LATERAL GRAIN PRESSURES IN POLYETHYLENE CONTAINERS

INTRODUCTION

Many of the problems in transporting grain in bulk from the farmer's field to the processor could be reduced or eliminated by handling the grain in containers. Containers could be filled directly from the combine in the farmer's field thereby reducing the labour and equipment required during the busy harvest season. Weatherproof containers could be filled directly from the combine in the farmer's field thereby reducing the labour and equipment required during the busy harvest season. Weatherproof containers could be left in the field until they could be conveniently transported to a railroad and loaded on to railroad cars. Each container of grain could be graded according to protein content and equipment required during the busy harvest season. Weatherproof containers could be left in the field until they could be conveniently transported to a railroad and loaded on to railroad cars. Each container of grain could be graded according to protein content and quality factors before it was mixed with other grain. Also chemically treated grain and spoiled grain could be detected before it contaminated large bulks of grain in an elevator. Storage pests such as rusty grain beetles would be restricted to an individual container instead of being spread throughout a large quantity of grain as can occur under the present bulk handling system.

There is a need for increased storage space because of abandonment of many railroad lines, high grain yields, and variable markets. Weatherproof containers can be designed to act as grain storage units at any point in the transportation system. If the containers are made air-tight, insects cannot enter the containers, and insects already in the grain are inactivated due to the shortage of oxygen. It would not be necessary to treat the grain with insecticides, thus the cost of the treatment, as well as the risk of toxicity to humans and animals, would be reduced.

If the containers can be constructed from flexible plastic or synthetic rubber sheets, then the empty containers could be readily stowed or transported. Also containers made from such materials can be made air-tight and weatherproof providing rodent and mechanical damage are prevented. To design flexible containers, the distribution of grain pressures on the walls of the containers must be known. Information is available on the design of rigid bins in which the walls resist compressive loads, but no work has been done on grain pressures on walls which do not resist compression.

The lateral pressures exerted by hard red spring wheat on the walls of cylindrical polyethylene containers were determined and compared to those predicted by Janssen's equation. The effect of container diameter, wall thickness, and grain height on lateral pressure was investigated. A dimensional analysis equation was fitted to experimental data.

MATERIALS AND METHODS

Four sizes of test containers (Table I) were made from sheets of low density polyethylene (density 0.92g/cm³). Material thickness was chosen so that the circumferential elongation would be measurable but not excessive. The vertical joints in the walls were constructed by overlapping the sheets 15% of the container circumference and gluing (Swift Canada Company adhesive, no. 7813). The container walls and the circular sheet which formed the bottom of the container were overlapped 10% of the container diameter and glued.

Lateral pressures at different height-to-diameter ratios were determined in each container by loading the containers in layers. The 25-cm diameter containers were filled in layers with a depth-to-diameter ratio of 0.625 whereas the larger containers were filled in layers with a depth-to-diameter ratio of 0.33. Hard red spring wheat, variety Manitou, was used as load material (Table II).

Lateral pressures were calculated from measurements of the circumferential elongation. To reduce the restraining effect of the container bottom, measurements were taken at the top of the first grain layer augered into the container instead of at the bottom of the bin. The circumference was measured with a steel tape before each test was begun and 30 min after loading each grain layer. Percent circumferential elongation based on the original unstrained circumference was calculated. Measured elongations were corrected for the effect of the vertical glued joint. The amount of correction was determined by comparing elongations in polyethylene strips having glued joints to those in strips having no joints.

The stress-elongation characteristics of polyethylene are affected by many factors including material thickness, rate of loading, and temperature (2). Therefore, separate stress-elongation curves were plotted for each test container. To obtain data for the stress-elongation curves, 12 calibration strips, 5 cm wide, were made from the same material as the container. For each test container, three strips were subjected to tensile stresses corresponding to 50%, 75%, 100%, and 125% of the lateral pressures.
TABLE I. POLYETHYLENE TEST CONTAINERS

<table>
<thead>
<tr>
<th>Container diameter cm</th>
<th>Maximum grain height in containers cm</th>
<th>Material thickness mm</th>
<th>K’</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>63</td>
<td>0.04</td>
<td>0.0609</td>
</tr>
<tr>
<td>47</td>
<td>88</td>
<td>0.10</td>
<td>0.0543</td>
</tr>
<tr>
<td>67</td>
<td>105</td>
<td>0.15</td>
<td>0.0572</td>
</tr>
<tr>
<td>67</td>
<td>154</td>
<td>0.25</td>
<td>0.0572</td>
</tr>
<tr>
<td>90</td>
<td>147</td>
<td>0.25</td>
<td>0.0457</td>
</tr>
</tbody>
</table>

TABLE II. PHYSICAL PROPERTIES OF WHEAT(3)

<table>
<thead>
<tr>
<th>Property</th>
<th>Experimental value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>No. 1 Northern</td>
</tr>
<tr>
<td>Dockage, %</td>
<td>2.0</td>
</tr>
<tr>
<td>Moisture content, % wet weight basis</td>
<td>10.3</td>
</tr>
<tr>
<td>Density, kg/hl</td>
<td>88.2</td>
</tr>
<tr>
<td>Coefficient of friction on polyethylene</td>
<td>0.37</td>
</tr>
<tr>
<td>Ratio of lateral to vertical pressure</td>
<td>0.45</td>
</tr>
<tr>
<td>Angle of repose, deg.</td>
<td>21.7</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

As in rigid-walled bins (3), lateral pressure increases with grain height at a decreasing rate in grain containers with flexible walls (Figure 1). At a constant height, lateral pressure increased with container diameter in 25-cm, 47-cm, and 67-cm diameter containers but appeared to decrease in the 90-cm diameter containers (Figure 1). However, at a constant height-to-diameter ratio, lateral pressure increased nonlinearly with container diameter (Figures 2 to 5).

For the 67-cm diameter containers, lateral pressures in containers made from 0.25-mm and 0.15-mm thick polyethylene sheets were not significantly different at the 5% level. At a height-to-diameter ratio of 1.67, the circumferential elongation in the container made from 0.15-mm thick polyethylene was 72% greater than that in the container made from 0.25-mm polyethylene. This large difference in movement of the walls did not significantly affect the lateral pressure.

To compare the experimental results with those predicted by Janssen’s equation (1) properties of the wheat and polyethylene used were determined (Table II). Angle of repose, which is the angle of slope of the granular material under zero normal pressure, was measured to be 21.7°. Differences in kernel size, shape, and surface roughness between the varieties of wheat tested probably caused this value to be considerably less than the commonly used value of 28° (1, 3). This difference in measured angle of repose caused a difference in
Because the development of Janssen's equation for rigid bins is based on the assumption that the walls take some of the vertical load, it could be expected that the lateral pressures predicted by the equation would be different from those measured in a flexible walled container. Although this is true for all four sizes of containers tested (Figures 2 to 5), the differences are small except for the 25-cm diameter containers. However, if Janssen's equation is used to design these types of containers, an increased factor of safety should be added since Janssen's equation underestimates the lateral pressures in most of the containers tested. Also in applying Janssen's equation or any other equation the density of the material should not be under-estimated. The density of wheat increased with increasing height of fall up to at least 1.5 m and was greater in a flexible container than in a rigid container. Presumably the grain kernels were more readily reoriented in a flexible-walled container than in a rigid-walled container. For the calculations in this paper a density of 88.2 kg/hl was used. This was the density of the wheat when dropped 1.5 m into a polyethylene container. This density is about 18% greater than the normally used value for wheat of 74.8 kg/hl.

An equation was developed to fit the lateral grain pressures determined in the flexible containers. The functional relationship between lateral pressure and factors affecting it can be expressed as:

\[ L_p = f(w, h, D, \mu, \mu') \ldots (3) \]

where:
- \( i \) = functional notation,
- \( w \) = bulk density of grain,
- \( h \) = height of grain above the point under consideration,
- \( \mu \) = coefficient of internal friction,
- \( \mu' \) = coefficient of friction between wall and grain.

By assuming that the values of \( \mu \) and \( \mu' \) are constant for a particular combination of grain and container material, the following equation was obtained using a dimensional analysis procedure (2):

\[ L_p = K' w h l^n D^m \ldots \ldots \ldots (4) \]

The coefficients of the equation \( K' \) and \( n \) were determined by fitting the equation to the experimental data. A value of 0.45 was obtained for \( n \) for all containers. The value of \( K' \) varied


Figure 4 Lateral pressures in 67-cm diameter containers.

Figure 5 Lateral pressures in 90-cm diameter containers.

CONCLUSIONS

The following conclusions may be drawn regarding the lateral pressure of wheat in flexible polyethylene containers:

1. Janssen's equation does not accurately predict lateral pressures of wheat in flexible polyethylene containers.
2. For the test conditions used, an equation based on dimensional analysis closely represented lateral pressures in flexible polyethylene containers.
3. Lateral pressures were not significantly affected by a 60% change in thickness of the polyethylene walls of the containers.
4. Lateral pressures of wheat in flexible polyethylene containers increase non-linearly with grain depth and with container diameter.

SUMMARY

Many of the problems in the transporting and storing of grain in bulk could be reduced by handling grain in containers. The use of containers could reduce labour, grain deterioration, and the need for insecticides and could improve grading procedures and storage facilities. Lateral pressures exerted by hard red spring wheat on the walls of cylindrical polyethylene containers, varying in diameter from 25-cm to 90-cm, were calculated from measurements of the circumferential elongation of the containers. Stresses in container walls were determined by comparing the percent elongation in the containers to those in strips of polyethylene subjected to tensile loads. Lateral pressures were calculated from the indicated stresses in the walls. Janssen's equation did not accurately predict the lateral pressures but an equation based on dimensional analysis closely fit the data. Lateral pressures were not significantly affected by a 60% change in thickness of the polyethylene walls.
The containers did not fail by bursting but apparently became unstable when the percent elongation near the bottom reached a limiting value.

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REFERENCES