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FLUID MECHANICS

A STUDY ON THE THREE-PHASE SEPARATOR MACHINE (TRICANTER) FOR OLIVE OIL EXTRACTION

ASHKAN SHOKRIAN[1], HOSSEIN MOBLI[2*], ABBAS AKBARNIA[3], ALI JAFARI[2], HOSSEIN MOUSAZADE[2], BAOSHAN ZHU[4]

[1]*College of Agriculture & Natural Resources, University of Tehran, Karaj, Iran*

[2]*College of Agriculture & Natural Resources, University of Tehran, Tehran, Iran*

[3]*Iranian Research Organization for Science and Technology, Karaj, Iran*

[4]*Department of Energy and Power Engineering, Tsinghua University, Beijing, China*

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ABSTRACT: The present study is a simulation by using Computational Fluid Dynamics (CFD) technique for the multiphase complex fluid flow motion in a centrifugal separate machine (tricanter). The CFD model uses Volume of Fluid multiphase model coupled with Reynolds Stress turbulence model for two-phase flow predictions. This centrifugal device is designed for separated three-phase flow, two- phase liquid (water and olive oil) and one phase solid materials (olive pomace(. The contours of pressure, velocity and volume fraction of each phase were obtained by CFD simulation. The results showed that the centrifuge machine is designed well to separate three different phases.

KEY WORDS: centrifugal separate machine (tricanter), computational fluid dynamics (CFD), three-phase, olive oil.

1 INTRODUCTION

A tricanter centrifuge is a device that uses centripetal acceleration to continuously separate a mixture of particulate solids and a liquid, where the solids have higher density than the liquid. The versatility of tricanter centrifuges has led to their widespread use in industrial applications [1]. Olive oil is the most widely used fat in the diet of Mediterranean countries, thanks especially to its healthy properties, unique aroma and long shelf life, and due to its natural antioxidant content, which make it different from other vegetable oils [2].

Evolution of the oil extraction process has led to the replacement of traditional discontinuous lines, using the pressure system extraction, with continuous ones, using centrifugal extraction. In particular, the horizontal centrifuge with a screw conveyor

*Corresponding author e-mail: hmobli@ut.ac.ir

(i.e. tricanter) is widely used in olive oil extraction, especially if large amounts of olives have to be processed in a short time [3, 4]. However, olive oil extraction by centrifuge is dramatically affected by changes in the rheological characteristics of the olive paste in relation to water content, fruit variety, maturity level and seasonal temperature variations [5].

ANSYS Fluent is used for simulation and prediction of fluid flow. ANSYS Fluent software contains the broad physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications [6].

2 Materials and Methods

Centrifugal horizontal machine (Tricanter) has become a major processing tool in a wide range of liquid/solid separation applications. Although a complicated piece of machinery, the tricanter centrifuge embodies a simple principle, that of the screw conveyor [7].

The tricanter centrifuge is, in principle, a relatively simple device, though far from simple to manufacture, being a rotating drum with a screw conveyor in it; clarified liquid decants out of one end while dewatered solids are scrolled out of the other. The prime virtue of the tricanter is its ability to remove quite high levels of suspended solids from a liquid, with a reasonably low level of retained liquids in the separated solids.

A schematic of a tricanter centrifuge is shown in Fig. 1, with an example of dimensions and operating parameters for a typical application listed in Table 1.

Table 1. Example parameters for a tricanter centrifuge separating

Variable	Value
Liquid density	800 kg/m^3
Solid density	2010 kg/m^3
Rotation speed	3000 RPM
Differential speed	40 RPM
Mass flow rate	0.25 kg/s
Liquid discharge radius	20 mm
Solid discharge radius	20 cm
Scroll pitch	50 mm
Scroll pitch angle	12°
Bowl radius	160 cm
Cone half angle	12°
Length of conical section	300 mm
Length of cylindrical section	400 mm

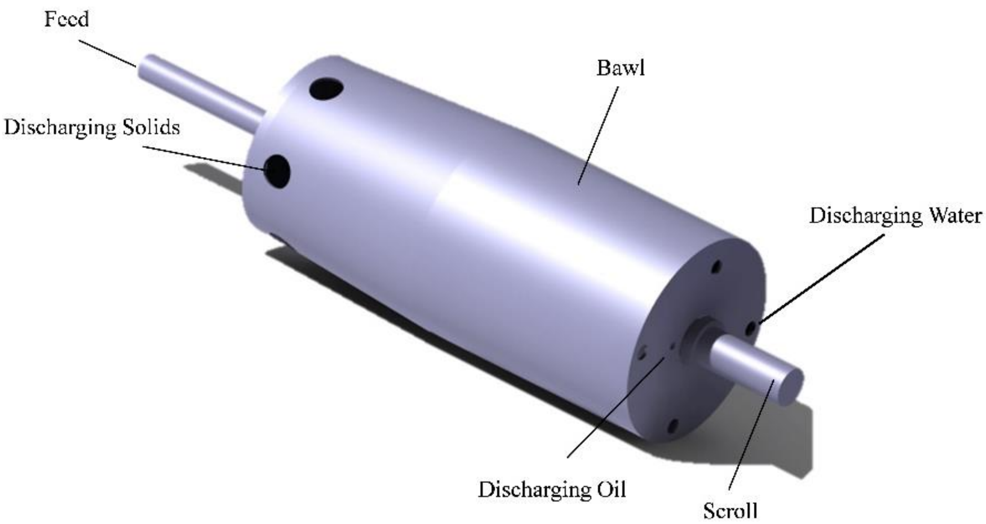

Fig. 1. (Color online) Schematic of a tricanter centrifuge.

2.1 Basic theory

In the centrifuge, it is the liquid that moves round in a circle, and the particles in suspension are free to move relative to the liquid. Thus, relative to the liquid, the suspended particles experience an acceleration, $\omega^2 r$, radially outwards.

Thus, the gravitational force, F, on a particle of mass m, is the product of its mass and acceleration, where

$$F = mr\omega^2 . \tag{1}$$

In centrifuge parlance the term "g" (or g-level) is often used. This is the number of times the acceleration in the centrifuge is greater than that due to gravity alone [7].

2.2 Methodology

Flow governing equations in terms of Navier-Stokes equations are solved. Multiphase simulation flow inside the tricanter machine is resolved by VOF method. We used ANSYS CFX software package for simulation of fluid motion in the centrifugal tricanter. The CFD simulation allows us to predict the performance of a tricanter machine [8].

2.3 VOF model

VOF model is a numerical technique used for tracking the interface between free surfaces by solving the momentum (2). Continuity (3) is solved for the volume fraction of the air (α_q) and this tracks the position of the air core in this problem [9].

$$\frac{\partial(\rho u_j)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_i} = -\frac{\partial p}{\partial x_i}\rho g_i + \frac{\partial}{\partial x_i}\mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}) \,, \tag{2}$$

$$\frac{\partial \alpha_q}{\partial t} + u_j \frac{\partial \alpha_q}{\partial x_i} = 0 \,, \tag{3}$$

where α_q is the volume fraction of the q-th phase, which varies between 1 and 0. u_j is the j-th component of the velocity. A constant value of 0.078 N/m is used for the surface tension between air and water. The average density and viscosity are calculated by the following manner [9]:

$$\rho = \alpha\rho_{\text{water}} + (1-\alpha)\rho_{\text{air}} \,, \tag{4}$$

$$\mu = \alpha\mu_{\text{water}} + (1-\alpha)\mu_{\text{air}} \,. \tag{5}$$

2.4 Olive Samples

This study included olive oil samples produced from olives (Fashemi) of the Manjil cultivar, which is considered as the most prized Iranian olive variety for oil production, originating from the area of Gilan province, Iran. This variety grows well on mountain slopes and produces small fruit; the high ratio of skin to flesh giving the oil its coveted aromatic qualities. Olive fruits grown in an organic farm in Manjil, were picked by hand during February 2014. The maturity of olive fruits was confirmed by their color: 70% were green and 30% brown. Olives' average diameter was 12.8 mm and their average weight was 0.78 g. Overall, 200 kg of olive fruits were collected.

3 Results and Discussion

3.1 Solid Velocity

The contour velocity profiles of solid materials inside tricanter machine are displayed in Fig. 2. It can be seen that the velocity of solid material in near to the surface shell has maximum value, but the velocity near the outer scroll is zero, and causes the suspended solids to settle and accumulate at the scroll wall.

Increasing the differential speed between bowl and scroll from 40 rpm to 120 rpm provides the conveying motion to collect and remove the solids, which accumulate at the scroll wall (Fig. 3).

3.2 Pressure

The highest pressure occurs at the entrance of the separator, where the flow velocity is also decreased. It was noticed that the pressure at the middle of the tricanter was lower than atmospheric pressure and ideally lower than the inflow inlet for the tricanter to have optimum efficiency (Fig. 4).

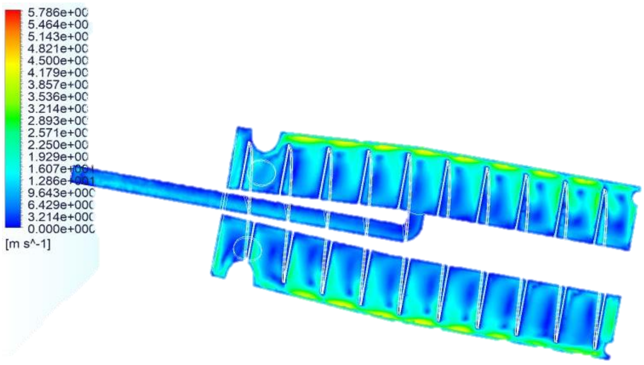

Fig. 2. (Color online) Solid materials velocity counter.

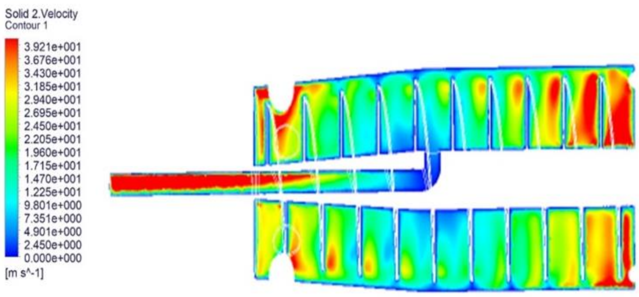

Fig. 3. (Color online) Solid materials velocity contour after the increase of the differential speed.

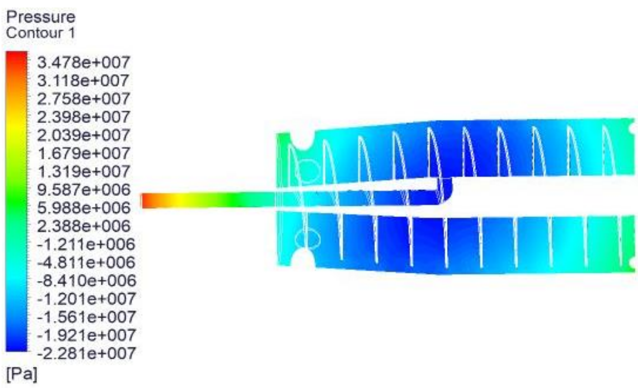

Fig. 4. (Color online) Pressure contour inside the tricanter machine.

3.3 Volume fraction

According to Fig. 5a, biggest oil concentration is near to the scroll, and this is due to the lower density of the oil than the density of oil and solid materials. Also, the water concentration is close to the centrifugal rotor (scroll) body. According

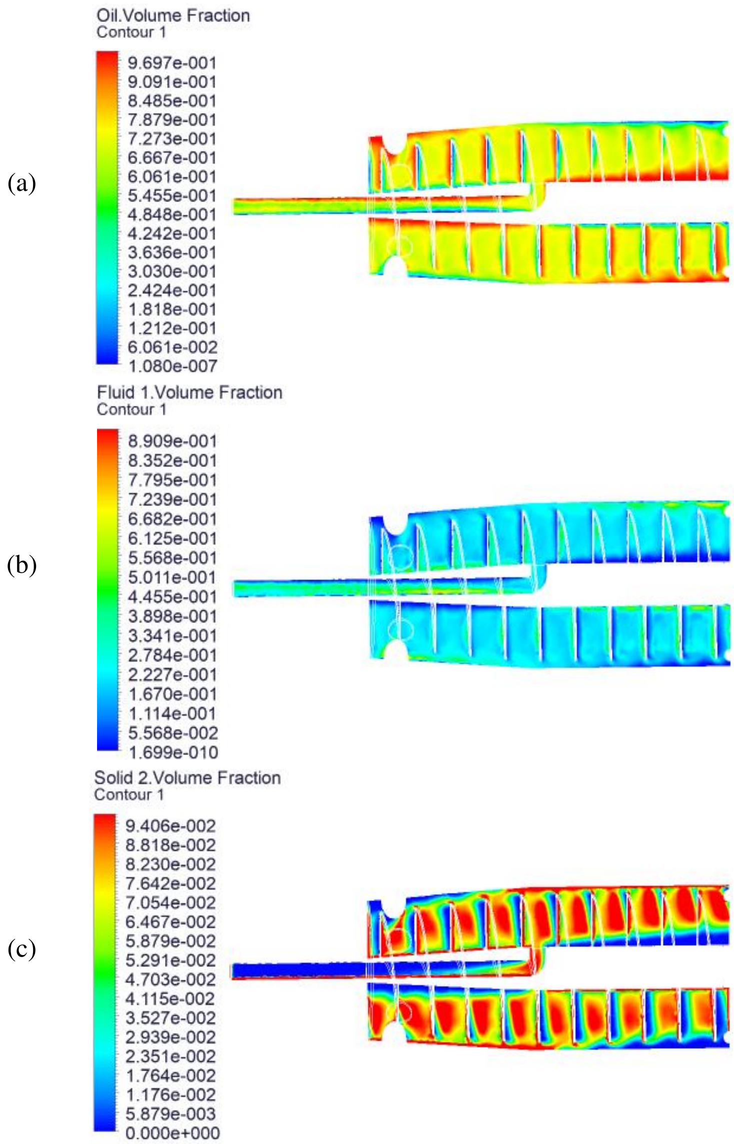

Fig. 5. (Color online) Volume fraction contour: Oil (a), Water (b), Solid materials (c).

to Figs. 5b and 5a, it can be proved that the lowest concentration occurs where the water concentration is bigger. This shows that the separation of the mixture starts around the centrifugal rotor.

Figure 5c shows that the suspended solid materials settle and accumulate at the shell wall because the density of the solids is higher than the density of water and oil.

4 Conclusion

The overall results reported in this paper show that the centrifugation system strongly separate each phase. A slurry of liquid and suspended solids is fed along the center line to some fixed position within the bow, and is accelerated outwards to join the pond of liquid held on the bowl wall by the centrifugal force. This same force then causes the suspended solids to settle and accumulate at the bowl wall. In this paper the flow inside the tricanter is simulated by Computational Fluid Dynamics (CFD) technique. The CFD model uses Volume of Fluid multiphase model coupled with Reynolds Stress turbulence model for three-phase flow predictions.

Inside the tricanter centrifuge the separation of water, oil and solid parts are performed efficiently. At the outlet it is possible to see, that on the water outlet comes out water, on the oil outlet comes out oil and on the solid particles outlet come out solid particles, mainly.

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References

[1] G.R.A. Bell, D.B. Symons, J.R. Pearse (2014) Mathematical Model for Solids Transport Power in a Decanter Centrifuge. *Chemical Engineering Science Pearse* **107** 114-122.

[2] M. Salvador, F. Aranda, S. Gomez-Alonso, G. Fregapane (2013) Influence of Extraction System, Production Year and Area on Cornicabra Virgin Olive Oil: A Study of Five Crop Seasons. *Journal of Food Chemistry* **80**(3) 359-366.

[3] A. Ranalli, G. De Mattia, M.L. Ferrante (1997) Comparative Evaluation of the Olive Oil Given by a New Processing System. *Journal of Food Science and Technology* **32**(4) 289-297.

[4] P. Piacquadio, D.S. Giovanni, V. Sciancalepore (1998) Quality of Virgin Olive Oil Extracted with the New Centrifugation System Using a Two-Phases Decanter. *Fett/Lipid* **100**(10) 472-474.

[5] G. ALTIERI (2010) Comparative Trials and an Empirical Model to Assess Throughput Indices in Olive Oil Extraction by Decanter Centrifuge. *Journal of Food Engineering* **97**(1) 46-56.

[6] T.S. KANNAN, S.A. MUTASHER, Y.H. KENNY (2013) Design and Flow Velocity Simulation of Diffuser Augmented Wind Turbine Using CFD. *Journal of Engineering Science Technology* **8**(4) 372-384.

[7] A. RECORDS, K. SUTHERLAND (2001) "Decanter Centrifuge Handbook". Elsevier Science.

[8] A. DAVAILLES E. CLIMENT, F. BOURGEOIS (2012) Fundamental Understanding of Swirling Flow Pattern in Hydro Cyclones. *Separation Purification Technology* **92** 152-160.

[9] C.W. HIRT, D.N. BILLY (1981) Volume of Fluid (VoF) Method for the Dynamics of Free Boundaries. *Journal of Computational Physics* **39**(1) 201-225.