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Non-Newtonian fluid pumping using 3D printed mechanism

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Abstract. The non-linear relation between shear rate and shear stress is the property of a Non-Newtonian fluid. A major problem existing in the extrusion of a Non-Newtonian fluid is the design of specific pumps with desired properties. Here, it is resolved by using positive displacement mechanisms. Commonly employed positive displacement mechanisms are augers and progressive cavity pumps (Moineau pumps). In this study experiments are performed using these positive displacement mechanisms for the flow of a Non-Newtonian fluid. For this study, toothpaste is used as the working fluid. The flow outputs from each mechanism are compared to determine the effectiveness of the mechanism by means of rotating the rotor at constant angular velocity for the same nozzle diameter. Further the effect of variation of angular speed of the rotor on the mass flow rate is conducted on a progressive cavity pump.

1 Introduction

Increased usage of Non-Newtonian fluids for various applications requires design knowledge and fundamental understanding of pumps for such fluids for various process applications. Auger type processing pumps can even handle materials such as sludge's, pastes, slurries and food stuffs. The flow of such Non-Newtonian fluid through an annulus is of great appeal as it has many widespread technological applications. These include oil and gas drilling, rotating machinery and in tribology. Limited works are reported in literature on Non-Newtonian fluid flows when compared to Newtonian fluid flow. Annular eccentricity is an important factor that influences the efficiency of cutting transport in oil and gas drilling applications which is demonstrated in [1].

The stability of a mixture of deionized water and glycerol flowing axially with a rotating inner cylinder was discussed in [2]. The variations of tangential and axial velocities in the radial direction are presented for a Newtonian and a shear-thinning fluid in [3]. The effects of axial and tangential flow of a Bingham plastic fluid in a concentric annulus is investigated in [4]. The characteristic parameters of a Bingham fluid flowing axially between concentric cylinders is developed in [5].

At a particular eccentricity, inner cylinder rotation and diameter ratio, the velocity components of a Newtonian and a weakly elastic Non-Newtonian fluid were presented in [6]. Calculations of flow field for different values of eccentricity and radius ratio were reported in [7]. A model for accurately predicting the pressure gradient for a Yield Power-Law fluid flowing through an elliptical well hole was shown in [8]. Velocity profiles in a partially blocked eccentric annulus of a Power-Law fluid and a Yield Power-Law fluid were presented in [9] and [10] respectively.

Positive displacement pumps pump fluid through an annular cross-section. A simulation model of a Moineau pump was created. The effect of the variation of operational parameters of the pump on its outlet flow rate was studied in [11]. The screw of an auger has been coupled with the rotor of a progressive cavity pump and this mechanism was used to extrude recycle plastic pellets and this has been described in [12].

As indicated by the literature mentioned above, not many works have been reported for flow of a Non-Newtonian fluid through different positive displacement mechanisms. The present work is an experimental comparison of the effectiveness between two different

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types of positive displacement pumps, i.e., auger and progressive cavity pumps at a constant rotor angular speed.

2 Experimental setup

Two experimental setups are considered in the present work and are shown in Fig. 1 and Fig. 2. The first is a progressive cavity pump and the other one is a helical auger rotating inside a cylinder. The figures below exhibit both setups.

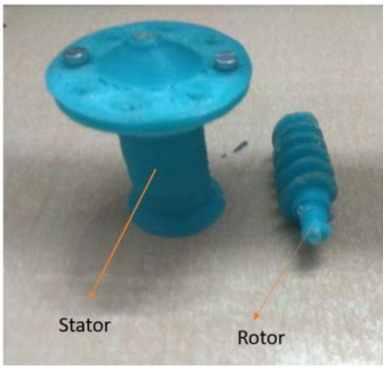

Fig. 1. Components of a progressive cavity pump

Fig. 2. Stator and rotor of the auger

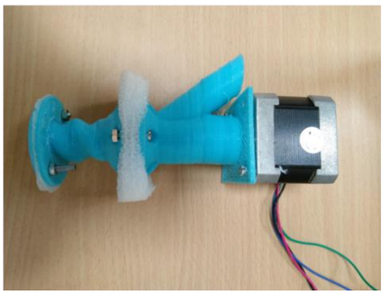

Fig. 3. Fully assembled Progressive cavity pump setup

The components used in this setup are fabricated using a 3D printer available at Foundation for Innovation & Research at SASTRA - Technology Business Incubator (FIRST-TBI). The stator for auger mechanism does not have a separate hopper and all the material feeding has to be done through the top of the stator. In the progressive cavity pump a separate hopper is provided for convenient feed of material. The internal diameter of the stator used in auger mechanism is 1.3 cm. The diameter of the auger is 1.2 cm. The helical profile has 5 turns at an axial pitch of 0.5 cm. The heights of both the stator and the auger are 2.5 cm. A stepper motor is used to provide drive to the rotor. Input to the motor is given through Arduino board. The stepper motor used is NEMA 17. The toothpaste used is a commercially available toothpaste.

The properties of the toothpaste are shown in Table 1. Fig. 3 indicates the fuly assembled progressive cavity pump with a stepper motor.

Table 1. Properties of toothpaste

Density (g/cm^3)	1.45
Dynamic viscosity (Pa. s)	70

The experimental setup is shown as a block diagram in Fig.4.

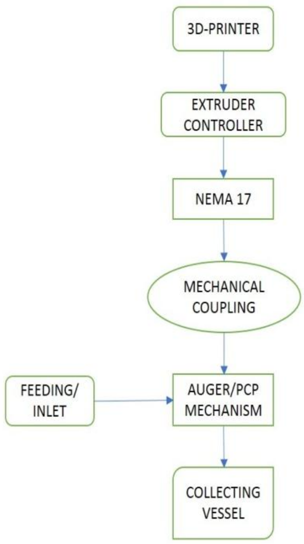

Fig. 4. Experimental Block Diagram

Toothpaste is given at the inlet. The rotor is rotated at constant angular velocity of (N=65 rpm) and paste is allowed to extrude through the nozzle. The extrusion is allowed to happen for time period of 20 secs and delivery mass flow rate (/sec) is calculated using the samples collected at the outlet of the nozzle.

3 Results and discussions

The results from experiments conducted in auger and progressive cavity pump are shown below.

Table 2. Results for Auger mechanism at N=65 rpm

	Trial 1	Trial 2
Extruded mass (g)	0.642	0.824
Mass flow rate (g/s)	0.0321	0.0412

Table 3. Using progressive cavity pump at 65 rpm

	Trial 1	Trial 2
Extruded mass (g)	0.9622	1.1039
Mass flow rate (g/s)	0.04811	0.055195

The above tables describe the extruded mass that is calculated in two trials at the rotor for the constant angular speed of 65 rpm. The mass flow rate is calculated by dividing the extruded mass with the extrusion time (20 seconds).

From the data it is noticed that the average mass flow rate delivered by Auger mechanism is 0.03665g/sec. whereas for progressive cavity pump the average flow rate at the outlet is 0.05165g/sec.

The flowrate at the outlet for auger is lower when compared with progressive cavity pump mechanism

In a progressive cavity pump, the material flows as the rotor rotates due to the profile of the rotor. This mechanism is better than an auger mechanism as there is always a negative pressure gradient developed inside the stator. This enables the material to flow in a single direction which reduces the possibilities of material being stuck onto the walls of the stator. If a pump is connected, this mechanism also prevents backflow into the pump.

It is clear from the tables that the progressive cavity pump mechanism gives positive delivery of material (mass flow rate) at the outlet than the auger.

Even when the viscosity of the viscous liquid is varying, progressive cavity pump will give constant flow rate whereas auger mechanism will vary the output according to the viscosity.

4 Conclusion

In this study, a simple model of auger mechanism and progressive cavity pump is fabricated by a 3D printer. Experiments are conduced and the results show that progressive cavity pump mechanism provides constant flow rate of material at the outlet when compared with the Auger mechanism. The positive displacement of material in progressive cavity pump mechanism makes it suitable for extruding highly viscous fluids like clay, ceramics, food stuffs etc. which has a vast use in 3D printing.

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