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Energy analysis in the screw pressing of whole and dehulled flaxseed

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Abstract

Specific Mechanical Energy (SME) is an important parameter of screw press design and performance. Analysis of SME and its dissipation will improve our understanding of temperature increase during screw pressing, and will in turn lead to better protection of heat sensitive materials, such as alpha-linolenic acid in flaxseed oil. SME, net enthalpy change, and heat loss were estimated from steady state data for screw pressing whole flaxseed and flaxseed with different fraction of hull removal (FHR). The decrease of moisture content and FHR all resulted in significant increases of both oil and meal temperature and net enthalpy change. Conduction dissipated up to half of the mechanical energy input, while convection was low. SME increased significantly from 81.1 to 104.7 kJ/kg when the moisture content of whole flaxseed decreased from 12.6% to 6.3%. SME when pressing whole flaxseed was significantly higher than when pressing dehulled flaxseed.

Keywords: Conduction; Convection; Dehulling; Enthalpy; Flaxseed oil; Moisture content; Oil recovery; Screw press; Specific mechanical energy

1. Introduction

Mechanical pressing and solvent extraction with a petroleum distillate such as n-hexane are commonly used in commercial oil extraction. The organic food industry allows mechanical pressing but not solvent extraction as usually performed (USDA, 2000). Screw pressing is a simple, flexible, safe and continuous mechanical pressing procedure (Singh & Bargale, 2000).

Flaxseed (*Linum usitatissimum*) has exceptionally high content of alpha-linolenic acid (ALA) among established oilseeds in North America. ALA is classified as an omega-3 fatty acid, and Simopoulos (1999) concluded that omega-3 fatty acids have anti-inflammatory, anti-thrombotic, and anti-arrhythmic properties. Omega-3 fatty acids are sensitive to heat, oxygen, and light, thus flaxseed oil is usually cold pressed from whole seed. In order to stabilize the omega-3 fatty acids, process temperature should be as low as possible. All forms of excess heating should be avoided (Shukla, 2003). The friction within the barrel generates heat, and hence raises oil temperature, so a cooling mechanism is important and is common on large screw press. Flaxseed can be dehulled to yield hull as a concentrated lignan source; the remaining embryo is a richer source of ALA. Kurzer, Slavin, and Adlercreutz (1995) stated that lignans had an anti-cancer effect, especially against breast and colon cancer.

The moisture content of oilseeds influences the screw press performance (Fils, 2000; Singh & Bargale, 1990, 2000; Singh, Wiesenborn, Tostenson, & Kangas, 2002; Wiesenborn, Doddapaneni, Tostenson, & Kangas, 2001). Low moisture content typically resulted in better oil yield, but also elevated oil temperature the most. The high oil temperature may promote oxidation in flaxseed oil and disallow a 'cold-pressed' claim for the product (Zheng, Wiesenborn, Tostenson, & Kangas, 2003). The hull in the whole flaxseed can aid the flow of the seed, but increase the friction inside barrel. Therefore, dehulling can reduce the heat produced by friction in the screw press, in addition to the health benefit of flaxseed hull mentioned earlier. However, dehulled flaxseed is challenging to press because of the low fiber content and the high oil content. We recently described a method for pressing dehulled flaxseed with 15% less oil recovery than from whole flaxseed, but with a doubling of oil

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Nomenclature

FHR	Fraction of hull removed (%)
A	heat transfer area (m^2)
c_p	specific heat (J/g K)
D	diameter (m)
h	convection heat transfer coefficient (W/m^2 °C)
k	thermal conductivity (W/m °C)
l	axial position with respect to feed end of press barrel (m)
m	mass fraction
M	mass flow rate (g/s)
Q	heat loss (J/s)
T	temperature (°C)
W	energy input of the screw (J/s)
x	oil content (%)

Subscripts

a	ash
b	press barrel
c	carbohydrate
d	conductive
e	pure embryo
f	fat
h	pure hull
he	press head
hs	hot surface
l	dehulled flaxseed embryo
m	meal
o	oil
p	protein
r	reference
ra	radiation
s	raw material
sh	screw
t	water
v	convective
w	whole flaxseed

production rate. Furthermore, the oil and meal temperatures from pressing dehulled flaxseed were an average of 20 °C lower than those from whole flaxseed (Zheng et al., 2003).

Viscous dissipation of the mechanical energy into heat inside the material is the major source of energy transformation inside the twin-screw extruder (Godavarti & Karwe, 1997). Specific mechanical energy (SME) is a commonly used parameter with the extrusion operations, and is the net mechanical energy input divided by mass flow rate (Mercier, Linko, & Harper, 1989). Mechanical energy input into the materials during screw pressing is also important in the design of the screw press (Singh & Bargale, 2000) and the modeling of the screw press operation (Omobuwajo, Ige, & Ajayi, 1997). If measured indirectly through measuring the electrical energy input, the efficiency of the motor should be taken into account (Singh & Bargale, 2000), but efficiency data are often not available. Direct measure by torque and rotational speed requires an accurate screw torque meter that is expensive. Calculating mechanical energy input from a thermal energy balance appeared to be a simple, inexpensive alternative. Analysis of mechanical energy input and its dissipation will also help understand the phenomenon of oil temperature increase during screw pressing.

Therefore, the objective of this research was to quantify mechanical energy input through the calculation of heat loss and enthalpy change of the materials, and to study the influence of fraction of hull removal and moisture content on oil recovery, oil and meal temperature, heat loss, enthalpy change, and SME.

2. Materials and methods

2.1. Materials and pretreatment

A golden-yellow Omega flaxseed from Reimer's Seed Farm (Carrington, ND) was used for this research. Seeds were stored at 5 °C, and equilibrated overnight in sealed plastic bags to room temperature before use.

Flaxseed was dehulled by a model VSH-8088 Huller (Codema, Inc., Maple Grove, MN). Fines were removed using a sifter, and the embryo fraction was obtained using a gravity table (Zheng et al., 2003). Moisture content of raw seed was increased by sprinkling a calculated quantity of distilled water, and was decreased by keeping in a hot air oven at less than 50 °C. The conditioned raw seed was stored in a closed polyethylene bag for more than 5 d for equilibration at 5 °C (Zheng et al., 2003).

2.2. Pressing and temperature collecting

A Komet screw press (Model S 87G, IBG Monforts Gmbh & Co., Monchengladbach, Germany) was used to press the flaxseed in one pass. Samples were fed from the hopper to the press on demand by gravity. The length of the press barrel was 95.8 mm and the constant inside diameter of the press barrel was 75.1 mm (Fig. 1). The length of the screw was 198.3 mm and the constant outside diameter of the screw was 53.7 mm. An R8 screw was used to press whole flaxseed. An R11 screw was used to press dehulled flaxseed embryo. The flight helix angle (as a measure of pitch) and flight-to-flight