Parameters Affecting the Extraction Process of *Jatropha curcas* Oil Using a Single Screw Extruder

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Abstract. The most commonly used technique to separate oil and cake from *J. curcas* seeds is mechanical extraction. It uses simple tools such as a piston and a screw extruder to produce high pressure, driven by hand or by engine. A single screw extruder has one screw rotating inside the barrel and materials simultaneously flow from the feed to the die zone. The highest oil yield can be obtained by a well-designed oil press as well as finding the optimum conditions for all parameters involved during the extraction process. The influence of the parameters in a single screw extruder was studied using finite element analysis and computational fluid dynamics simulation with ANSYS POLYFLOW. The research focused on predicting the velocity, pressure and shear rate in the metering section that influenced the screw rotational speed and mass flow rate. The obtained results revealed that increasing the screw rotational speed will increase the pressure, velocity and shear rate. Meanwhile, increasing the mass flow rate results in decreasing the pressure while the velocity and shear rate remain constant.

Keywords: *single screw extruder; fluid-dynamic analysis; Jatropha curcas; oil extraction; oil press.*

1 Introduction

Jatropha curcas (physic nut) is a plant that belongs to the *Euphorbiaceae* family, sub-family Platilobeae [1]. *J. curcas* seeds are considered to the best energy source among oil seeds and their oil content is the highest among non-edible vegetable oilseed crops [2]. It appears to be a serious candidate as an alternative energy source because the energy balance and greenhouse impact are positive, it is the cheapest biodiesel feed stock available, and the oil content has similar properties to that of petroleum based fuels [3].

A single screw extruder was investigated as the best oil press to get a high oil yield. It was chosen because of its low cost of energy and the input power

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required being only 1-2.5% of the energy of the oil produced [4]. Karaj and Müller [5] reported that the highest oil recovery achieved was 89.4% (m/m) with a nozzle size of 8 mm and a rotational speed of 220 rpm. Beerens [6] reported that an oil yield of 79% can be obtained with a rotational speed of 49 rpm and a restriction diameter of 9 mm. More research is needed to examine the application of single screw extruders. Unfortunately, only few data are available in the scientific literature that can be used to study the performance of a single screw extruder in the *J. curcas* extraction process. This is because of the high costs incurred to buy such a machine and many of its parts. This problem can be avoided by using finite element method simulation.

The finite element method (FEM) is a numerical method to solve various boundary value problems. It was used in this research because it is easy, accurate and able to change many models with little cost. ANSYS POLYFLOW is a finite-element computational fluid dynamics (CFD) simulation program. It can be used to solve flow problems in polymer, injection molding, food rheology, glass-work furnaces and chemically reacting flows where material is identified as viscous and viscoelastic [7]. Its simulation was used to investigate the flow and behavior of *J. curcas* dough in a single-screw extruder as a Newtonian fluid of which the viscosity is constant. Many researchers have developed their own FEM codes to analyze a single screw extruder. Connelly and Kokini [8] investigated the mixing ability of a single screw extruder using 2D finite element method simulation. They evaluated the mixing process using the commercial CFD package POLYFLOW with a Carreau flow model. Bi and Jiang [9] studied the residence time distribution in a reciprocating single screw pin-barrel. Ghoreishy, *et al*. [10] used the finite element method to analyze a thermoplastic elastomer melt flow in the metering region of a single screw extruder.

In this paper, parameters affecting the extraction process of *J. curcas* oil using a single screw extruder were observed. The problem was focused on the steady state behavior problem of *J. curcas* dough in isothermal conditions. It was analyzed using FEM and CFD with ANSYS POLYFLOW simulation, using Newtonian law and power law equations to describe the influence of screw rotational speed and mass flow rate. Furthermore, the output data were studied to predict velocity magnitude, pressure and shear rate.

2 Material and Methods

Nowadays, the design of a screw press can be analyzed using computer aided design (CAD) software. First, a screw was designed complete with all of its important geometry, such as length (L), minor diameter (d), major diameter (D), clearance (Cl), helix angle (H), screw flight (SF), normal pitch (NP) and pitch

(P), as shown in Figure 1. Second, the designed screw was analyzed and calculated with the ANSYS POLYFLOW program.

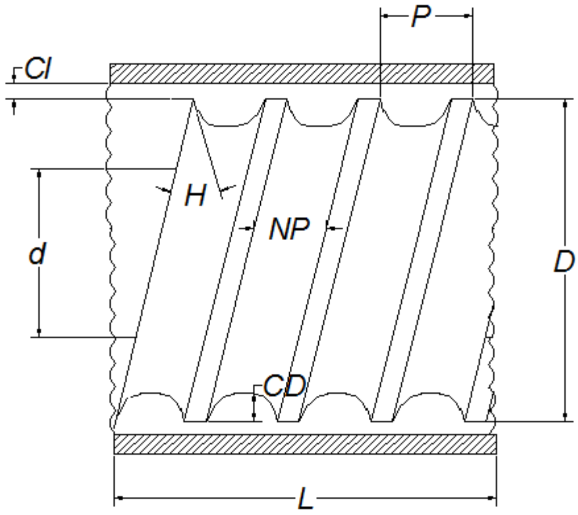


Figure 1 Design of a model screw.

2.1 Design of Screw

The screw is the most important part in a single screw extruder, thus an optimal design of the screw can improve the performance of the machine. A model of the screw was created using SOLIDWORKS 2008, with geometrical dimensions as shown in Table 1.

Table 1 Geometrical dimensions of model screw.

Dimension	**L (mm)**	**d (mm)**	**D (mm)**	**Cl (mm)**	**H (^{o})**	**CD (mm)**	**NP (mm)**	**P (mm)**
Screw 1	236	40	60	0.5	20	3	27	30

2.2 Simulation Model

The boundary condition was defined in ANSYS POLYFLOW before simulation. The boundary condition is the space between the wall of the screw and the inner surface of the barrel, as shown in Figure 2. Further, the model of the screw was meshed with ANSYS Meshing, as shown in Figure 3.

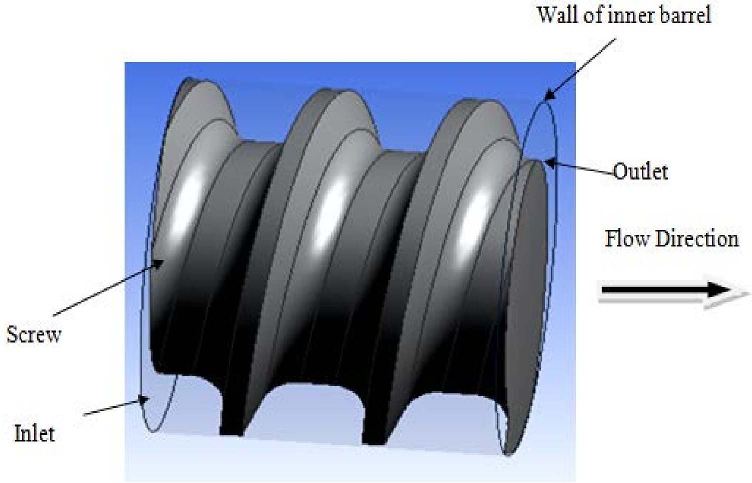
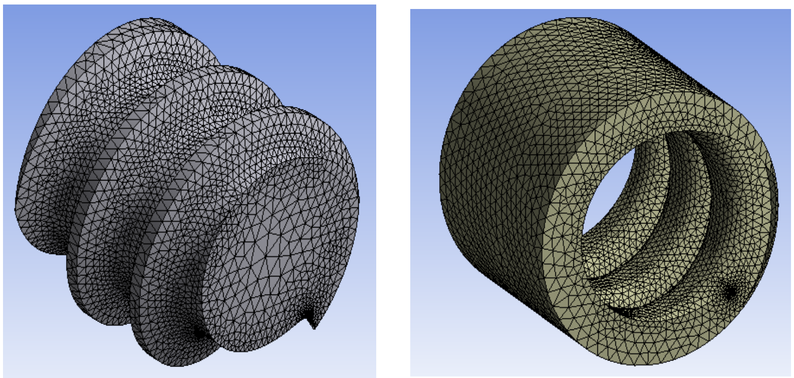


Figure 2 Boundary condition.



(a) (b)

Figure 3 ANSYS meshing (a) screw, (b) barrel.

In the problem of the extraction process it must be assumed that the flow is at steady state. This means that the flow is continuous while the barrel is rotating and the screw is stationary. Furthermore, the inertia and gravitational forces are considered negligible. For a generalized Newtonian flow, ANSYS POLYFLOW can solve the problem for conservation of mass and momentum and non-isothermal flows of viscoelastic fluid with basic equation [7].

$$\nabla . v = 0 \tag{1}$$

$$\nabla . T + f - \nabla p = \rho \frac{dv}{dt} \tag{2}$$

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.

The power law describes a type of generalized Newtonian fluid. The model was used to calculate the viscosity of the fluid depending on the shear stress rate according to the following equation [7].

$$\eta = K\left(\lambda\right)^{n-1} \tag{3}$$

where K is the consistency factor, λ is the natural time, and n is the power law index.

$$T = 2\eta D \tag{4}$$

$$T = 2K\left(\lambda\right)^{n-1} D \tag{5}$$

where D is the rate of the strain tensor with shear stress rate $(\dot{\gamma})$ and T is the stress tensor and shear rate stress, defined as

$$\dot{\gamma} = \sqrt{2D^2} \tag{6}$$

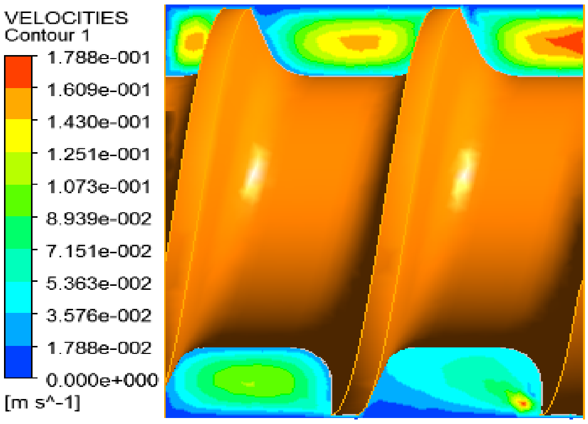
The input parameters used to calculate the simulation process are shown in Table 2.

Table 2 Input parameters in simulation process.

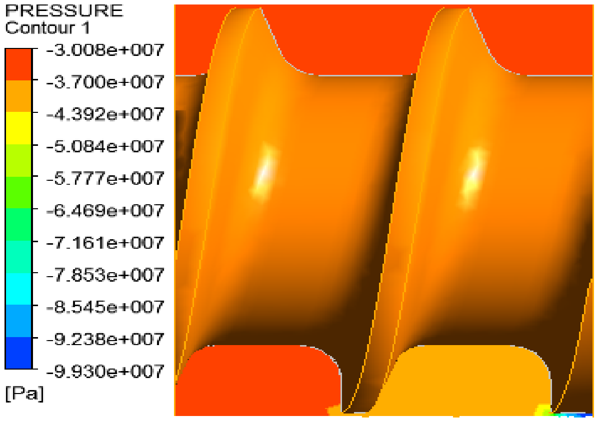
Parameter			Reference
Density of Jatropha (kg/m^3)		278	[11]
Viscosity (Pa s)	consistency factor	2500 Pa s^n	[12]
	natural time	0.52 s	[12]
	power law index	0.8	[12]

3 Result and Discussion

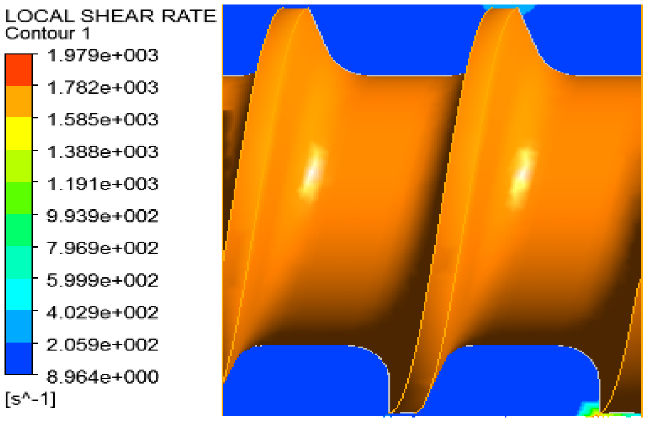
In the finite element analysis, the data were identified by investigating the change of color on the contour map. CFD simulation was used to predict the behavior of *J. curcas* dough flowing in the boundary condition area. The process begins when the screw rotates in the barrel and the *J. curcas* seed will be split and meshed to become dough. Later, the material is moved from one channel to the next, due to the drag force exerted by the screw rotation in the *z* direction. High velocity is usually shown at the center of circulation. In Figure 4, the contour velocity, pressure and shear stress rate of the screw are shown.



(a) Velocity



(b) Pressure



(c) Shear rate stress

Figure 4 Contour map of model screw.

The oil extraction process has the same mechanism as the extrusion process. Therefore, the results of experiments on the extrusion process could be used to validate the results of this simulation. Ghoreishy, *et al*. [10] conducted an experiment on thermoplastic elastomer melt flow to investigate the effects of screw rotation speed on pressure and mass flow rate, as shown in Table 3.

Table 3 Experimental pressure and flow rate in screw channel.

RPM	Input pressure (Pa)	Output pressure (Pa)	Measured flow rate (g/s)
10	0.782×10^7	0.919×10^7	0.103
20	1.005×10^7	1.148×10^7	0.204
30	1.076×10^7	1.286×10^7	0.293
40	1.082×10^7	1.373×10^7	0.384
50	1.109×10^7	1.472×10^7	0.484
60	1.162×10^7	1.514×10^7	0.552

3.1 Influence of Screw Rotational Speed

Figure 5 shows that increasing the screw rotational speed from 10 rpm to 60 rpm increased the pressure from 0.782×10^7 (Pa) to 1.162×10^7(Pa). Furthermore, in Figure 6 it can be seen that increasing the screw rotational speed from 10 rpm to 60 rpm, increased the pressure from 3×10^7 (Pa) to 12.8×10^7 (Pa). A higher screw rotation generates a higher pressure in the extruder channel. These effects reduce the negative pressure flow with respect to the drag flow. Furthermore, the flow in the x direction is driven by the plate motion whereas in the z direction it is driven by the upper plate.

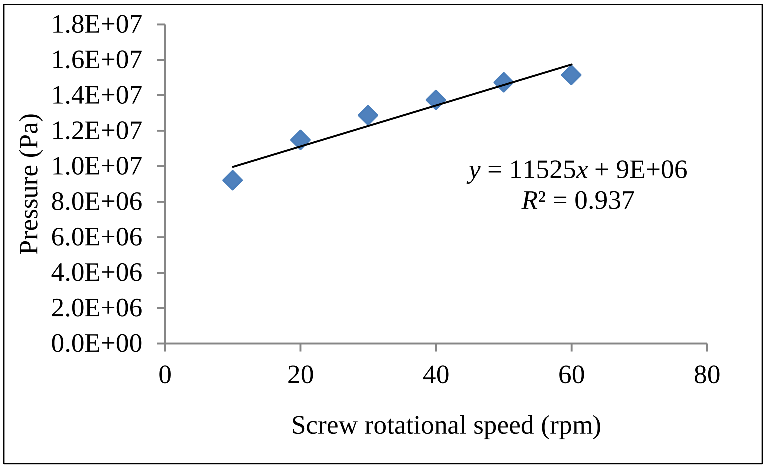


Figure 5 Comparison of screw rotational speeds with pressure in Ghoreishy, *et al*. [10].

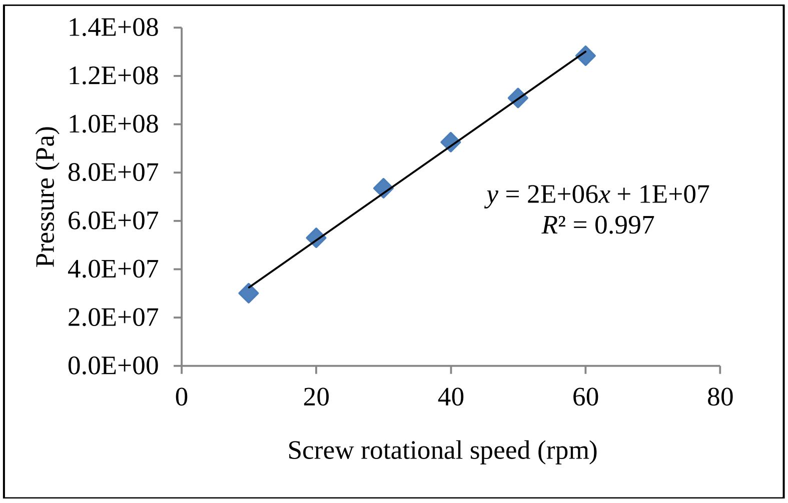


Figure 6 Simulation of relationship between screw rotational speeds and pressure.

Pressure from the drag flow is an important variable, while other important variables, such as velocity and mass flow rate, can also be analyzed by FEM. The influence of the screw rotational speed on the velocity profile was simulated, as shown in Figure 7. The result of the simulation was that increasing the screw rotational speed from 10 rpm to 60 rpm increased the velocity magnitude from 0.92 m/s to 1.514 m/s. As expected, a higher screw rotational speed caused an increase in velocity magnitude. This increase was due to the rotation being able to send the material to the end of the nozzle at a faster rate [13].

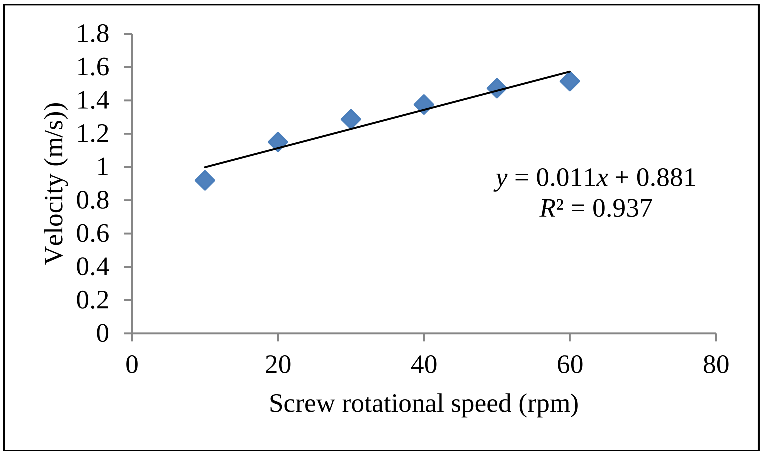


Figure 7 Simulation of relationship between screw rotational speed and velocity.

Figure 8 shows the simulation results of the relationship between screw rotational speed and shear rate. It can be seen that increasing the screw rotational speed from 10 rpm to 60 rpm caused the shear rate to increase from 8.96 s^{-1} to 54.15 s^{-1}. Increasing the screw rotational speed increases the shear rate due to the increase of the axial force on the channel so that the drag flow increases [14].

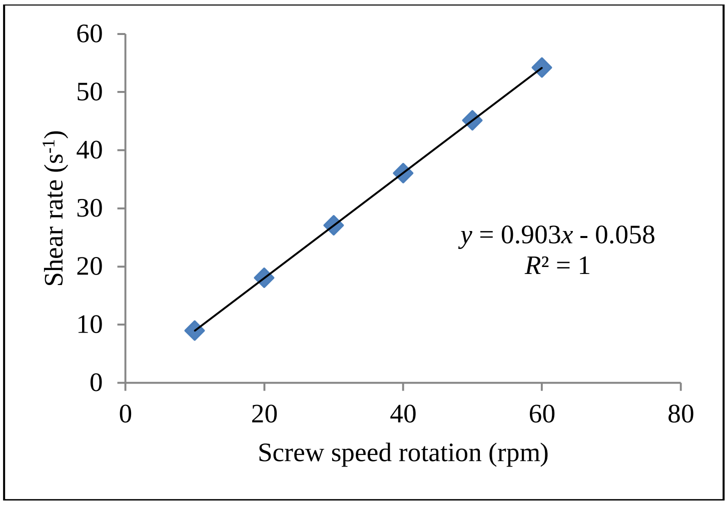


Figure 8 Simulation of relationship between screw rotational speed and shear rate.

Therefore, increasing the screw speed rotation can increase velocity, pressure and shear stress rate. It is required to obtain a strong drag flow in the *z* direction and cross channel flow in the *x* direction [9,15].

3.2 Influence of Mass Flow Rate

Figure 9 shows that increasing the mass flow rate from 0.103 (g/s) to 0.552 (g/s) will increase the pressure from 0.919 x 10^7 (Pa) to 1.514 x 10^7(Pa). However, the increase in pressure is very small. This is mainly because the screw rotational speed also increases.

The results of the simulation of the relationship between mass flow rate and pressure are shown in Figure 10. Increasing the mass flow rate from 40 g/s to 140 g/s decreased the pressure from 9.24 x 10^7 (Pa) to 9.13 x 10^7 (Pa). Increasing the mass flow rate caused a decrease in pressure. This is due to the increasing volume of material in the channel, which can decrease screw rotational speed and cause drag flow [9].

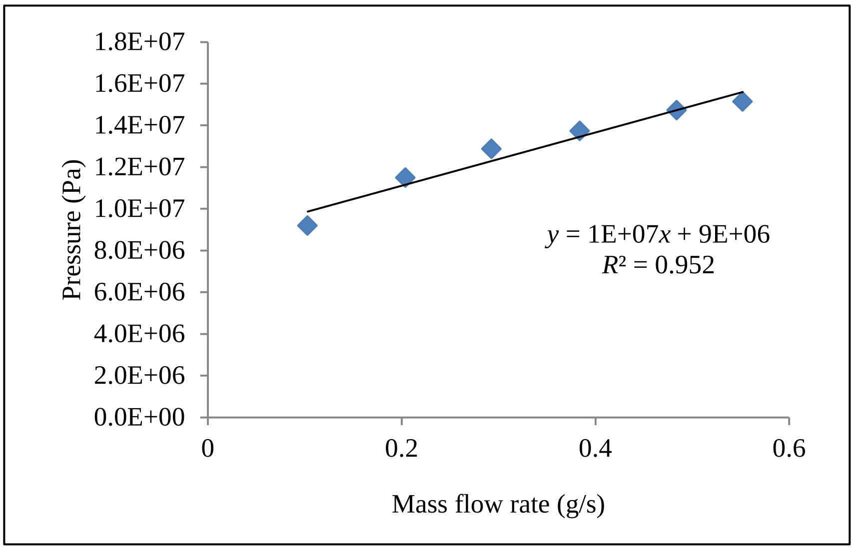


Figure 9 Comparison of mass flow rate and pressure in Ghoreishy, *et al*. [10].

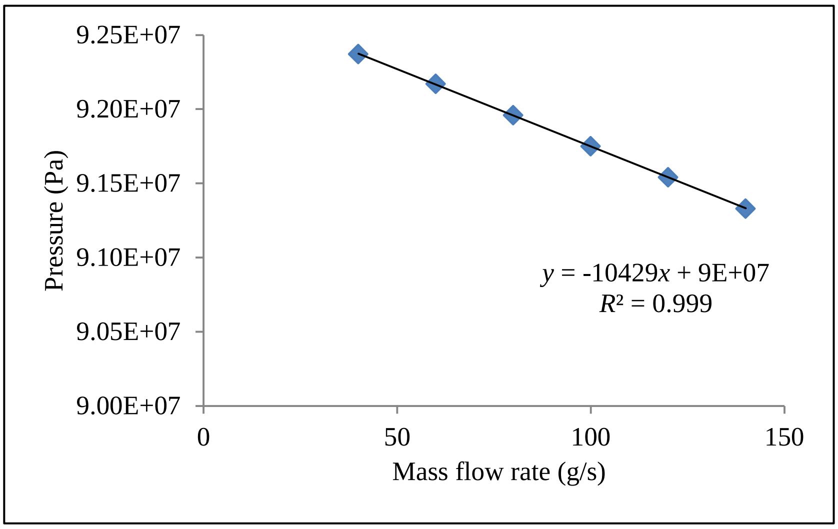


Figure 10 Simulation of relationship between mass flow rate and pressure.

Simulation was also used to investigate the effects of velocity magnitude and shear rate. Figure 11 shows that the mass flow rate increasing from 40 g/s to 140 g/s did not increase the velocity magnitude. Figure 12 shows that when increasing the mass flow rate from 40 g/s to 140 g/s, the shear rate remained constant.

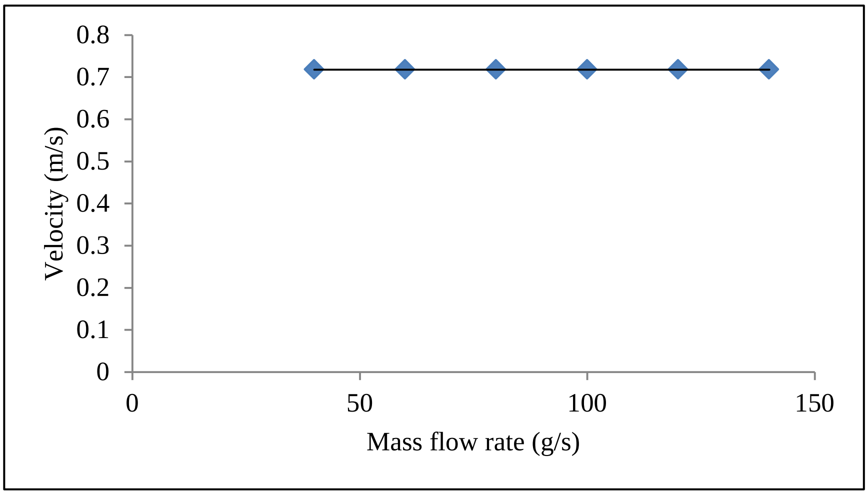


Figure 11 Simulation of relationship between mass flow rate and velocity.

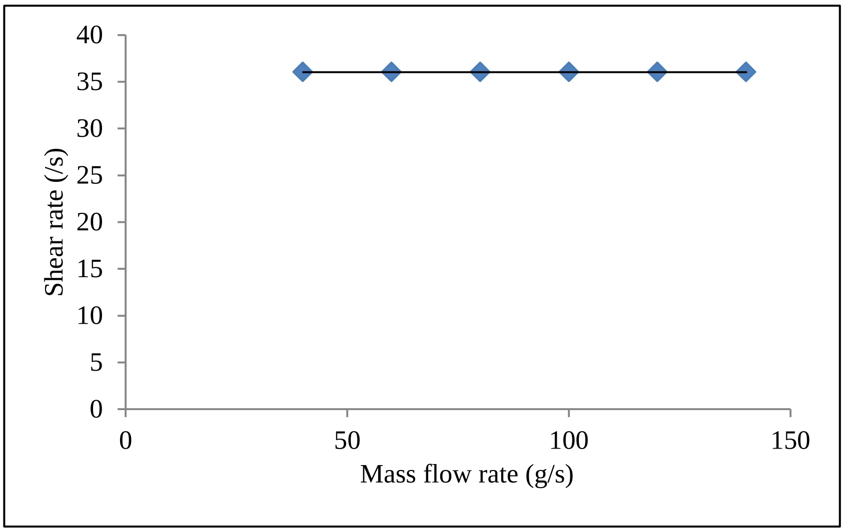


Figure 12 Simulation of relationship between mass flow rate and shear rate.

The mass flow rate depends on the volume and density of the material so that increasing the mass flow rate does not increase pressure, velocity or shear rate if the design of the channel is constant [9]. Therefore, the mass flow rate can be ignored in the process of oil extraction.

4 Conclusion

From the study that was performed, the following can be concluded:

1. The finite element method using the ANSYS POLYFLOW program can be used to simulate the flow and behavior of *Jatropha curcas* dough in a single screw extruder and is capable of predicting the performance of various parameters in the extraction process.
2. Increasing the screw rotational speed will increase the velocity, pressure and shear stress rate.
3. Increasing the mass flow rate did not increase the pressure, velocity or shear rate. Therefore, this parameter can be ignored in the process of oil extraction.

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