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To cite this article: R. Liu *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **81** 012185

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# Calculation of equivalent friction coefficient for castor seed by single screw press

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**Abstract:** Based on the traction angle and transportation rate equation, castor beans were pressed by application of single screw under different cake diameter and different screw speed. The results showed that the greater the cake diameter and screw rotation speed, the greater the actual transmission rate was. The equivalent friction coefficient was defined and calculated as 0.4136, and the friction coefficients between press material and screw, bar cage were less than the equivalent friction coefficient value.

## 1 Introduction

Castor is one kind of Euphorbiaceae oil crops, the oil content of its seeds is high, the oil contains about 90% of the hydroxy fatty acids [9], the unique molecular structure of this fatty acid determines the castor is an importantly industrial oil crops, which is known as a eco-friendly and renewable oil resource [8] [9]. In addition, the fatty acid is the best vegetable oil which can replace oil production of chemical raw materials, the best vegetable oil. Because it has high economic value and ecological benefits, thereby having a huge market demand [8].

The preparation methods of castor oil are mechanical pressing and solvent leaching [1]. Without chemical treatment, the product by mechanical press method has good oil quality and light color [6]. When producing oil by castor seed, the oil enters the screw groove in the form of a curl [3] [4]. In the process of forward delivery, the particles are gradually compacted with the pressure increasing, after being compacted to a certain extent, the non-plug fluid is converted into a plug fluid [5] [7].

At present, the theoretical study of the screw oil press machine is mainly based on the theory of friction drag transport. But there are not any reported study of the friction coefficient between the machine and the material [3] [13]. This study has carried out this work in order to provide theoretical support for the process of castor oil pressing.

## 2 Materials and Methods

### 2.1 Materials

The castor (XPD028-2009) was supplied from National Engineering Research Center for Oil-tea Camellia, Hunan Academy of Forestry, China. Before the mechanical compression of s-screw (single screw) treatment, the castor was shelled by the huller (TFBM400, Jinzhou qiao brand group co., LTD, China) to collect the castor seed, which was air-dried (6% of moisture) and used as the feedstock in this research.



## 2.2 Mechanical compression of s-screw process

150 g of castor seed was taken into the screw-type oil expeller (CA59G, KOMET, Germany) to extract the castor oil within various speed of mechanical compression ( $16 \text{ r}\cdot\text{min}^{-1}$ ,  $38 \text{ r}\cdot\text{min}^{-1}$ ,  $62 \text{ r}\cdot\text{min}^{-1}$  and  $85 \text{ r}\cdot\text{min}^{-1}$ ) and aperture of pressed cake (4 mm, 5 mm, 6 mm and 10 mm). After the compression, the crude oil was centrifuged at low velocity ( $\sim 3000 \text{ rpm}$ ) by the centrifugal machine (TDL5M, Hunan kaida scientific instruments co., LTD, China), and then conserved in a sealed bag at  $4 \text{ }^\circ\text{C}$  for further purification. In addition, the castor seed cake was collected to detect the weight and oil content of residual for evaluated the efficiency of the compression, meanwhile the squeeze time would be also investigated [3].

## 2.3 Analytical procedures

### 2.3.1 Force of solid plug infinitesimal analysis

As shown in Figure 1, there are eight forces ( $F_1 \sim F_8$ ) acting on this infinitesimal, respectively.  $F_1$  means the friction between solid plug and squeeze in a cage.  $F_2$  and  $F_6$  means the pressure on solid plug with the face of front and back along the direction of spiral groove, respectively.  $F_3$  and  $F_4$  respects the friction between solid plug and screw aris of left and right, respectively.  $F_5$  means the friction between solid plug and squeezing axle.  $F_7$  and  $F_8$  means the pressure between solid plug and screw aris of left and right, respectively.

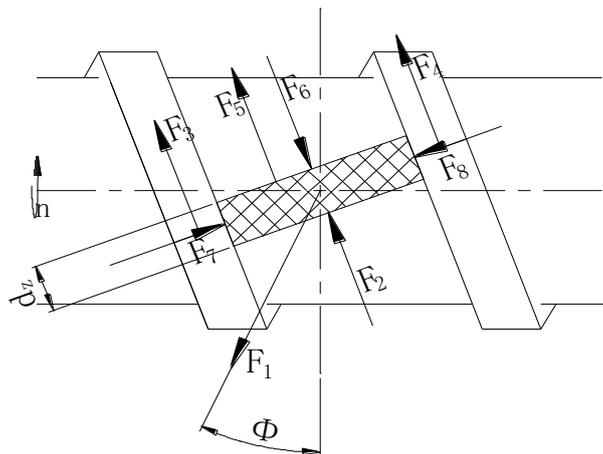


Figure 1: Force of solid plug infinitesimal analysis

In addition, the angle of traction was still one of important factors to effect on the production yield of oil. Thereafter, the traction angle of solid ( $\phi$ ) was obtained by calculation, as follows [4] [7]:

$$\sin \phi = \frac{\sqrt{H \cdot K^2 - M^2} - K \cdot M}{H \cdot K^2} \quad (1)$$

Thereinto:

$$K = \frac{D_m}{D_b} \cdot \frac{\sin \theta_m + f_s \cdot \cos \theta_m}{\cos \theta_m - f_s \cdot \sin \theta_m} \quad M = 2 \frac{H}{W_b} \cdot \frac{f_s}{f_b} \cdot \sin \theta_b \cdot \left( K + \frac{D_m}{D_b} \cot \theta_m \right) + \frac{W_s}{W_b} \cdot \frac{f_s}{f_b} \sin \theta_b \cdot \left( K + \frac{D_m}{D_b} \cdot \cot \theta_s \right)$$

Where  $P_0$  represents the initial pressure, which the  $P_0$ -value was up to experiment;

$D_b$  and  $D_m$  means the external diameter and pitch diameter of screw, respectively;

$\theta_b$ ,  $\theta_m$  and  $\theta_s$  means the lead angle of external diameter and pitch diameter and basal diameter of screw, respectively;

$H$  means the channel depth;

$f_s$  and  $f_b$  represents the friction between materials and screw and the friction between materials and cage, respectively;

$W_b$ ,  $W_m$  and  $W_s$  means the spiral groove width of external diameter and pitch diameter and basal diameter of screw, respectively;

### 2.3.2 Velocity of solid plug infinitesimal analysis

Some recent studies have showed that the angle of traction is an important parameter for the transport rate [4] [12] [13] [14][16]. Therefore, as shown in Figure 2, it indicated the effect of the angle of traction on transport rate.  $V_e$  means the translational motion, namely, the velocity of screw diameter circular;  $V_r$  represents the relative movement that the material relative to the screw;  $V_a$  means the absolute movement of material.

The transport rate ( $Q$ ) of mechanical compression of s-screw was calculated in this part, as follows [3] [4]:

$$Q = \pi^2 \cdot n \cdot D_b \cdot (D_b - H) \cdot H \cdot \frac{\tan \phi \cdot \tan \theta_b}{\tan \phi + \tan \theta_b} \cdot \left( \frac{W_m}{W_m + e_m} \right) \cdot \rho_s \quad (2)$$

Where:  $n$  means the speed of mechanical compression;

$e_m$  means the screw edge width of pitch diameter;

$\rho_s$  means the bulk density of material;

$D_b$  means the external diameter of screw;

$\theta_b$  means the lead angle of external diameter of screw;

$H$  means the channel depth;

$W_m$  means the spiral groove width of pitch diameter of screw;

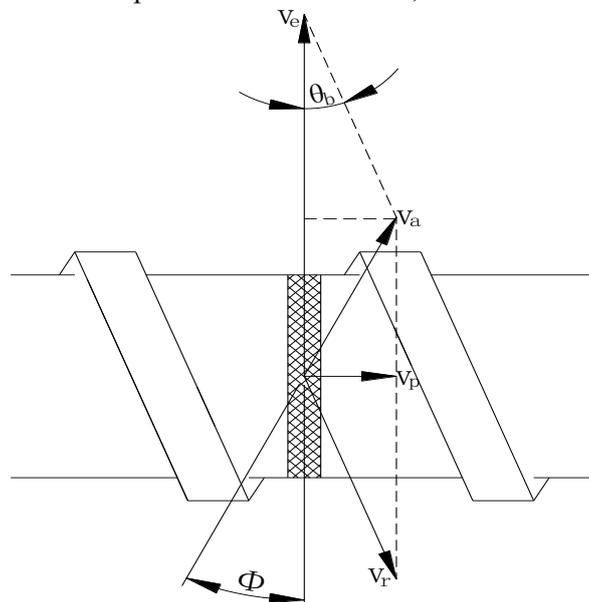


Figure 2: Velocity of solid plug infinitesimal analysis

### 2.3.3 Coefficient of friction assumption

In this study, our group found that the friction coefficient was an important factor for the delivery rate existed in mechanical compression process, such as the friction between materials and screw, and / or

the friction between materials and cage. In this process, which material was compressed constantly meanwhile the chamber was closed, so the friction coefficient would be always changing. Consequently, we have made some assumptions about the friction coefficient for researching in the ideal condition, as follows [2] [6] .

- 1) Suppose the friction coefficients of screw and cage were constant in the main press section.
- 2) Suppose the friction coefficients between screw and material was equal to the friction coefficients between cage and material, which  $f_d$  was considered the equivalent coefficient of friction, namely,  $f_s = f_b = f_d$ .

### 3 Results and Discussion

#### 3.1 Mechanical compression of s-screw process

In mechanical compression process, as we all know, the transport rate of material in cage have an important influence for the efficiency of oil squeeze because of chamber temperature, delivery rate and the tolerance equipment, etc. [4] [10], Zheng et al. 2005). In addition, [4] indicated some parameters have a significant impact for the transport rate, thereinto, the speed of compression and aperture of pressed cake were common one of them, which have been also researched in this part. As shown in Table 1, effect of speed of compression on oil content of residual was observed. The oil content of residual increased with a big speed till up to 85 rpm, even reached 30% at aperture of pressed cake of 10. And the transport rate also increase. On the contrary, the squeeze time was decrease. On the other hand, the aperture of pressed cake had a positive correlation to the transport rate, in which the big aperture resulted in a high of transport rate, and so was the oil content of residual. Therefore, it was necessary to control the aperture of pressed cake for improving the efficiency of compression [15]. With a big aperture, the oil content of residual increase gradually, while the increase of transport rate was relatively small. At 10 of aperture of pressed cake, 7.8 kg.h<sup>-1</sup> of transport rate was reached that only added a few then 6 of aperture. Additionally, as shown in Table 1, it was interesting to indicate that the signification of speed of compression better than the aperture of pressed cake on efficiency of compression, such as oil content of residual and transport rate, which might be due to the impact of the friction coefficient in mechanical compression of s-screw process, as the friction between solid plug and squeeze in a cage, the friction between solid plug and screw arris of left and right and the friction between materials and screw, etc. (Zhang & Sernas 2002). Accordingly, it was reasonable and meaningful to study and verify it in the ensuing experiment in consideration of the mechanism.

Table 1: Effect of speed of compression and aperture of pressed cake on the efficiency of oil squeeze

APC / mm	SOC / rpm	OCR / %	MOM / g	Time / min	$Q$ / kg·h <sup>-1</sup>
4	16	10.28	81.96	6.46	1.39
	38	11.45	82.05	2.58	3.49
	62	13.49	82.06	1.74	5.17
	85	14.25	82.18	1.23	7.32
5	16	13.29	82.42	6.32	1.42
	38	14.33	83.03	2.54	3.54
	62	16.25	86.61	1.73	5.20
	85	17.72	86.91	1.22	7.38
6	16	14.15	83.31	6.02	1.49
	38	15.14	84.99	2.50	3.60
	62	18.75	88.67	1.68	5.36
	85	19.22	89.07	1.20	7.50
10	16	21.32	93.04	5.41	1.66
	38	23.25	96.08	2.41	3.73
	62	27.19	103.88	1.53	5.88
	85	29.73	108.69	1.16	7.76

*APC* aperture of pressed cake, *OCR* oil content of residual, *SOC* speed of compression, *MOM* mass of material.

### 3.2 Equivalent coefficient of friction within the press cage

As represented in Eq. (1), the coefficient of friction between material and screw (or press cage) was significant effect for the angle of traction. Additionally, the angle of traction was the importance factor for effect of transport rate, in which could be inferred by Eq. (2). According to Tab.1, therefore, the equivalent coefficient ( $f_d$ ) of friction was obtained by Eq.s (1) and (2) with 38 rpm of speed of mechanical compression, 4 mm of aperture of pressed cake and 3.5 kg.h<sup>-1</sup> of transport rate, as follows:

$$\begin{cases} f_{d1} = 0.8128 \\ f_{d2} = -13.3647 \\ f_{d3} = 0.4129 \end{cases}$$

Where  $f_{d1}$  and  $f_{d2}$  contradicts with the practical situation, thus  $f_{d3}$  would be the right one on this condition.

### 3.3 Analysis of equivalent and practical coefficient of friction

In the practical oil production by mechanical compression, many researchers [4] [6] [7] [14] [16] had found that the speed of mechanical compression and aperture (or thickness) of pressed cake should not be too big for maintaining the enough time and pressure of squeezing material in the press cage, which would be consistent with our experimental results in this paper. Correspondingly, we just had discussed the effect of appropriate speed (16 and 38 rpm) and aperture (4 mm, 5 mm and 6 mm) for the equivalent coefficient of friction ( $f_d$  and  $\overline{f_d}$ ), as shown in Table 2.

Table 2: Equivalent coefficient of friction within the press cage

Speed of compression / rpm	APC / mm	$f_d$	$\overline{f_d}$
16	4	0.3921	0.4047
	5	0.3996	
	6	0.4225	
38	4	0.4129	0.4219
	5	0.4213	
	6	0.4316	

Table 2 shown all the equivalent coefficient of friction ( $f_d$ ) were less than 0.4316 under those conditions. In addition, there might due to the different numerical values of  $f_s$  and  $f_b$  with practical, namely  $f_s < f_b$ , so that the equivalent coefficient of friction could not represent the practical value. With section of 3.2 equivalent coefficient of friction within the press cage, it was beneficial to increase the transport rate with the increase of  $f_b$ -value and / or the decrease of  $f_s$ -value. However, it would not accord with the practical while  $f_s$ -value was less than  $f_d$ -value and / or  $f_b$ -value was more than  $f_d$ -value which might increase the transport rate. Besides, it would not be also accorded with the practical while  $f_s$ -value was more than  $f_d$ -value and / or  $f_b$ -value was less than  $f_d$ -value which might decrease the transport rate. Accordingly, both of  $f_s$ -value and  $f_b$ -value should be less or more than  $f_d$ -value simultaneously, so that remained the same of transport rate. According to practical, therefore, both of  $f_s$ -value and  $f_b$ -value was less than  $f_d$ -value, namely was less than 0.4316 (shown in Table 2).

## 4 Conclusions

The force analysis of castor, which was squeezed within mechanical compression of s-screw process, would be studied to explore the mechanism research for this process. The speed of compression and aperture of pressed cake have an important influence for the efficiency of oil squeeze because of the

change of transport rate, particularly the speed of mechanical. Thereafter, equivalent coefficient of friction within the press cage was obtained and analyzed the relationship with practical coefficient of friction, which both of  $f_s$ -value and  $f_b$ -value was less than  $f_d$ -value, namely was less than 0.4316. This paper can provide certain theory support for the current research of castor oil.

### Acknowledgements

This work was supported by the Major Scientific & Technological Project of Hunan Province (2016NK1001-3). The authors would like to thank Prof. Zhihui Huang for providing support in technical recommendation.

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