SO_2 contents after treatment.

Figures 3 and 4 show the drying profiles for five representative sampling times for the center and hatch locations, respectively. Between 20 and 41 days, little drying occurred in the corn at the center of the bin (Fig. 3). Appreciable drying occurred at the hatch area 2 (Fig. 4), whereas the middle third of the bin depth decreased from 24 to 18% mc. After 35 days, the airflow distribution in the bin was measured. There was considerable variation in the airflow between the areas near the wall and the center of the bin. In general, airflow increased with increased distance from the radial center of the bin. Values ranged from 0.15 $m^3/min{\cdot}t$ (0.14 cfm/bu) at the center of the bin to 0.99 $m^3/min{\cdot}t$ (0.90 cfm/bu) at the outer edges of the bin. Fine material segregation was probably responsible for the variation, although it appeared that some mold growth and clumping may have occurred in the areas of the bin containing high amounts of broken corn and foreign material (BCFM) by this time.

After seven weeks (on December 8) a 15-cm wide incomplete ring of moldy grain was seen on the surface about 0.1 m from the bin wall. As the corn was unloaded in the spring, the area of corn mold was observed to extend about 2.1 m down and was 0.15–0.30 m wide, but occasionally 0.6–0.9 m wide. The mold was usually associated with the accumulation of BCFM distributed by the grain spreader. The higher BCFM is presumed to have reduced both the drying rate and the diffusion of SO_2. *Penicillium* and *Trichoderma* predominated in the grain at the surface of this moldy ring, accompanied by corn moisture contents as high as 44%. *Gibberella zeae* was common 7–10 cm below the surface, and *Aspergillus fumigatus* and *A. flavus* were common deeper in the corn mass. It is believed that some *Gibberella zeae* survived the SO_2 treatment, whereas the other fungi listed produce abundant spores that could have been blown in by the drying fan. Six samples that showed different kinds of visible mold growth and damage were taken from the upper 0.3 m of the mold ring and analyzed for mycotoxins. Three of the six samples had detectable levels of aflatoxin (68, 75, and 291 ppb), and one of these samples had a high level of zearalenone (2,100 ppb) as well as 75 ppb aflatoxin. The very high moisture content of the corn at the surface of this mold ring was probably caused by moisture condensing on the grain and bin ceiling and fungal metabolic water. Weather from the third to seventh weeks, generally warm and moist during the day and cool at night, encouraged condensation on the upper grain and the bin ceiling. However, because of the depth that mold extended into the corn, it appears that the primary causes of the advanced mold deterioration were inadequate distribution of SO_2 and delay of the second application of SO_2. Distribution of SO_2 in the corn was relatively uniform radially at 0.6 m down (range 627–558 ppm) and, as expected, varied with depth of the corn, but it appears that some of the SO_2 was diverted around the corn with high BCFM. Moist corn absorbed more SO_2 during the second treatment than dry corn, but moldy corn, clumped or separated, absorbed less SO_2 than sound corn. The separate molded corn kernels were on the surface and low in moisture content, 15.2%. Significantly, although SO_2 is an effective gaseous fungicide, it did not eliminate the fungi from heavily molded kernels at a concentration of 0.05%. Samples taken from the molded area three days after the second treatment had WE-SO_2 levels ranging from 243 ppm on the surface to 48 ppm 0.5 m below the surface. This was about half the amount absorbed by nonmoldy kernels. Plated kernels from areas without visible mold yielded no fungi, whereas samples from the moldy areas had *Penicillium* sp. levels in excess of 2.6×10^5 per gram, but the percentage of infected kernels had been reduced to 2–4%. Individual separated kernels were also not sterilized, but they were

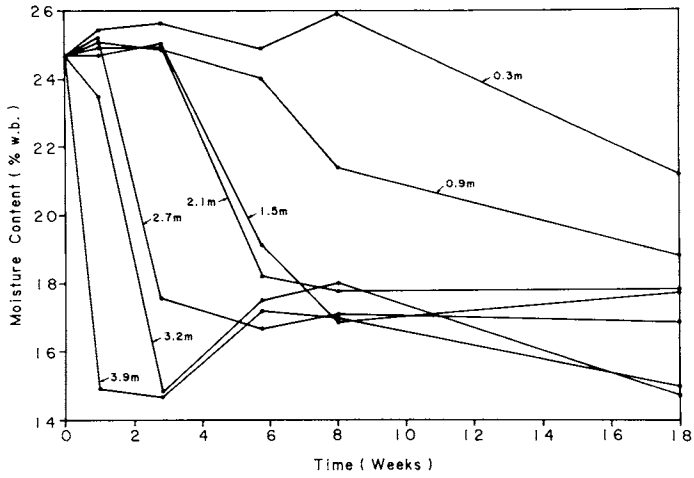

Fig. 3. Moisture content of the corn at 0.3 m northeast of the center at various depths.

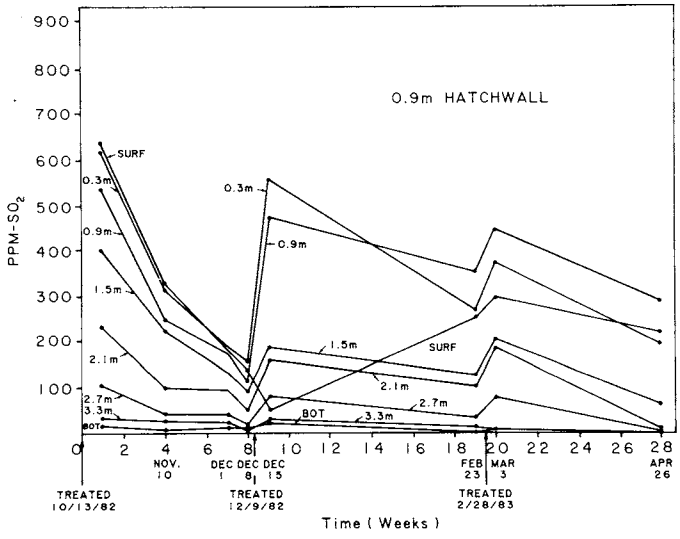

Fig. 2. Water-extractable SO_2 amounts in corn kernels at 0.9 m from the hatch wall at various depths.

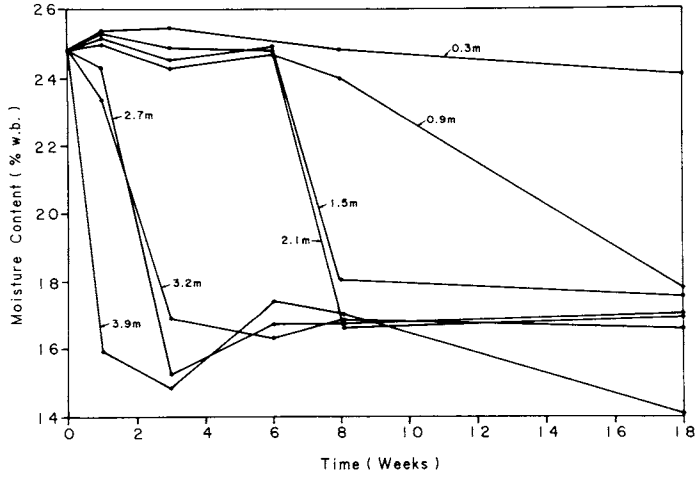

Fig. 4. Moisture content of the corn at 0.9 m from the hatch wall at various depths.

dry and absorbed less SO_2.

Sulfite residue in the corn at the end of the test varied with location. The amount of residue observed was greater than would normally be expected from the process because of the attempt to stop the microbial growth at 56 and 138 days.

Before and during unloading, an effort was made to separate and remove obviously molded corn. Approximately 10.5% of the initial 66.0 t (2,600 bu) was discarded. Of nine truck loads of suitable corn hauled to a local elevator, five had damage in excess of No. 2 corn standards as determined by unofficial grading. Damage ranged from 0.6 to 22.3%, with an average of 7.1%. Financial loss because of discarded and discounted damaged grain was estimated at $958, an approximate loss of 11.9%. A portion of this loss would be offset by the reduced energy costs associated with low-temperature drying estimated at $390. No aflatoxin or zearalenone was detected in five random samples taken from the marketed corn.

Thermocouples did not reveal heating, although one of the two thermocouples was within 0.3 m of the active heating zone determined by a probed thermometer, where extensive molding was occurring.

CONCLUSIONS

The use of a simple distribution apparatus in the top air space of the grain bin appeared to give satisfactory radial distribution of SO_2 in a downflow system.

A downflow treatment procedure with 0.13% SO_2 basically eradicated microflora in the top two-thirds of the bin.

Failure, determined as significant molding and mycotoxin production, appeared to be associated with the delay of the second treatment of SO_2 beyond three weeks and use of uncleaned grain and the nonuniform distribution of BCFM.

SO_2 should be used as a preventative and not a curative treatment.

ACKNOWLEDGMENTS

We appreciate the help received from Cindi Koh-Knox, Ron Blankenship, Kevin Baker, and USDA financial support, cooperative agreement 59-519B-2-1126.

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[Received January 13, 1986. Revision received June 3, 1986. Accepted June 6, 1986.]