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Design Analysis of A Single Screw Extruder For Jatropha Oil Extraction Using Finite Element Method

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ABSTRACT

he design of a single screw extruder can be analysed using a 3-D Finite Element Method with Computational Fluid Dynamic simulation. This simulation was used to investigate the flow and behaviour of Jatropha dough in a single screw extruder. In a preliminary study, this paper focused to simulate the velocity profile in the die section, using a power law model to predict effect clearance and normal pitch. Three screw designs were created with different dimensions. The results obtained reveal that the clearance must be 0.5 mm and the normal pitch should not exceed 22 mm.

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INTRODUCTION

A single screw extruder (Figure 1) can be used to extract oil from Jatropha seeds during an oil extraction process. With a screw rotating in a cylinder, it can obtain an oil yield of 89.4% (Karaj, S. and J. Müller, 2011). Seeds are fed into a hopper and crushed, conveyed, and pushed forwards towards the end of the machine, as the screw rotates. Oil comes out of the oil outlet and the cake comes out through a nozzle (Beerens, P., 2007; Oyinlola, A., et al., 2004).

A Finite Element Method (FEM) is a numerical method used to solve boundary value problems. It can be used to predict and analyse the design of a single screw extruder faster, with efficiency and high accuracy, and can easily replace different models. ANSYS POLYFLOW is a Computational Fluid Dynamics (CFD) simulation program that is used to solve flow problems in polymer, injection moulding, food rheology, glass-work furnaces, and chemically reacting flows; where materials are identified as viscous and viscoelastic (ANSYS, I., 2011).

This paper proposes three single screw extruder screw designs and analyses them using FEM and CFD simulations, with a power law model to study the velocity profile of J. Curcas dough in the die section.

Methodology:

The screw is an important part of the design of a single screw extruder. Furthermore, three screw designs were created using SOLID WORKS 2008, and imported by POLYFLOW into the design modeller. The dimensions defined for the screw's design were length (L), internal diameter (D_i), external diameter (D_e), clearance (C), helix angel (HA), screw flight (SF), normal pitch (NT), and pitch (T) (as shown in Table 1). The basic geometry of the screws is shown in Figure 2.

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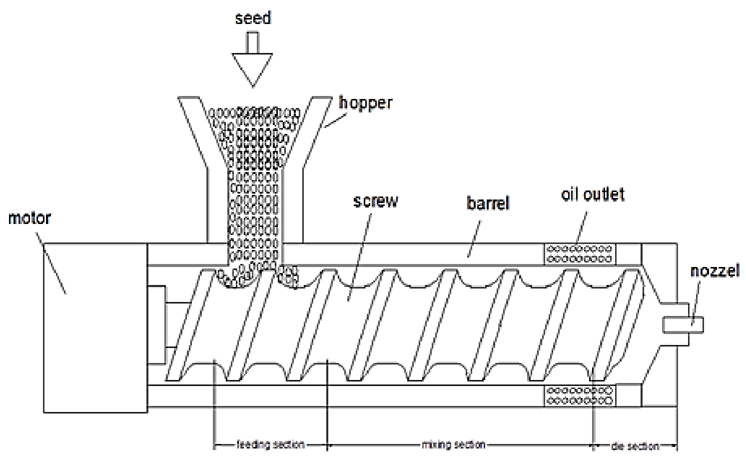

Fig. 1: A single screw extruder

Table 1: Geometrical dimensions of screws

Dimension	L (mm)	Di (mm)	De (mm)	C (mm)	HA (⁰)	SF (mm)	NT (mm)	T (mm)
Screw 1	236	40	60	0.5-1.5	20	3	17	20
Screw 2	236	40	60	0.5-1.5	20	3	22	25
Screw 3	236	40	60	0.5-1.5	20	3	27	30

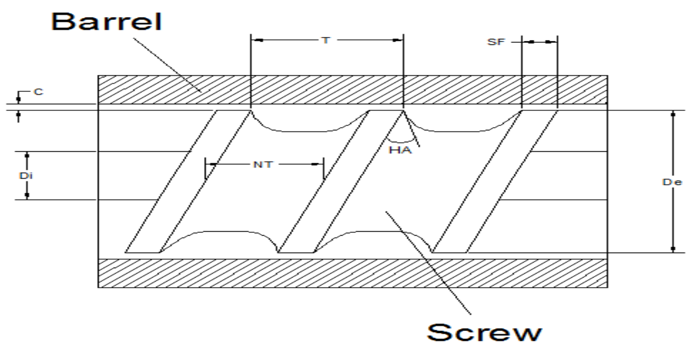

Fig. 2: Geometry of screw

The boundary condition is the space between the wall of the screw and the inner surface of the barrel (as shown in Figure 3). Furthermore, an ANSYS meshing application was used to create the mesh elements on both the screw and the barrel.

The conditions at the boundaries are:

- Boundary 1 : CE, input
- Boundary 2 : EF, Wall of the inner barrel
- Boundary 3 : DF, Output
- Boundary 4 : CD, Surface of the screw

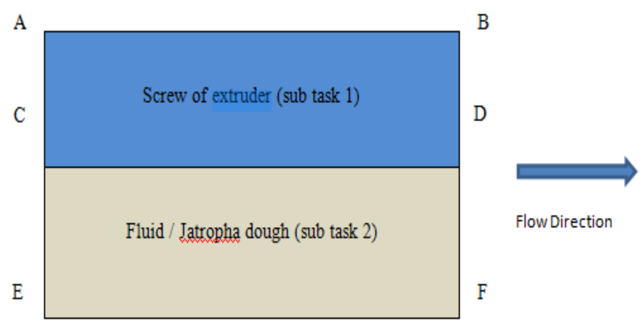

Fig. 3: Boundary condition

FEM and CFD with software ANSYS Polyflow 14.0 solves the conservation of mass and momentum (ANSYS 2011)

$$\nabla . v = 0 \quad (1)$$
$$\nabla . T + f - \nabla p = \rho \frac{Dv}{Dt} \quad (2)$$

Where, v is the velocity vector, T is the stress tensor, f is the volume force, p is the pressure, ρ is the fluid density, and t is time.

A power law model was used to calculate the viscosity of the fluid; depending on the shear rate according to the following equation (ANSYS 2011):

$$\alpha = L(\beta \dot{t})^{n-1} \quad (3)$$

Where, L is the consistency factor, $\beta\dot{t}$ is the natural time, and n is the power law index

$$T = 2\alpha D \quad (4)$$
$$T = 2\, L(\beta \dot{t})^{n-1} D \quad (5)$$

Finally, the velocity magnitude can be calculated as:

$$2\, L(\beta \dot{t})^{n-1} D + f - \nabla p = \rho \frac{Dv}{Dt} \quad (6)$$

In order to simulate the flow and behaviour of the fluid, input parameters were used (as shown in Table 2). This data was obtained from previous researchers (as indicated).

Table 2: Input parameters in the simulation process

Parameter			Reference
Screw speed (rad/s)		7.33	(Karaj and Müller, 2011)[1]
Mass flow rate (gr/s)		30	
Density of J. Curcas (gr/mm^3)		0.278	(Pradhan et al., 2009)[5]
Viscosity (cm/s)	consistency factor	2500 Pa s^n	(Dhanasekharan, Huang and Kokini, 1999)[6]
	natural time	0.52 s	
	power law index	0.8	

RESULTS AND DISCUSSION

The steady state problem was solved using the CFD Post Solver, after calculating the POLYDATA. The simulation's results were used to modify several variables, in order to find the best expected results. The contour was colour coded, from blue as the lowest to red as the highest velocity.

Effect of Clearance:

Figure 4 shows three different clearances for screw design 1. There were two clearance areas, namely upper clearance and bottom clearance. These areas (also known as the zero velocity area; because the material is not allowed to pass through) are the distance between the inner surface of the barrel and the surface of the screw flight. Figure 4(a) shows a blue code with a clearance of 0.5 mm. This means that there was no material passing through. Figure 4(b) shows a sea blue code, with a clearance of 1 mm, which can be interpreted as material passing through this area, but not too much and a velocity magnitude of about 10 cm/s. Meanwhile, Figure 4(c) shows a sky blue code with a clearance of 1.5 mm. In this design, the clearance is too large; and material can pass through with a velocity magnitude of 20 cm/s. Evidently, the clearance should be coded blue, and as such, the best design from all three was the design with a clearance of 0.5 mm. If the gap area is too large, it is difficult to push the material forward, but if it is too small, the screw flight will rub against the surface of the inner barrel, and overheating will occur.

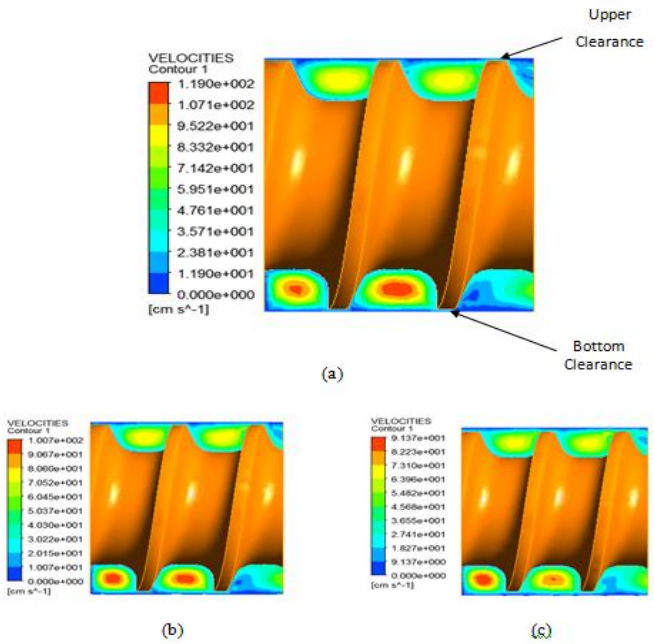

Fig. 4: Screw design 1; with a screw speed of 7.333 rad/s (a) Clearance 0.5 mm (b) Clearance 1 mm, and (c) Clearance 1.5 mm

Effect of Normal Pitch:

In Figure 5(a), Normal pitch is 27 mm and shows a green code with a velocity magnitude of 37.62 cm/s. This equates to low pressure on the central circulation. In Figure 5(b), Normal pitch is 22 mm and shows a red code at the centre of circulation, with a velocity magnitude of 126.1 cm/s. Drag pressure is very strong in this design. Meanwhile, in Figure 5(c), Normal Pitch is 17 mm and has a velocity magnitude of approximately 119 cm/s at the bottom. It can be predicted that the drag force ahead is not smooth; therefore, the materials gain power from behind. From these figures, it can be concluded that the best design has a normal pitch of 22 mm.

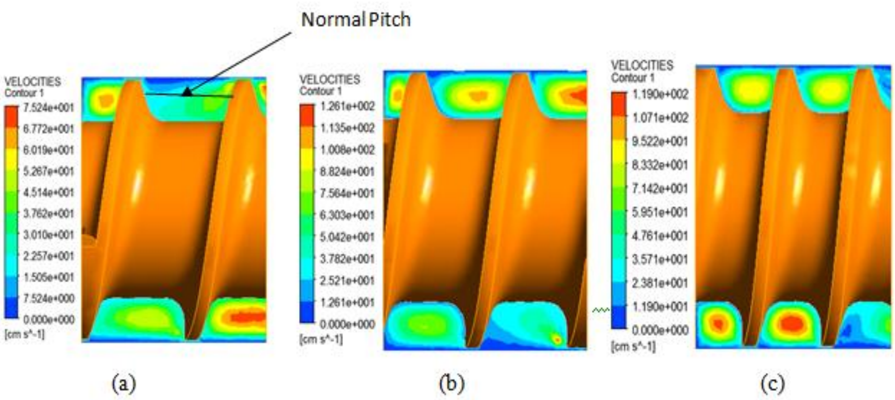

Fig. 5: Screw design with a screw speed of 7.333 rad/s (a) Screw 1, (b) Screw 2, and (c) Screw 3

Conclusion:

Screw design, of a single screw extruder, can be analysed using a Finite Element Method using ANSYS Polyflow. For the design of a single screw extruder, the size of clearance must be 0.5 cm and the size of normal pitch must not exceed 22 mm.

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