Storing Farmers Stock Peanuts in Monolithic Domes

Christopher L. Butts, Ph.D., P.E.
USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia

Jack T. Chastain, President
Doster Warehouse, Inc., Rochelle, Georgia

Joe W. Dorner, Microbiologist
USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia

Timothy H. Sanders, Ph.D., Research Leader
USDA, ARS, Market Quality and Handling Research, Raleigh, North Carolina

Marshall C. Lamb, Ph.D., Research Leader
USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia

Diane L. Rowland, Ph.D., Physiologist
USDA, ARS, National Peanut Research Laboratory, Dawson, Georgia

Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. Commercial and research facilities were constructed to store farmer stock peanuts in monolithic concrete domes. These structures have potential advantages over conventional metal buildings used to store peanuts including sanitation, construction time, and temperature stability. Four 3.7m diameter domes were constructed, instrumented, and equipped to control temperature and humidity using either air conditioning or ambient aeration. Two of the domes were equipped to provide a low oxygen atmosphere to store the peanuts and determine its effect on peanut quality. Temperatures have been very stable throughout the storage period. Some condensation occurred subsequently wetting the peanuts in the air conditioned units. Improved distribution systems are needed to prevent concentrating foreign material in the middle of the peanut mass.

Keywords. peanuts, groundnuts, storage, low oxygen, controlled atmosphere
**Introduction**

In the U.S., peanuts are harvested, cured, and marketed in the fall of the year. Farmer stock peanuts is the term used to describe in-shell peanuts that have been delivered by the grower, sold to a processor with minimal post harvest processing. Farmer stock peanuts have typically been cured to kernel moisture content between 7 and 10%, contain 2-4% loose shelled kernels (LSK), and 3-10% foreign material (FM). If percent LSK or FM is above specified limits or if FM consists of high moisture material, then farmer stock peanuts may be cleaned. LSK are at a greater risk of being contaminated with aflatoxin than kernels protected by an intact shell (Dorner and Cole, 1997; Dowell et al., 1988). After marketing, farmer stock peanuts are emptied from a farm wagon or semi-trailer into a dump pit. From the dump pit, the peanuts empty into a bucket elevator, on to a horizontal belt conveyor, and into the warehouse (Figure 1). Most farmer stock warehouses are steel buildings with no insulation and are 24m wide with a 7.3m eave height. The roof pitch is most often 37° or 45°. The length of the building ranges from 55 to 122m depending on the desired capacity. A 122-m farmer stock peanut warehouse will hold approximately 10,000 t of runner type peanuts.

![Figure 1. Typical farmer stock peanut warehouse.](image)

Peanuts are stored in these warehouses for periods ranging from 30 d to 9 months. As with other agricultural commodities, the quality deteriorates during storage due to excessive moisture loss, condensation, insect infestations, and mold growth (Davidson et al., 1982; Sanders et al., 1981). In a 3-yr study, (Butts and Smith, 1995) found that the value of farmer stock peanuts decreased by 2 to 4% during storage. Excessive moisture loss was a significant factor in the decrease.

Indian meal moth, *Plodia interpunctella* (Hübner) and Almond moth, *Ephestia cautella* (Walker), are the predominant insect pest in farmer stock warehouses (Redlinger and Davis, 1982). As in any stored agricultural commodity, sanitation is the first step in controlling the post harvest insect infestations. In farmer stock warehouses this includes removing dust and peanut residue from elevator buckets and cleanouts, belt conveyors, cleaning equipment, and support structures. Peanuts typically collect on the wall purlins and between the exterior wall and support structures during unloading. During loading considerable dust and peanut residue collect on the support structures for the conveyor belt and tripper and on screens covering the...
hooded inlets and fan intakes. Most storage facilities use a crack and crevice insecticide to treat the structure prior to loading. However, very few, if any, apply chemicals to the peanut surface during loading. Many farmer stock warehouses use aerosols such as dichlorvos on a daily basis to fog the headspace. However, efficacy has been questioned in recent years due to potential resistance and poor maintenance of equipment. A surface application of diatomaceous earth after the warehouse is loaded has been used with some success in controlling Indian meal moth and Almond moth. However, Arthur (2001) showed that the high relative humidity experienced in the southeastern U.S. may reduce the efficacy of diatomaceous earth. Fumigation with phosphine is used after insect populations reach threshold levels or webbing by the larvae has become apparent. However, it is difficult to seal the metal warehouses well enough to maintain recommended phosphine concentrations and prevent exposure to personnel and surrounding areas.

Smith et al. (1995) reported that a second roof with an air gap over the top of the existing roof had been installed on some aging warehouses instead of replacing the existing roofing. This double roof reduced the maximum temperature in the headspace and reduced condensation in the warehouse. Smith et al. (1995) stated that these were about the only real changes in farmer stock warehouse structures since about 1985. Due to the shortened harvest and rapid filling of farmer stock warehouses, aeration systems have been designed and installed in new and existing warehouses to assist with the initial cooling and equilibration of the peanuts (Blankenship et al., 2000; Smith and Davidson, 1984).

Monolithic domes are thin-shell structures constructed using a continuous spray-in-place process first patented in 1979 (Monolithic Dome Institute, 2005). The first monolithic dome was constructed in Idaho as a bulk storage facility for potatoes. Since then, most of the domes built for bulk storage have been used to store products other than agricultural commodities such as bulk cement powder, ice-melting chemicals, and fertilizer. A cutaway section shows the general method of constructing a monolithic dome (Figure 2). A concrete ring beam footing is poured with steel reinforcing bar protruding vertically from the ring. A fabric-reinforced membrane or airform, is unrolled with its bottom edge attached to the outer surface of the ring beam and inflated. After the airform is inflated, fans continuously operate for the duration of the construction process.

Urethane foam insulation is sprayed on to the interior surface of the inflated airform in multiple layers. Each layer is approximately 3 cm thick and the final thickness is usually 8-10 cm. A grid of steel reinforcing bar is assembled in place and tied to anchors in the urethane foam and to the reinforcing steel in the foundation ring. Metal framing for doors and other openings are installed at this time. Shotcrete®, a spray-on formulation of concrete, is applied in several thin layers until the desired thickness is achieved. The thickness of the concrete depends on the sidewall loading imposed by the lateral pressure of the material stored. The fan is turned off and airform fabric trimmed from the openings after the concrete has cured. A conventional monolithic concrete slab is then poured for the floor of the bulk storage facility.

This type of structure offers several potential advantages over conventional steel farmer stock peanut warehouses. The monolithic dome has an R-value of 4.5 m²·K W⁻¹ compared to and R-value of 0.1 m²·K W⁻¹ for a sheet metal building with no insulation. However, the thermal mass of the concrete structure gives it an equivalent R-value of at least 11 m²·K W⁻¹ (Monolithic Dome Institute, 2005). Sanitation of the interior surface of the dome should be easier due to the absence of support structures to hold peanuts after unloading. The dome should also be easier to seal for fumigation due to the absence of seams in the wall or roof structure.
Objective

The objective of this manuscript is to describe a monolithic dome structure constructed for commercial storage of farmer stock peanuts and a research facility to investigate the use of monolithic domes to store farmer stock peanuts.

Commercial Storage Facility

Two 37-m diameter x 22 m tall domes were designed and constructed to store approximately 5000 t of farmer stock peanuts each (Figure 3) at Doster Warehouse, Inc. in Rochelle, GA. Each dome is 37-m diameter hemisphere with a 3.5-m vertical stem wall. After the site preparation and ring beam footing was completed, construction of the dome shell was completed in about 30 d. Once the airform is inflated, all work proceeded inside the airform and was not subject to any delays due to inclement weather. An additional 30-45 d was required to complete the installation of aeration, loading, and cleaning equipment, service platform, and the concrete floor. Peanuts were loaded into the first dome approximately 130 d after site preparation began. A typical warehouse would require at least 150 d with no weather delays.

Peanuts are delivered to the warehouse in hopper bottom trucks and emptied into one of the dump pits feeding the same elevator. The dump pit elevator (Elevator #1) feeds a surge bin for the cleaner to remove dirt, sticks, rocks, and other FM. The second elevator lifts peanuts from the cleaner outlet to one of the covered, horizontal conveyor belts. The belts then carry the peanuts to an opening at the center of the top of the dome, where they fall into the center of the warehouse. Once the peak of the pile reaches a depth of about 18 m, a 6-m long open-flight
auger mounted below the service platform pushes peanuts from the center toward the outside wall. This creates a pile with a level top surface approximate 12 m in diameter. Peanuts are approximately 11 m deep at the outer wall and 18 m deep in the center.

Each warehouse is equipped with a 7.5 kW aeration fan that provides 410 m$^3$min$^{-1}$ against a static pressure of 600 Pa. The airflow rate is sufficient to provide an air change in the headspace and peanut void space every 15 min. Air enters the top of the dome through the 1.8 m x 1.8 m hole through which peanuts are loaded. Air is pulled down through the peanuts, through five 0.6 m x 0.6 m square openings in the floor, into an air duct below the floor. The fan then exhausts the air or can be recirculated, if desired, through a duct that returns into the dome approximately 14 m above the floor.

**Dome Research Facility**

Four 3.7-m diameter monolithic domes were constructed at the same time and using the same personnel that constructed 37-m diameter peanut storage domes in Rochelle, GA. The floors of the 1/10$^{th}$ scale domes were constructed by welding two 1.8m x 3.6m x 9.5mm steel plates together to form a 3.7 x 3.7 m$^2$ plate. Steel bar stock, 203mm x 9.5mm, was formed into a 3.7m diameter hoop then welded to the floor plate. This ring served as the ring footer beam and tied the wall in to the floor when the steel rebar was attached. Four lift points were welded to the

![Figure 3. Site plan for monolithic domes for storing farmer stock peanuts at Doster Warehouse, Inc](image)
floor (Figure 4). The domes were constructed using the same techniques previously described. A 61-cm diameter sleeve and cap was installed at the top of the dome through which peanuts are loaded. A 0.9 m x 1.5 m bulkhead door was installed to through which peanuts are unloaded.

![Image](image-url)

Figure 4. Floor assembly for 3.7 m diameter monolithic domes for peanut storage research.

After construction, the domes were lifted by lowering a cable through the hole in the top of the dome and a hook connected to each of the four lift points. The domes were set on two trucks and transported from Rochelle, GA to Dawson, GA and set on a 12 m x 12 m concrete slab (Figure 5).

An aeration system was installed using perforated 10-cm PVC pipe cut in half anchored to the floor. A plastic in-line duct fan (Model FR100, Fantech, Sarasota, FL) pulls air down through the peanuts and either exhausts or recirculates the air depending on the desired ventilation strategy. The fan provides an air change every 15 min of the head and void space in the dome after filling.

The domes are instrumented to measure peanut temperature throughout the peanut mass using three thermistor cables hung horizontally across the dome every 0.6 m beginning 0.6 m above the floor. Thirteen thermistor nodes are located in the dome as shown in Figure 6. An oxygen sensor (GCS90, Storage Control Systems, Inc., Sparta, MI) and relative humidity sensor (HMD60U, Vaisala, Inc., Woburn, MA) were mounted just above the peak of the peanut mass. A type T thermocouple and relative humidity sensor are mounted in a radiation shield 2.4 m above the ground to monitor ambient conditions. A data logger (CR7X, Campbell Scientific, Inc., Logan, UT) scans all sensors in each dome on a 60-s interval. Aeration fans, air conditioning units, and nitrogen injectors are controlled by the data logger based on the conditions in each dome. Aeration/chiller configurations and storage oxygen levels are shown in Table 1.
Figure 5. Setting domes at the USDA, ARS, National Peanut Research Laboratory.

Figure 6. Thermistor sensor layout for dome storage research.
Domes 1 and 4 were cooled using ambient air aeration. During the first 36 d of storage, aeration fans were operated if the average of the three temperatures down the center of the peanuts was greater than the ambient temperature and the ambient relative humidity was less than 80%. These control parameters were used to cool the peanuts and to remove excess moisture. After 36 d in storage, the ambient relative humidity had to be between 65 and 80% for the fans to operate. The control parameter for temperature remained unchanged.

Conventional window air conditioning units were modified so that the dome aeration system drew air down through the peanuts, across the cooling coils, and returned to the headspace in the dome. The set point was compared to the average temperature down the middle of the peanut mass. If the peanut temperature was warmer than the set point, the air conditioner and aeration system were energized. The set point was gradually decreased from ambient to 15.6 °C over a period several weeks. This gradual step down was an attempt to prevent condensation on the uninsulated surface of the loading chute.

Table 1. Storage treatment protocol for storing farmer stock peanuts in monolithic domes.

<table>
<thead>
<tr>
<th>Storage Treatment</th>
<th>Dome 1</th>
<th>Dome 2</th>
<th>Dome 3</th>
<th>Dome 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeration type</td>
<td>Ambient</td>
<td>Chilled</td>
<td>Chilled</td>
<td>Ambient</td>
</tr>
<tr>
<td>Oxygen level</td>
<td>Ambient</td>
<td>Ambient</td>
<td>Ambient</td>
<td>Low</td>
</tr>
</tbody>
</table>

After 141 d into the storage period in domes 3 and 4, controls were activated to reduce the oxygen concentration in the dome to less than 5%. The exhaust and fresh air intake were sealed so that the aeration fan only circulated air within the dome. A manifold to inject nitrogen from high pressure cylinders into the aeration system was installed. The %O₂ set point was gradually decreased from ambient to 5% over several weeks.

**Results**

All four domes were loaded with farmer stock peanuts on 27 Oct 2005. An average of 4481 kg of peanuts were loaded into each dome using an inclined belt conveyor. Dome 3 had originally been planned as a low oxygen treatment. However, the condensate drain pan for the cooling coil and its sheet metal ducting had not be sealed to prevent leakage of oxygen. Refabrication of the condensate drain pan and the cooling coil ducting is necessary to prevent aeration fan from drawing ambient air.

Comparisons of the center line and ambient temperatures for the first 12 of storage are shown in Figure 7. The air conditioned dome began to cool rather rapidly compared to the aerated dome because of the condition that required the ambient temperature to be cooler than the average center temperature. After approximately 7 d in storage, the ambient temperature decreased approximately 16°C in about 36 h causing a relatively rapid decrease of 12°C in the core temperature of the peanuts in 48 h.
Figure 7. Comparison of ambient, center line temperatures of dome 1 with ambient air aeration and dome 2 with air conditioning during the first 12 d of storage

The relative humidity in the headspace of the aerated dome followed the ambient relative humidity fairly closely (Figure 8). The range between daily maximum and minimum was noticeably smaller in the aerated dome than the ambient relative humidity. The maximum relative humidity in the air conditioned dome never exceeded 80%, whereas the maximum ambient relative humidity was 95% or greater. However, the uninsulated metal used to form the inlet spout was cooled below the dewpoint temperature of the headspace of the dome. Condensation formed on the inside of the spout and dripped on the peanuts below. The wetted and moldy peanuts were found when the hatch was removed for inspection. The spout will be insulated in future research to prevent condensation from occurring.

Dome 4 was closed and a system to inject 100% nitrogen from industrial cylinders into the aeration system was activated. The exhaust vent on the aeration system was sealed so that the aeration fan was used to recirculate air in the dome. A pressure relief valve had been installed during construction to relieve excessive positive or negative pressure while flushing the dome. The oxygen (O2) set point was stepped down gradually over a two-week period. A leak was found while trying to maintain the O2 level below 5% causing excessive nitrogen consumption. The leak was sealed and the O2 level has been maintained for a period of two weeks with nitrogen being injected approximately 15 min or less out of the hour (Figure 9). The O2 level in the other domes has remained at normal atmospheric levels of 21%.

Temperatures have remained very stable throughout the storage period (Figure 10). After sealing dome 4, the core temperature has risen approximately 1°C above that of dome 1. However, the core temperature in both domes is 21°C or less. The air conditioned dome has maintained a core temperature of 15.6 with slight oscillations about the set point.
Figure 8. Comparison of headspace relative humidity in aerated (dome 1) and air conditioned (dome 3) storage.
Figure 9. Oxygen levels maintained in scale model monolithic domes for peanut storage.

Figure 10. Centerline temperatures in aerated, chilled, and low oxygen atmosphere storage in monolithic domes from 01 May to 13 May 2005.
Conclusion

Commercial and research facilities using monolithic concrete domes to store farmer stock peanuts have been constructed and filled with peanuts. The commercial facility has successfully stored peanuts from the 2004 crop. Improved systems for distributing the peanuts during loading are need to distribute the foreign material and other fines throughout the peanut mass. Similar problems occur in loading grain bins without stirring or spreading devices. The research facility was operational with the harvest of the 2004 peanut harvest. Systems for aeration, chilling, and low oxygen atmosphere storage appear to be working well. Temperatures in the monolithic domes are very stable with little condensation except on exposed uninsulated metal surfaces. Research will continue for the purpose of evaluating the cost effectiveness of the facilities for storage of peanuts including the cost of maintaining low oxygen atmospheres.

Acknowledgements

The authors gratefully acknowledge the technical support of Mr. Manuel Hall, Engineering Technician, in organizing the transportation, set up, instrumentation, and loading of the domes at the National Peanut Research Laboratory. We appreciate the assistance of other USDA personnel including Otis Oxford, John Gardner, Larry Powell, Larry Dettore, Gordon Bonner, and Kathy Gray. The authors acknowledge DOMTEC International for building the research domes and the personnel in the fabrication shop of Doster Warehouse, Inc. for their contribution to construction of the floor.
References


Hatch, R. J. 1994. Large thin shell concrete domes using air supported forms and cable nets. MS thesis. Provo, Utah: Brigham Young University, Department of Civil Engineering.


