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Determining external friction angle of barley malt and malt crush

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Abstract. This paper deals with determining the amount of external friction angle of barley malt and malt crush depending on the load size. Barley malt is a basic raw material for production of the traditional Czech Pilsner type of beer. The angle of internal and external friction is one of the basic parameters of bulk materials. Friction among individual grains of material, i.e. a connection with the forces, applied between individual material particles, includes the internal friction angle. Conversely, the external friction angle is the angle in which the bulk material begins to move on the other material (steel). A two-roll mill (or disc mill and hammer mill) was used for the malt crush manufacture, which is used in the traditional malt processing in beer production. During crushing on this machine, we used the passage of the milled material through a gap between two counter-rotating cylinders. The results of barley malt and malt crush external friction angle, depending on the load size of the barley malt and the malt crush on mobile prototype device, are from 8 to 22°. The mobile prototype device is based on the following principle: a square chamber filled with a loaded material moves on the pad (steel).

Key words: barley malt, external friction angle, food industry, particulate matter.

INTRODUCTION

The light malt is a product made from barley, after four- to five- week ripening in containers. The germinating process is interrupted by drying the malt and kilning to prevent further transformation and losses. To do this, one aims for the following: The water content is lowered from over 40.0% to less than 5.0% to make the malt more storable and to increase its preservability. With the lowering of the water content, all life processes in the malt such as germination and modification as well as further enzymic activity are stopped. In contrast, the enzymatic potential forrned should be completely retained. Great attention must be paid to the formation or avoidance of colour and flavour compounds corresponding to the type of beer to be produced from the malt during this process. The rootlets are cut off and removed. Based on the targets set, the following occur: The water content is lowered. Germination and modification are stopped. Colour and flavour compounds are formed.

To make the malt storable, the water content mu st be decreased from over 40.0% to 4.0 to 5.0%. Water removal is effected by passing a large amount of hot air through the green malt. When heating the moist green malt during kilning, care must be taken not to destroy the enzymes by wet heat - they withstand dry heat much better. Because the enzyme s are needed to break down substrates in the brewhouse it is important to protect the enzymes to a large extent. To protect the enzymes the malt mu st first be predried before it is subjected to high tem peratures. The moist starch in the green malt gelatinises at high temperatures and after cooling the malt is no longer suitable for use. Its inside has a steely appearance (vitreous malt).

On heating whilst the starch is wet, unusable vitreous steely malt is formed. The temperature must only be raised above 50.0 °C when the water content has been decreased to 10.0 to 12.0%. The slow lowering of the water content at temperatures of 40.0 to 50.0 °C is known as stewing. Long stewing times at low temperatures have a favourable effect on the flavour stability of the beer (Basařová, 2010; Kunze, 2010).

The storage and the transport require knowledge of the basic parameters of the processed materials, ie. bulk materials (Smejtková et al., 2016). Among basic properties of the bulk materials, wjich are undoubtedly malt barley and malt crush, are: density, bulk density, internal friction angle, external friction angle (Arias Barreto et al., 2013; Chotěborský & Linda, 2014; Bogdan & Kordialik-Bogacka, 2017).

The aim of this paper is a determination of selected physical parameters of colored and light malt, i.e. angle of external friction angle and determination of tension limits (Afzalinia & Roberge, 2007; Boac et al., 2010; Gil et al., 2013; Khatchatourian & Binelo, 2008; Silva, L.C. et al., 2012).

MATERIAL AND METHODS

Before the actual determination of tension limits of the barley malt and the malt crush, depending on the material of storage area, the moisture content of the processed materials was defined.

The water content slowly increases during storage to 4.0 to 5.0%. This results in physical and chemical changes in the endosperm which make further processing easier. Freshly kilned malt if used immediately can cause lautering and fermentation difficulties. Malt is therefore stored at least 4 weeks in silos or stores. Since most of the seedlings are no longer alive and respiration in the com would only cause undesirable losses, the malt silo is not ventilated. A precondition for proper storage is that the malt does not become moist because it is hygroscopic. Moist air therefore has to be kept away. The malt which is to be stored has to be well cleaned, cold and dry. In silo storage, because of the smaller surface area, the risk of water uptake is lower than when storing in malt stores. In malt stores the malt layer is about 3 m high. Previously this was often covered by a layer of germs which absorbed the moisture and consequently prevented water uptake by the malt (Kosař & Procházka, 2000; Dendy & Dobraszczyk, 2001; Kunze, 2010).

Knowledge of the moisture content is necessary to ensure optimal conditions for further experiments (Fourar-Belaifa et al., 2011; Hammami et al., 2017). Determining the moisture content of the assessed barley malt was implemented using a moisture analyzer OHAUS MB25 (Table 1 and Fig. 1). The OHAUS MB25 provides precise moisture content determination at value. With a large backlit LCD display, standard RS232 port, 110.0 g capacity with a readability of 0.005 g/0.05% and halogen heating, the OHAUS MB25 offers moisture analysis.

Sieve analysis of grist. For the determination of crushed malt dispersity, a test sieve shaker (sieve analyzer) HAVER EML 200 digital plus T (Table 2 and Fig. 2).

Figure 1. Moisture analyzer OHAUS MB 25 (Source: https://asiapacific.ohaus.com/en-AP/Products/Balances-Scales/Moisture-Analyzers/MB25/MB25).

Table 1. Technical parameters of Moisture analyzer OHAUS MB 25

Maximum capacity	(g)	110.0
Readability moisture content	(mg / %)	5.0 / 0.05
Pan size	(mm)	90.0
Heater type	(-)	Halogen lamp
Communication	(-)	RS232 (Included)
Dimensions (h x l x w)	(mm)	127.0 x 280.0 x 165.0
Display	(-)	LCD, backlight
In-use cover	(-)	Included
Net weight	(kg)	2.1
Power	(-)	AC power (included)
Shut-off criteria	(-)	Automatic - preset weight loss/time; timed; manual
Temperature range	(°C)	50.0–160.0
Units of measurement	(g)	Gram
Working environment	(°C)	10.0–40.0

Table 2. Technical parameters of test sieve shaker HAVER EML 200 digital plus T

Sieve diameters	(mm)	76.0, 100.0, 150.0, 200.0, 203.0
Sample weight	(kg)	approx. 3.0
Weight of sieve set	(kg)	max. 8.7
Amplitude	(mm)	max. 3.0
Sound emission	(dBA)	≤ 70.0 dBA
Weight (without test sieves)	(kg)	approx. 34.0
Dimensions (h x l x w)	(mm)	345.0×285.0×950.0

Figure 2. Test sieve shaker HAVER EML 200 digital plus T (Source: https://www.haverparticleanalysis.com/en/sieve-analysis/haver-test-sieve-shakers/haver-eml-200-pure/)

The results of the moisture content establishing of the individual samples of processed raw materials are shown in Table 3. Selected mechanical and physical parameters (density, volume weight, friction angle) of the colored and light barley malt and the malt crush are in (Vaculík et al., 2013; Hromasova et al., 2018; Chladek et al., 2018). Grain size was determined by network analysis (Table 3).

Table 3. The results of the moisture content establishing (Hromasova et al., 2018).

Light barley malt		Humidity (%)	Colored barley malt	
Whole grain	Crushed grain		Whole grain	Crushed grain
1.904 ± 0.014	1.997 ± 0.127		1.877 ± 0.073	1.983 ± 0.097
		Size (mm)		
3.6 ± 0.11	0.91 ± 0.155		3.48 ± 0.131	1.05 ± 0.133

The following methods is aimed at determining external friction angle of barley malt and malt crush. Angle of external friction - the angle between the abscissa and the tangent of the curve representing the relationship of shearing resistance to normal stress acting between material and the surface of material of storage area (also known as angle of wall friction) (Fig. 3).

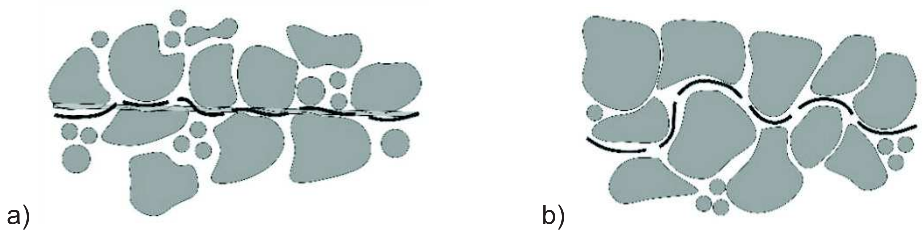

Figure 3. The shear area in material: a) the shear area in material – idealized; b) the shear area in material – realistic.

For the incoherent bulk materials, the maximum tangential stress is dependent. τmax in areas of normal tension σ described by (Feynman et al., 2011, Hromasova et al., 2018).

For the cohesive bulk materials, the ratios are more complex and the characteristic is described by (Maloun, 2001; ČSN ISO TS 17892-10; Feynman et al., 2011; Hromasova et al., 2018).

Particle substance parameter measurements were performed on the device (Fig. 4).

When determing of limit tensions in relation to a load size of the barley malt and the malt crush on the prototype device, which was adapted to measure the properties of bulk materials. The measurement procedure is as follows (Fig. 4):

- using a electric motor 1, the upper square chamber 2 (area of the chamber is 8,100 mm^2) slides down the steel plate 3;
- in between chamber 2 and steel plate 3 is the particular material stressed by tangential force T (N);
- normal force N (N), exerted by the weight 5 acting on the malt through the loading plate 6 (weight of the load plate was 219.68 g);
- load weights were used for loading 1,000; 2,000; 3,000; 4,000 and 5,000 g;

- depending on the size of the deformation, the force can be determined *T* (N) (Hromasova et al., 2018).

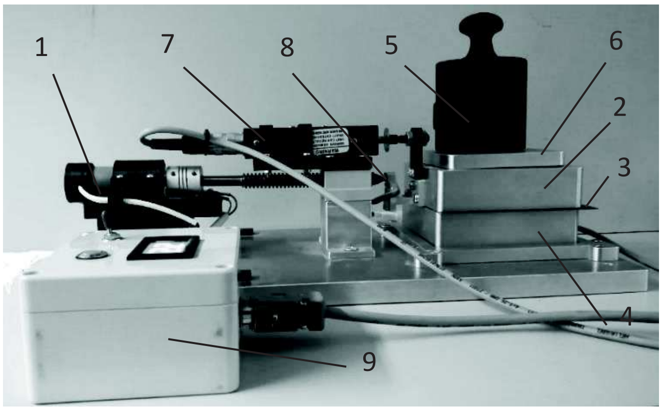

Figure 4. Device for measuring shear cohesion and friction properties of bulk materials (Evolution 2). Annotations: 1 – electric motor; 2 – the upper square chamber - movable; 3 – steel plate; 4 – the dividing gap between the chambers; 5 – weight; 6 – loading plate; 7 – shift sensor; 8 – deformational component with strain gauges for measurement of the force; 9 – control device. The device is complemented with measuring electronics and evaluation software.

The strain gauges were silicon resistance type AP130-3-12/SP/Au. The data are given in Table 4 for used strain gauges.

Table 4. Parameters on strain gauges

Parameters	Type
Type A (-)	layout without pad
Type P (-)	positive deformation sensitivity
Value of multiplier of deformation sensitivity (-)	130.0
Lenght (mm)	3.0
End shape of silicon part of strain gauges (-)	SP
Material for outlets (-)	gold

In Eq. 1 is calculated dependence of strain gauge resistance on deformation. The constants C_1, C_2 are calculated from the resistance changes of the strain gauges stick to with cyanoacrylate adhesive glue. The coefficients are given in Table 5.

$$R_{\varepsilon,25} = R_{0.25}(1 + C_1\varepsilon + C_2\varepsilon^2) \tag{1}$$

where $R_{0,25}$ – electrical resistance of the free strain gauge (Ω); $R_{\varepsilon,25}$ – electrical resistance of the strain gauge deformed at a constant temperature of 25 °C (Ω); C_1 – linear coefficient of deformation equation (-); C_2 – quadratic coefficient of deformation equation (-); ε – ratio of deformation (m).

Table 5. The coefficients for strain gauges

Coefficients	Value
$R_{0,25}$ (Ω ±%)	119.4 Ω ± 0.24
C_1 (- ±%)	127.3 ± 2.00%
C_2 (- ±%)	5,101 ± 8.00%
A (%.°C^{-1})	0.0932 ± 0.38%
B (%.°C^{-1})	-0.18

RESULTS AND DISCUSSION

In the following figures (Fig. 5 to 8) are shown the courses of the limit tensions (Table 6) for the barley malt and malt crush in relation to the load size 1,000 and 5,000 g. The point charts were chosen because it is measured for each sample at least 2,000 values.

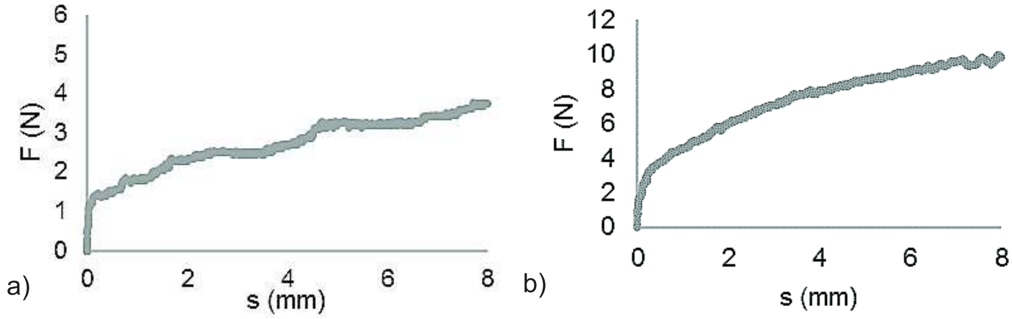

Figure 5. The graph of force dependence on the displacement for light barley malt – crushed grain – a) load 1,000 g, b) load 5,000 g.

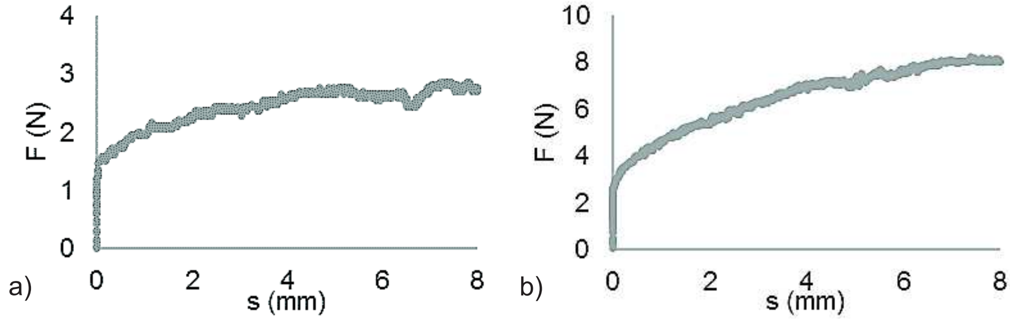

Figure 6. The graph of force dependence on the displacement for light barley malt – whole grain – a) load 1,000 g, b) load 5,000 g.

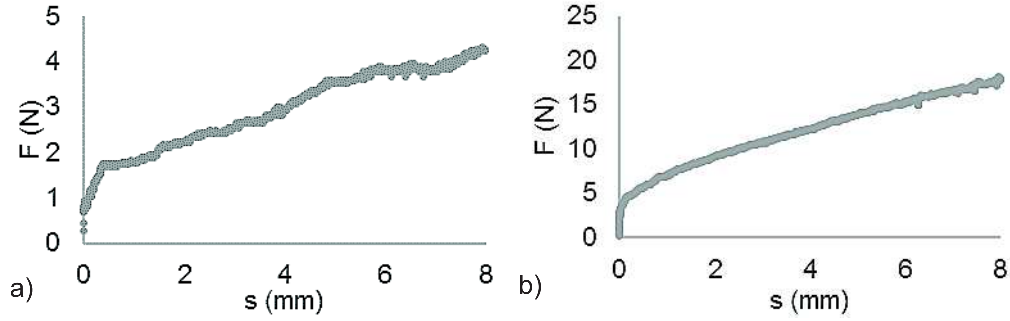

Figure 7. The graph of force dependence on the displacement for colored barley malt – crushed grain – a) load 1,000 g, b) load 5,000 g.

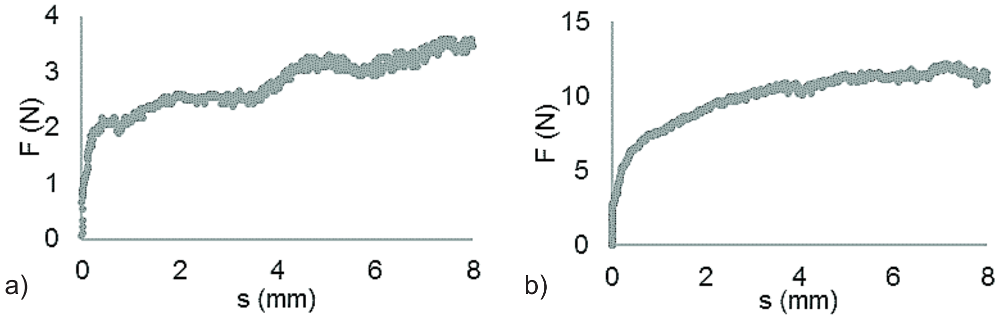

Figure 8. The graph of force dependence on the displacement for colored barley malt – whole grain – a) load 1,000 g, b) load 5,000 g.

The Table 6 shows limit tension, which is maximal fore of tension at 8 mm displacement. For the crushed malt it is necessary to provide greater force of at least 22% compared with the whole grain (light barley malt). For the crushed malt it is necessary to provide greater force of at least 19% compared with the whole grain (colored barley malt).

Table 6. The results of the limit tension

	Limit tension (N)			
	Light barley malt		Colored barley malt	
Loading mass (g)	Whole grain	Crushed grain	Whole grain	Crushed grain
1,000	2.87	5.03	3.57	4.38
2,000	4.44	6.14	5.25	6.71
3,000	6.28	7.85	6.82	10.66
4,000	7.20	8.93	10.23	14.04
5,000	8.61	11.31	12.18	19.81

The external friction angle (Table 7) of the whole grain light barley malt is less by 4.71° than the colored malt; the crushed colored barley malt is lower by 13.26° than the colored malt. The external friction angle by steel is from 6% to 17% (Kovalyshyn et al., 2014) for different particular material. The external friction angle of the barley is from 13.77 to 33.50° (Kaliniewicz, 2013) when humidity at 12.6%. The external friction angle of the barley is from 15.66 to 38.05° (Kaliniewicz et al., 2018) when humidity at 10.2%.

Table 7. The external friction angle

External friction angle (°)			
Light barley malt		Colored barley malt	
Whole grain	Crushed grain	Whole grain	Crushed grain
8.19	8.31	12.90	21.57

CONCLUSION

By optimizing the angle of inclination of the hopper and the outer friction angle parameter at the inner wall can be achieved that the material flows through the entire cross section. To ensure mass flow in the magazine, the following applies: The smaller external friction angle and the smaller inclination angle of the hopper mean better flow properties of the material in the container.

Based on knowledge of the parameters of individual substances (eg limiting force, angles of internal and external friction) we can calculations of storage and manipulation devices. All results can be used for DEM modeling in warehouse management.

Measured values correspond with the results published in article 'Mathematical-model of filtration process in beer production' (Chládek, 1977), 'Impact of malt granulometry on lauter proces' (Chládek et al., 2013), 'Pivovarnictví (Brewing)' (Chládek, 2007) and 'Pivovarství: teorie a praxe výroby piva' (Basařová, 2010) and others.

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