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Research Paper

Bulk properties of densified hop cones related to storage and throughput measurements

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Hop is one of the most important materials for beer production. Nevertheless the material density of hop is little known even though this information is needed for the harvesting, processing and storage of the hop cones. To fill this gap in knowledge, densification experiments were carried out during 2013 harvesting season with wet and dry hop cones of different varieties. It was shown that for hop cones of all varieties in dry state that pressure increased with increasing material density. In a wet state, Sladek and Vital varieties showed different behaviour. Higher initial densities meant greater hardness of those two varieties. The densification process caused significant increase in the densification curve slope at the initial and final points. The initial slope was very high for the Sladek and Vital varieties in a wet state. Resulting pressure values were statistically different for most of the tested varieties. The differences in densification parameters were in all cases transferred from the wet to dry states. Differences found between varieties can significantly influence hop material throughput during harvesting as well as the behaviour of hop cones during post-harvest processing and storage.

1. Introduction

Hop (*Humulus lupulus* L.) cones are the most important raw material for beer production due to their bitter taste, which is decisive in the final taste of beer (Rybáček, 1991). From a brewing point of view, hops are the dried hop cones of the female hop plant (Kunze, 2010). According to information from Food and Agriculture Organization of the United Nations (FAO) published in 2011, the total quantity of hops harvested worldwide was about 94,000 tonnes from an area of about 50,000 ha (http://faostat.fao.org). The global annual demand is for approximately 100,000 tonnes of dried hops (Kunze, 2010).

The high labour requirements of manual hop picking have led to the introduction of mechanised picking. For example, as long ago as 1972, 92% of the total area of hops grown in Czechoslovakia was harvested mechanically. Nevertheless, right from the beginning of its development, the mechanisation of hop picking has brought many problems related to efficiency and quality of work of the picking machines (Rybáček, 1991).

Historically, two basic mechanisms have been used for picking hop cones: drums and conveyers. However, nowadays

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Nomenclature

a	parameter of Eq. (2), Pa
A	parameter of Eq. (4), Pa^{-1}
b	parameter of Eq. (2), Pa
c	parameter of Eq. (2), Pa
k	parameter of Eq. (4), dimensionless
p	external pressure, Pa
p_1	external pressure at $x = 1$, Pa
$[p]$	reciprocal slope transformation of p, Pa^{-1}
PSCH 325	bend drier (producer: Vzduchotechnika Nové Mesto n./Váhom, Slovak Republic)
PT-30	hop picking machine (producer: Chmelařství, družstvo Žatec, Czech Republic)
S_0	initial slope of p–x relation, Pa
S_1	slope of p–x plot at $x = 1$, Pa
ρ	density of hop layer in the cylinder, kg m^{-3}
ρ_0	initial density of hop layer in the cylinder, kg m^{-3}
x	relative change of hop density – see Eq. (1), dimensionless

the conveyer system has become the more popular (Kumhála, Kavka, & Prošek, 2013). In the Czech Republic, stationary hop picking machines are preferred (Podsedník, 2001). Rybáček (1991) highlighted that macroscopic injuries of hop cones primarily depend on the standard of the picking and harvesting equipment and the hop variety while the technology of post-harvest treatment depends on other characteristics, the most important of which are the moisture content of the picked hop and the density of the fresh hop.

During measurement of the throughput of a stationary hop picking machine Kumhála et al. (2013) raised the problem of how to characterise as a source of signal for stationary hop picking machine control (Kumhála et al., 2013) raised a problem how to characterise differences in physical properties of harvested material. These differences may, with others, affect the accuracy of measuring throughput.

According to Kunze (2010), the number of breweries using hop cones is continually decreasing due to introduction of other hop products. On global basis, the following proportions of hop products are processed: natural hop cones (15–20%), hop pellets (40–45%), hop extracts (30%) and isomerised hop products (10%). According to the World Food Logistic Organization, a natural hop is supplied in either normal-compressed or double-compressed hop bales (http://gcca.sononaco.net/wp-content/uploads/2012/09/Hops.pdf).

It is therefore clear that physical properties of hop cones are important for post-harvest treatment (hop cone packaging, storage or pelleting) and hop picking machine throughput control point of view and that material density is an important physical property alongside moisture content. However, knowledge of hop cone density and its relationship with moisture content, variety and the action of external forces is almost unknown although it forms a significant part of the information needed for the harvesting, processing and storage of hop cones.

The density of biomass is an important parameter for technologies that are termed “densification” (Adapa, Tabil, & Schoenau, 2009; Tumuluru, Wright, Kenny, & Hess, 2010) which are widely applied in biomass fuel industry. For a deeper understanding of the densification process and the development of more effective presses some simple theory of the densification process is required. Present theories have their sources in the consolidation theories that were applied either to soils (Taylor, 1966) or powder metallurgy and ceramics (Balshin, 1972).

Compression densification can be easily described by simple models that are based on simplified analysis of the processes that accompany the pressing of particles inside compressed materials. They are usually represented by functions expressing the relationship between external pressure (axial in the simplest cases) and density (or some other parameter describing material porosity). Adapa et al. (2009) gave eight different equations of this type. In most practical cases formulae suitable for the description of the real data can be found (Talebi, Tabil, Opoku, & Shaw, 2011). Two simplest relationships are frequently used and have been found to be useful in many cases. They are both based on the Balshin's Laws (Balshin, 1972): the first of Balshin's Laws describes an exponential relationship between pressure and density whilst the second of Balshin's laws describes a power relationship between the same parameters. The First Balshin Law is also known as the Walker model (Walker, 1923) and the Second Balshin Law is frequently used to describe straw compression where it is known as Skalweit's Law (Blahovec & Kubát, 1987; Matthies & Busse, 1966).

Information on hop pressing is therefore missing from the literature, despite it being important for harvesting (picked material throughput control) and for the following stages of hop processing (drying and storage). Thus, the aim of this paper is to fill this gap in knowledge for the harvesting, drying and processing of hop cones taking into account different hop varieties and harvest fractions.

2. Material and methods

All densification experiments were performed during the 2013 hop harvesting season using a stationary hop harvesting line equipped with a PT-30 picking machine (Chmelařství družstvo Žatec, CR), and a PSCH 325 band drier (Vzduchotechnika Nove Mesto nad Vahom, SK). The harvesting line belonged to Hop Research Institute Co., Ltd., Saaz, Czech Republic and is located at hop growing farm Stekník. This company was chosen because it grows the largest number of hop varieties in the Czech Republic.

Two different types of hop cone were tested, wet hop cones coming from the picking machine and dry hop cones coming from the band drier. The moisture content of the material was determined by ASABE Standard S358.2 (oven drying at 103 °C for 24 h), in all cases it was expressed as an average from three samples. Table 1 gives an overview of the tested hop cones types, varieties and their moisture content (wet basis).

A 342 mm long cylindrical box with 246.7 mm in diameter, made from stainless steel with plywood base, was used for densification measurement. At start of each measurement, the cylinder was carefully filled with tested material and closed using a 10 mm thick plywood piston with 236 mm in