Development of a 350kg Double-Walled Insulated Metallic Silo for Tropical Climate

By

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Research Article

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ABSTRACT

In the warm and humid climate prevalent in Nigeria, metal silos which are predominantly used for grain storage in strategic grain reserves experience moisture condensation and high temperature fluctuations, resulting in grain deterioration. There is therefore the need to source for construction materials that will eliminate moisture condensation, reduce temperature fluctuations, cheap and readily available for use in construction. A 350 kg double-walled insulated metallic silo was designed and the prototype was constructed with galvanized iron sheet, using wood shavings as an insulating material between the walls. The silo has a total height of 2.70 m above the ground level with an internal and external diameter of 0.80 m and 0.90 m respectively. The silo consists of four major sections, viz – the roof, cylindrical section, conical hopper and foundation. A pre-storage evaluation of the double-walled metallic silo demonstrated some prospects for use in grain storage, especially in unloading the stored grains and reduction in temperature within the silo.

Keywords: Double walled, Insulation, Sawdust, Silo.

INTRODUCTION

In recent years, the Nigerian government has provided incentives to the rural and medium scale farmers in order to increase production from the agricultural sector of the economy. Different programmes that have been put in place in order to achieve this includes: the establishment of river basin authorities, agricultural development programmes, research institutes, agricultural input supplies, bulk purchase companies and improved post harvest practices. So far, all these programmes have been yielding the desired results (Oyewole and Oloko, 2006). However, about 2.4 billion tonnes of agricultural products equivalent to a total of N48 billion is lost annually to inadequate post harvest techniques in Nigeria (Olose, 1999). This emphasizes the need to harness more resources to combat post harvest losses in order to achieve an increase in food security and income. This is however not only important to small and medium scale farmers but also to the country at large (Mejia, 2001). In Nigeria, post harvest losses have been recognized as the greatest threats to food security amongst other factors. In actual sense, pre and post harvest losses in African countries are estimated at 10% which is greater than the world’s average (Njoku, 2007). Similarly, Oyewole and Oloko (2001) reported that Nigerian efforts to develop Agriculture and attain self-sufficiency in food production are faced with a host of problems despite the measures taken or currently being considered by various organs of government and professionals.

It is an established fact that a large percentage of the food produced by the local farmers in Nigeria is retained on the farm for their personal consumption. Depending on such factors as the size of operational holding, level of commitment and the type of labour employed, the excesses (if available) are sent to the market to generate income for the upkeep of the family. In most cases, the ones kept at home do not last for a long time or even result into wastage due to the absence of proper post harvest techniques to cater for the rapid physiochemical changes taking place in the farm produce. Storage is an important activity in the sequence of post harvest operations. It is an interim and repeated phase in the transit of agricultural products from the producer till it gets to the final consumer (Adejumo and Raji, 2007).

In Nigeria, grains are stored in a variety of traditional storage structures ranging from calabashes, gourds, rhumbu, clean oil drums etc. These structures are generally adapted to the socio-economic and climatic conditions of the environment where they are used and they require only locally available materials such as clay, straw, woven twigs, wood etc. for their construction. The use of improved structures such as local stores and metallic drums (with shelter) also features at the traditional level of storage (Adejumo and Raji, 2007). Modern storage of grains in this part of the world is often done in imported metallic silos located in every state and the Federal Capital Territory (Talabi, 1996). Silos are used for bulk storage because of their large unit capacities.
which could be as much as 500 tonnes. Although there are a number of construction materials such as steel, aluminum, concrete, wood rubber, clay etc, the common commercial silos in use in Nigeria are constructed of steel and aluminum (Mijinyawa, 1999).

Traditional structures made of locally available materials generally have the characteristics necessary for good conservation of harvested produce at a relatively low cost. Some of them provide a good protection against insects and pests and also present a cool and dry microclimate for safe storage of the grains. However, the ones made from clay (e.g. the Rhumbu) are susceptible to degradation by rain, moisture migration and termite infestation, thereby making regular repairs and rebuilding necessary. Also, the loading and unloading mechanism is usually through the roof. In improved structures such as metallic cylinders, condensation usually becomes a problem thereby resulting in the deterioration of the stored grains in addition to the unloading problem.

Silos are the most appropriate modern structures for the bulk storage of grains; their performances are greatly influenced by the materials of construction and the climatic environment where they are used. Under the warm and humid environment prevalent in Nigeria, these silos of temperate region origin, although purchased and stocked at very high costs, experience moisture condensation, hot spot development, high temperature fluctuation and caking which results into grain deterioration (Mijinyawa et al., 2007). The loading and unloading mechanism also requires some expertise. All these problems associated with the existing storage structures (traditional and modern) in this part of the world therefore necessitates the development of a storage structure that will provide a good storage condition for the grains produced by the farmers.

Concrete is usually the preferred construction material in coastal areas or where high corrosion risk is severe. It is also usually preferred where bins have to be very tall. Single-walled mass concrete silos or those of blocks have been tested and found to reduce the severity of moisture condensation while those of double walls constructed from concrete staves and incorporating an air-space completely eliminated the problem of moisture migration, temperature fluctuation and condensation. However, concrete is weak in tension and if used, must be reinforced with steel rods or welded mesh to withstand the lateral pressures due to the stored materials. Construction and labour costs are high while it is also prone to rise in ground moisture (Osunade, 1991). Rubber silos are most unsuitable for use under the warm humid climate as the material suffers severe moisture condensation under intense heat (Agboola, 1996).

The low thermal conductivity of wood products of about 0.12 W/(mK) and their availability most especially in Southwestern Nigeria encouraged their consideration for use in silo construction (Alabada, 2002). Alabada (2006) investigated the potentials of wooden silos in reducing temperature fluctuations. It has been reported that temperature fluctuations obtained within the wooden silos were lower than for those in metal silos. However, the difficulty in making the joints tight in order to eliminate crevices where insects could hibernate constitutes one of its disadvantages. Termites build their tunnels from the soil into the wooden structures leaving the surface untouched which makes it difficult to detect an attack in the early stages (John, 1995). Mijinyawa et al (2007) designed and fabricated a grain silo from termite mound clay and it demonstrates some prospects for use in grain storage limiting temperature fluctuation and moisture condensation. However, clay silos are susceptible to moisture ingress especially from the ground due to the foundation, thereby subjecting the grains close to the ground to deterioration. The availability of the construction material is something to worry about. The objectives of this is to develop a 350 Kg double-walled insulated metallic grain silo that is expected to reduce the effect of moisture migration, temperature fluctuation and condensation in grain storage as well as reduce the loading and unloading constraints imminent in traditional storage structures.

**MATERIALS AND METHODS**

2.1 Design

2.1.1 Design Considerations

In the design of the silo prototype, a number of factors were considered. In Nigeria, Maize has been recognized as the most common food grain (Talabi, 1996). Therefore, its engineering properties - density of 720kg/m² and angle of repose 27° (Mijinyawa, 2007) were utilized in the design.

2.1.2 Materials of Construction

In order to reduce the rate of corrosion of the silo walls, galvanized iron sheet was selected as the major material of construction. Galvanized metal has a zinc coating on it to protect it from rust. The zinc will corrode before the iron, and unlike rust, the zinc oxide will not fall off the pipe so it forms a protective coating on the base metal. The support/foundation of the structure is made of L-shaped angle iron. Wood shavings was chosen as the insulating material in the design because of its low thermal conductivity of 0.06W/(mK) and its wide availability to farmers at little or no cost.
2.1.3 Pressure Analysis

The depth-to-diameter ratio shows that the silo is a deep type. The basic difference between a deep silo and a shallow silo is the presence of wall friction arising from the stored grains (Carson and Jenkyn, 1993). The lateral pressure was estimated using the equations 1 and 2 given below.

\[ P = \frac{\gamma D}{4\mu} \left[ 1 - e^{\left(-\frac{2\mu K}{D}\right)Y} \right] \]

\[ K = \frac{1 - \sin \Theta}{1 + \sin \Theta} \]

where

- \( P \) is the lateral pressure on the structure, N/m²
- \( \gamma \) is the bulk density of grain, kg/m³
- \( D \) is the equivalent diameter, m
- \( \mu \) is the coefficient of friction of the material on the wall
- \( Y \) is the depth of fill, m
- \( K \) is the ratio of horizontal to vertical pressure
- \( \Theta \) is the angle of repose of the stored material

With a bulk density of 720 kg/m³, equivalent diameter of 0.8 m, depth of fill of 1.1 m, and an angle of repose of 27°, the maximum lateral pressure was estimated as 183.75 N/m². A factor of safety of 1.5 was introduced to take care of dynamic loads that may be developed during loading and unloading. The final design load was calculated to be 275.6 N/m². With this, a gauge 16 (1.5 mm) galvanized iron sheet was considered adequate to withstand the load.

2.1.4 Wind Load Design

Apart from grains, wind is another factor that imposes loads on a silo and which must be considered (Mijinyawa, 2007). A number of empirical formulae are available for predicting the wind load acting on a structure. However, in this case, the wind load was estimated using the Thomas (1995) as given in Equation 3, 4 and 5:

\[ q_2 = 0.613K_2K_2Iv^2 \]

\[ F = q_2 CG_f A_f \]

\[ F = 0.05CA v^2 \]

Where:

- \( F \) is the load due to wind imposed on the silo, N
- \( C \) is the pressure coefficient which takes into account the orientation of the structure to the main wind direction usually taken as 0.8 for cylindrical silos
- \( A_f \) is the projected area of the structure, m²
- \( V \) is the wind speed in the environment, m/s
- \( q_2 \) is the effective velocity pressure, N/m²
- \( K_2 \) is the velocity pressure exposure coefficient usually taken as 0.8 for exposure C structures
- \( K_{ti} \) is the topographic factor
- \( I \) is the importance factor usually taken as 0.87 for category I structures
- \( G \) is the gust factor
- \( C_i \) is the force coefficient for the structure

Using a wind speed of 3.3 m/s and a topographic factor of 1.0, the effective velocity pressure was estimated to be 4.94 N/m². With a projected area of 2.76 m², gust factor of 0.85, the wind load according to Thomas (1995) were
estimated as 8.11N and 10.0N respectively. The average of these values was chosen. The design wind load was therefore taken to be 9.05N.

### 2.1.5 Specifications of the Design

In order to reduce the number of joints in the structure and minimize areas of stress concentration, a cylindrical shape was chosen for the design. The silo was designed to have double walls with an insulating (lagging) material between the walls so as to reduce the temperature fluctuation within the silo. The design capacity of the silo prototype was put at 350 kg. The silo was designed in such a way that it will be loaded through the top of the roof and unloaded just at the end of the conical hopper through a discharge channel at the bottom of the structure. Considering the properties of the grain to be stored (i.e. maize) and the intended capacity of the silo, an internal diameter of 800 mm, external diameter of 900 mm, and a total height of 3700 mm was considered adequate for the design. For the silo prototype, the inlet diameter was put at 300 mm to allow for maintenance when necessary. The silo has four sections, these are:

- The roof
- The silo wall (cylindrical section)
- The conical hopper
- The foundation

The isometric view of the silo is as shown in Fig 1.

![Isometric view of the double-walled silo](image)

**Fig 1: Isometric view of the double-walled silo.**
a. **Roof**

The roof of the structure was designed as a conical frustum with the base resting on the silo top and since the material of construction is impermeable to water, an overhang was unnecessary. The base diameter of the cone was designed as the same as that of the cylinder (Fig 2). After considering the inlet diameter, the angle of repose of maize (27°) and the base diameter, a central height of 210 mm and an inclination angle of 35° were found to be adequate for the roof of the silo.

b. **Silo Walls**

The silo wall was designed to be cylindrical in shape in order to reduce the area of stress concentration and the number of joints in the structure. The dimensions of the cylindrical portion were estimated using equation 6 stated below. Since the cylindrical portion is the major storage area, then an internal diameter of 800 mm, external diameter of 900 mm and a height of 1200 mm was considered adequate to store the intended capacity (Fig 3).

\[
V = \frac{\pi D^2}{4} h = \frac{M}{\rho}
\]

Where:

- \(M\) = Intended capacity, kg
- \(\rho\) = Density of maize, kg/m³
- \(V\) = Volume of the cylinder, m³
- \(D\) = Diameter of the cylinder, m
- \(h\) = Height of the cylinder, m.

c. **Conical Hopper**

The conical hopper was designed with the same diameter as that of the cylinder with double walls. The angle of inclination of the conical hopper was greater than the angle of repose of maize. This is in order to permit gravity flow of the stored materials during unloading. The central height of the cone was 315 mm with an inclination angle of 35°. The discharge channel comprises of two hollow cylinders with an internal diameter of 100 mm, intersecting at an angle of 145° and located 336 mm away from the base of the cylindrical section while measuring along inclined face of the conical hopper. The double walls were truncated at a distance of 150 mm along the first cylinder to avoid material wastage (Fig 4). The discharge channel was designed in such a way that unloading will easily be carried out by standing in front of the silo and opening the silo gate to allow the stored grains to be discharged.
d. **Foundation**

Foundations for cylindrical structures are mostly designed to resist the vertical loads arising from the weight of the structures and the overturning moment due to the wind load (Mijinyawa, 2007). For the silo prototype, the resisting moment offered by the self weight of the structure and the weight of the grains when loaded is enough to overcome the overturning moment, therefore, the silo needs no additional anchorage. However, to further stabilize the structure, a concrete basement was introduced in the design. The material used in the construction of the foundation is a 1.5 inch, 4 mm angle iron (Fig 5).

e. **Accessories**

The accessories include the cover, inspection holes, cover opening mechanism and the silo unloading outlet. Inspection holes were incorporated into the design to facilitate proper monitoring of the grains during storage. A total of six holes each of 20 mm diameter, were uniformly spaced on the silo wall to serve as inspection probes. The holes were lined with aluminum pipes and covered with a lid in order to prevent pest entry. The cover opening mechanism consists of a fixed pulley attached to the roof of the structure. A rope attached to the cover handle runs over the pulley and along the silo walls to a point on the foundation where it is hinged. When the rope is tensioned, the cover on the roof opens in the direction of the pull such that it can be hinged. When the rope is released, the cover is returned to its original position on the roof with the aid of a spring attached to the cover from the inner wall of the silo. The silo unloading outlet is an accessory that locks the grains in the silo such that it is only opened when the grains are to be unloaded. It consists of a flat circular plate of the same diameter as that of the discharge channel. A line 2 mm is cut halfway through the discharge pipe. This is to enable the unloading outlet fit in perfectly into the pipe. An extruded arc runs halfway through the circumference of the circle in order to shield the grains in the pipe from the external environment. The handle assists in opening and closing of the unloading outlet.

3.2 **Construction**

The construction of the silo is divided into six sections namely:

- Marking out, cutting and rolling
- Assembling of members
- Incorporation of the insulation material
- Accessories
- Foundation
- Surface finishes
- Silo installation.

1. **Marking-out, Cutting and Rolling**

The silo majorly comprises of two open cylinders, two complete cones, two frustum cones and a host of other small parts. The two cylinders (outer and inner) were marked out on two different galvanized sheets such that when rolled between two parallel cylinders rotating in opposite direction, it forms the cylindrical shape desired for the structure. The cones were also marked out with their respective dimensions in such a way that when they are rolled between two cylinders rotating at an angle to each other, will form a complete or frustum of a cone. All the members were cut-out using a manual shear cutter immediately after the marking out stage and they were presented for rolling into their respective shapes.

2. **Assembling of Members**

After the rolling stage, the major members (i.e. inner and outer cylinders and the lower cones) were assembled by welding them one to another. The inner cylinder was centrally placed in the bigger/outer cylinder and supported by guides made of small metal chips to allow for a uniform spacing (5 cm) along the circumference of the two cylinders. With the two lower cones attached to the two cylinders, the small cylinders that form the discharge outlet were fixed on the outer cone by drilling the cones to facilitate easy attachment and discharge of grains from the silo.
3. Incorporation of the Insulation Material

The choice of the insulating material was wood shavings due to its low thermal conductivity of 0.06W/ (mK). The insulating material was placed in the spacing (5 cm) between the inner and outer cylinder and the lower and upper conical sections for the purpose of reducing temperature influx into the structure.

4. Incorporation of Accessories

The silo accessories include the inspection holes, the cover opening mechanism and the silo unloading outlet. Holes of diameter 20 mm were drilled from the external cylinder through the inner cylinder to serve as a means of inspecting the storage conditions in the structure. Six holes were made with three on each side and 20 mm metallic pipes were inserted in the holes to serve as a channel through which the probe of the thermocouple could be used to measure the temperature in the silo.

5. Foundation

The foundation of the structure was constructed using 1.5 inch 4 mm L-Shaped angle iron according to the design specifications.

6. Surface Finishes

After the construction, body filler was applied on the structure to fill-up the small holes in the welding and to improve the surface finish. After the application of body filler, the surface was grinded using an electric metal grinder. To further improve the appearance of the structure, it was painted with aluminum paint using a spraying machine.

7. Silo Installation

With the construction of the silo completed, it was installed with a concrete basement to further stabilize the structure. To install the structure, a pit was excavated with dimensions of 60 cm X 60 cm X 30 cm. The concrete mix used is 1:3:6 (cement: sand: coarse aggregate). Adequate precautions were taken to ensure that the structure stands upright.

3.2.2 Pre-storage Evaluation

Pre-storage temperature measurements were carried out to establish the efficiency of the silo before grains are stored in the structure. The temperature difference between the silo enclosure and the environment where it is located was measured using a thermocouple. Measurements were taken through each of the inspection probes located on the silo walls and outside the silo for a period of 15 days. Temperature readings were taken three times daily at 8:30 am, 12:30 pm and 3:30 pm.

RESULTS AND DISCUSSION

4.1 The Double-Walled Metallic Silo

The silo (Plate 1) is a cylindrical, double-walled structure made of galvanized iron steets. With a total height of 2.70 m above the ground level, the silo consists of four major sections, viz – the roof, cylindrical section, conical hopper and the foundation. The main objective of constructing a double-walled silo is to reduce temperature fluctuations between the environment and the silo enclosure thereby reducing the effect of condensation that could lead to faster spoilage of the stored grains. Grains will be loaded into the silo from the top and unloaded via the unloading channel on the conical hopper. The body of the silo comprises of two cylinders (outer and inner) of diameters 0.90 m and 0.80 m and length 1.22 m and 1.18 m respectively. Wood shavings was placed in the space (5 cm) between the two walls to serve as an insulating material. The choice of wood shavings was due to its low thermal conductivity (0.06W/(mK)) and the fact that it is readily available at little or no cost to the farmers who are the primary users of the structure.
The lower part of the structure (i.e the conical hopper) also made of galvanized iron sheet, consists of two inverted cones with the smaller one placed centrally inside the larger one such that there is a spacing of 5cm along the curved surface between the cones. The outer cone has its base radius equal to that of the outer cylinder so that the cylinder fits accurately on it. The space between the cones is filled with wood shavings to serve the purpose of an insulating material. The conical hopper was constructed with an angle of repose of $35^\circ$ to facilitate a free movement of grains under gravity during unloading.

The roof of the structure, like the conical hopper, is also made of galvanized iron sheets. It comprises of two frustum cones placed one inside the other such that there is a spacing of 5cm along the curved surface between the cones. In order to avoid the penetration of heat from the top of the structure as a result of its direct exposure to sunlight, wood shavings was also placed in the space created by the two cones to insulate the roof. The base radius of the outer conical frustum is equal to that of the outer cylinder such that it fits accurately on the outer cylinder.

The top radius of the two cones that make up the roof is 0.3m to allow for maintenance and repairs in the structure when necessary. The cover of the structure is designed and constructed to fit on the roof in order to protect the grains from the external environment and to prevent contamination of the stored grains. The cover is held in position by means of a spring to ensure that the structure is airtight. The foundation of the structure is made of 1.5 inch, 4 mm angle iron. It comprises majorly of four bars of angle iron each of 1.90 m length with 0.30 m buried in the concrete basement. With this dimension, the foundation raises the cylindrical section of the silo 1m above the ground surface.

The unloading channel of the structure is designed and constructed in such a way that the grains will be locked in the silo and free to move out of the structure when necessary. It comprises of two sections. The first section inclined at an angle of $35^\circ$ to the horizontal, consists of two pipes with diameters 0.10 m and 0.20 m and lengths 0.20 m and 0.15 m respectively. It houses the unloading control mechanism which is located towards the end of the longest pipe and moves transversely to the pipe to either allow grains through the pipe or keep the grains in the silo. The second section has the same diameter as the longest pipe in the first section and it extends from it but at an angle $90^\circ$ to the horizontal.
The silo also has six inspection holes of diameter 0.02 m drilled through the silo wall. It is meant to facilitate easy assessment of the quality of the stored grains and conditions within the structure of which temperature and relative humidity are of utmost importance. In addition to the inspection holes, a cover opening mechanism is also included in the design to secure the cover when it is opened. The mechanism comprises of a rope attached to the silo cover and secured on the foundation of the structure to prevent the cover from falling off.

4.2 Pre-storage Evaluation

The results of the pre-storage evaluation of the double-walled silo show that the temperatures recorded within the silo vary with respect to the time of day. The temperature within the silo increases with increase in the ambient temperature. The temperature within the silo enclosure increased with height, the highest temperature was recorded in the point nearest to the roof, this is an indication that the heat penetrates into the silo through the roof.

4.3 Advantages of the Double-Walled Silo

The advantages of the insulated double walled silo designed for grain storage includes the followings:

- Little or no expertise is required in the operation of the structure.
- The high cost of maintenance in most locally made grain storage structures is eliminated in the design because there is minimum maintenance in the various parts of the silo.
- The silo unloading channel provides for an easy and convenient discharge of grains from the structure.
- The silo makes efficient use of space as compared to other locally constructed storage structures.
- Small capacity silos such as the one developed in this study will suit the requirement of the individual farmers.

CONCLUSION

The double-walled metallic silo demonstrated some prospects for use in grain storage, especially in unloading the stored grains and reduced temperature within the silo. However, it is recommended that the roof should be redesigned to adequately insulate the structure. Further work should also be based on a comparative evaluation of the silo’s performance with those constructed from other materials and other local storage techniques.

REFERENCES


