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Uniaxial Compression Tests for Agricultural Materials

Uniaxial compression tests are carried out in order to examine the mechanical and rheological properties of agricultural materials. A large area of application is the determination of the density properties of grass, straw, and cereals for ensilage or for storage as bulk materials in silos. The required compression pressure can be exerted as long-term static pressure or as an alternation of load application and -alleviation. During trials with impeded radial extension (compression vessel trials), one must take into consideration that vertical pressure is reduced from the surface to the bottom due to wall friction. If the chosen geometry is disadvantageous, this pressure reduction can be significant.

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For the following reasons, the knowledge of storage density is particularly important:

- Storage density is decisive for pressure in containers.
- In material laws for the calculation of flow rates and stress for bulk materials in silos, parameters of elasticity and compression must be known.
- For the calculation of pressure losses during ventilation, knowledge of storage density is absolutely necessary.
- During the compression of silage, known minimum values must be observed during storage. Inadequate density results in losses and insufficient silage quality.

Experiments

Experimental Set-Up

A compression vessel with impeded radial extension is suitable for the determination of the compression properties (*Fig. 1*). In the present case, the area is 200 cm^2. The lowering of the piston is measured with the aid of a potentiometer (a), which is connected to the reverse roller (b) for the balance weight (c). In principle, however, this measurement can also be carried out using other physical methods. Due to wall friction, vertical pressure in the material horizons decreases towards the bottom of the container. Therefore, mean vertical pressure (p) must be calculated. The pressure conditions in the filling material assumed in these calculations are based on balance considerations in a differential layer. If the coordinate of mean vertical pressure p_v is termed z_0, this results in the following relation:

$$p_v = \frac{p_{v0}}{e^{k \cdot z_0 \cdot U / A}} \qquad (1)$$

with:

p_v = mean vertical pressure in the compression vessel

p_{v0} = vertical pressure at the surface

k = pressure ratio $k = \lambda \cdot \mu$

λ = horizontal pressure ratio

μ = friction coefficient of the material and the interior wall

U = circumference of the compression vessel

A = cross-sectional area of the compression vessel

Since the course of pressure in the area to be considered is approximately linear, one can

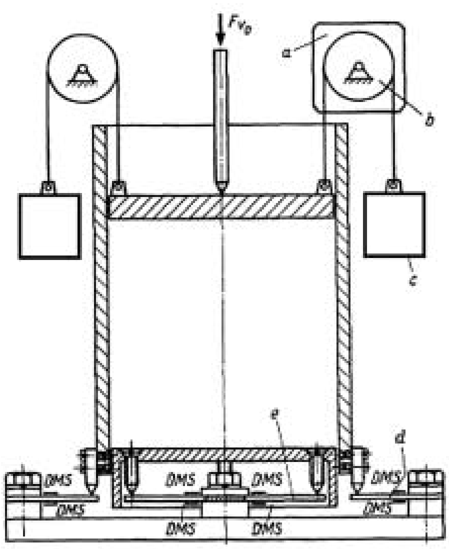

Fig. 1: Compression vessel for uniaxial compression tests

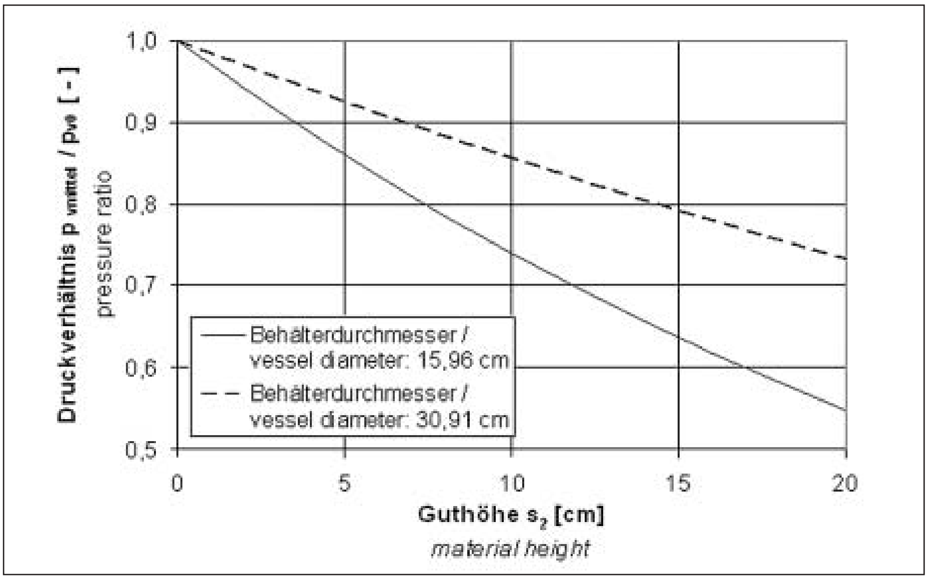

Fig. 2: Ratio of a middle vertical pressure to piston pressure depending ofn material height (μ = 0.6, λ= 0.4)

assume that in equation (1) $z_0 = s_2/2$. Under these conditions, mean vertical pressure p_v is determined by the following equation:

$$p_v = \frac{p_{vo}}{e^{k \cdot s_2 \cdot U/(2A)}} \qquad (2)$$

with s_2 = height of the compressed material in the compression vessel

The pressure ratio k is determined based on the measured values of piston pressure, bottom pressure, area, circumference, and material height in the compression vessel according to the following equation:

$$k = \frac{\ln(p_{vo}/p_b) \cdot A}{s_2 \cdot U} \qquad (3)$$

If the values of the horizontal pressure ratio λ and the wall friction coefficient μ are known, another possibility is the calculation of k based on the multiplication of these values (see the legend of equation 1). In the experiment (*Fig. 1*), bottom pressure and wall friction pressure are determined based on the relevant forces, which are measured with the aid of strain gauges (SG) on the cantilever beams (d) and (e). Equation (2) is based on the assumption that piston pressure p_{V0}= decreases linearly over the filling material height to bottom pressure p_B.

Consideration of Errors

In uniaxial compression tests, often only surface pressure p_{V0} is measured. However, this is only permissible if bottom pressure p_0 is slightly smaller and the error can thus be neglected. This primarily depends on the compression vessel diameter d, the horizontal pressure ratio λ, and the wall friction coefficient μ (*Fig. 2*). If, for example, an error of 5% were permitted between piston pressure and mean pressure, the height of the compressed material could only be 2 cm if the compression vessel has a diameter of 15.96 cm, which corresponds to an area of 200 cm^2 (*Fig. 2*). In a larger compression vessel with a diameter of 30.91 cm, which corresponds to 750 cm^2, material height could be 4 cm.

Realization of the Experiments

The compression vessel must be filled carefully and evenly. If one intends to calculate density over long storage periods in silos, the creep function $\rho_L = f(p_{V0,} t)$ must be measured in retardation tests, i.e. under statically acting pressure, during appropriately long storage times t, and at different vertical piston pressures p_{V0}. If the compression processes caused by tractors during ensilage are intended to be simulated, cyclical tests with alternating phases of load application and -alleviation must be carried out. Load application corresponds to the silage surface being rolled over and takes place within the range of one second. The phase of load alleviation should be chosen realistically and should last at least 5 minutes.

Results

Retardation Experiments

For the storage density of pre-wilted silage under static loads, the following compression function applies [1]:

$$\rho_L = C\, p_v^m + \rho_{Sch} \qquad (4)$$

with:

ρ_{bd} = bulk density
C = compression factor
M = exponent (= 0.5).

The compression factor C includes the influences of material density, the dry matter content, the resistance to bending of the leaves and stems, as well as the compression time. The experiments provide regression equations for the maximum and minimum range of the compression factor as a function of the storage time t and the dry matter content DM:

$$C_{max} = 280.3 + 43.86 \ln(t) + 31.86\, TM - 0.486\, TM^2 \qquad (5)$$

Determinateness D = 0.99

$$C_{min} = 684.4 + 21.93 \ln(t) - 0.081\, TM^2 \qquad (6)$$

Determinateness D = 0.96

Vertical pressure has the greatest influence on storage density, followed by storage duration, the dry matter content, and resistance to bending.

Experiments with Cyclical Load Application and -Alleviation

For the lasting deformation ε_{bl} of freshly cut meadow grass with a chopping length of l_H = 40 mm and a dry matter content of DM = 16 %, the following equation was determined as a function of vertical pressure p_V and the holding time t_H of the vertical pressure [2]:

$$\varepsilon_{bl} = 0.345 + 0.11\, p_v + 0.022\, p_v \lg(t_H - 1) \qquad (7)$$

Determinateness D = 0.838

Scope of application: p_V = 0.1 … 1.0 bar
t_H = 1.2 … 1,200 s

Here, vertical pressure has the greatest influence.

Summary

During uniaxial compression tests, pressure in the pressure vessel must be taken into consideration. In order to avoid systematic errors, average vertical pressure must be calculated precisely, or one must work with lower filling heights if small errors are tolerated.

Literatur

[1] *Fürll, Ch., et al.*: Einflüsse durch das Verdichten und den äußeren Luftabschluss auf die Qualität von Grassilagen – Ergebnisse und Anforderungen. Agrartechnische Forschung 12 (2006), S. 19-29

[2] *Herold, B.*: Rheologische Untersuchungen an Grashäcksel. Agrartechnik 20 (1970), H. 10, S. 475-476