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Numerical Simulation in Transient Flow of Non-Newtonian Fluid in Nozzles during Filling Process

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Abstract: The rheological complexities of non-Newtonian fluids can lead to a variety of difficulties including most importantly changes in viscosity during packaging process. In order to give more understanding in this phenomena, the effect of temperature to the viscosity of chili sauce during packaging is investigated. This paper also presents the influence of three different shape of nozzles to the chili sauce flow behavior during filling time. A transient simulation has been conducted in this work using computational fluid dynamics (CFD) ANSYS CFX 15.0. It was found that viscosity is inversely proportional with temperature drop and time. The filling time also improved when using bigger conical angle of the nozzle. The results indicate the increased in production of the chili sauce and improve packaging process.

Keywords: CFD, non-Newtonian fluid, transient simulation, chili sauce, nozzle, packaging process

1. Introduction

Non-Newtonian fluids are relevant to a number of industrial application including the manufacture of fine chemicals, pharmaceuticals, personal and home care product, paper and pulp, polymers, foodstuffs, clay, and suspension. These fluids are commonly grouped into three general classes that is time independent, viscoelastic and time dependent [1]. Newtonian fluids can be described as those fluids exhibiting a direct proportionality between stress and shear rate, in laminar flow where the resulting shear stress is equal to the product of the shear rate and the viscosity of fluid medium. Newtonian viscosity, or ratio of the shear stress to rate of shear is independent of the shear rate, or shear stress, and only depends on physical parameters such as temperature and pressure [1, 2].

Non-Newtonian fluids however act in opposite manner. Those kind of fluids is violated to the Newton's law due to nonlinearity or initial yield stress. The apparent viscosity, is not constant at a given temperature and pressure but is dependent on flow condition such as flow geometry, shear rate and as reported by [1, 2]. [3] Mentioned that the Non Newtonian fluid is well-known as an unstable fluid due to the complexity of its rheological structure.

Chili sauce flow characteristics are non-Newtonian with viscoelastic and shear thinning behavior with yield stress that could be described effectively by Herschel–Bulkley model. Chili sauces are considered as complex multiphase suspensions of deformable chili particles and sometimes liquid deformable particles such as oil droplets. Chili sauce is made from chili. Chili (Capsicum annul) is a spice cum vegetable of commercial importance. It is cultivated mainly in Southeast Asia, India, China and Mexico, while it is extensively used in cuisines around the world. Such a product is frequently consumed with a variety of foods to add piquant taste as well as to give better appearance and texture characteristics [4].

Chili sauce is very popular and widely consumed in Malaysia. Chili sauces are originally home cooked. However, nowadays they are commercially available due to high market demand, and are mostly produced by machines. Considering the Malaysian market, there are numerous brands of chili sauces such as Azad, Adabi, Cap Arnab, Cap Kipas Udang, Cap Tupai, Cintan, Del Monte, Giants, Golden Mountain, Heinz, Kampung Koh, Kimball, King, Life, Limgam's, Lotus, Maggi, Maju, Srirajapanich, Tesco, Tower Mas, and lots more as reported by [5].

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A manufacturing process for chili sauce production normally involves four different stages. Firstly, all raw materials are mixed and cooked under high shear conditions, typically around 3000 rpm, at temperature approximately between 90 °C and 95 °C. The resulting sauce is subsequently pumped into a reservoir to allow cooling down before being filled into containers [4].

Typically, raw materials used in producing chili sauces include chili, garlic, water, sugar, salt, vinegar, hydrocolloids and preservatives [4]. Formulation the raw materials used in producing chili sauce determines the sensory quality (appearance, colour, smell, texture and flavour) and nutritive values (chemical and microbial components and flavour) which influence in their shelf life [6].

Knowledge of the rheological properties of fluid and semisolid foodstuffs is important in the design of flow processes in the quality control, storage and the processing stability, and in understanding and designing texture. [7] reported that the viscosity is considered an important physical property related to the quality of food products. Therefore, reliable and accurate rheological data are necessary for designing and optimization of various food processing equipment such as pumps, piping, heat exchangers, evaporators, sterilizes, filters and mixers The viscosity of food products cannot be predicted theoretically, due to complicated physical and chemical structure as suggested by [8].

To understand and control those processes which used chili sauce, knowing the viscosity is important because of the chili sauce are subjected to different temperatures during processing, filling, storage, transport, marketing and consumption, it is important to study the effect temperature to the viscosity of chili sauces [8]. The effect of temperature on the apparent viscosity or consistency coefficient at a specific shear rate also been investigated by [9]. When packaging the chili sauce, one has to take extra caution because the sauce will thicken when the temperature drop. Therefore, the objective of this study is to study the effect of temperature drop during packaging process on viscosity using Computational Fluid Dynamics (CFD). Other than that, this paper also presents the influence of geometry shape of nozzle to velocity during chili sauce packaging process using CFD.

2. Methodology

In this study, ANSYS CFD version 15.0 is used to simulate the filling of chilli sauce to the bottles using three different shapes of nozzle. The nozzle geometry is shown in Table 1. Three mesh configurations of 310 000, 811 000 and 1 362 000 cells were conducted for the grid independency test. The velocity in *y*-axis with difference grid sizing was analyzed. The results show there is no significant difference between the 811 000 and 1 362 000 configurations as all lines of both configurations are almost overlapped. These indicate that using finer mesh does not improve the model prediction. Thus, meshing with lower number of mesh cells does not sacrifice the solution accuracy. Since the Central Processing Unit (CPU) time increases exponentially with the number of grids, the lower mesh cells, 811 000 were chosen. Less mesh cells reduce CPU time during CFD simulation which permits a significant number of cases to be run. The meshing gave a total of 246 000 nodes and had 811 000 elements that consisted of unstructured tetrahedral meshes. A higher mesh refinement was used at nozzle and bottle to maximize the accuracy of the simulation. The three shapes of nozzle and fluid domain consist of dispenser, nozzle and bottle is shown in Fig. 1. The simulation is conducted in transient with the total time was 15s and time step size was 0.05s. The boundary condition was set as shown in Fig. 2. The inlet mass flow rate used is 0.3 kg/s and the opening is set to outlet. The Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) scheme was selected for the pressure-velocity coupling while for spatial discretization section, the green-gauss node based was set. The second order upwind was used for the momentum, turbulent kinetic energy and turbulent dissipation rate to arrive at the best solution. The flow model chosen was laminar.

Table 1 The nozzle geometry

Nozzle	Diameter, cm	Conicity Angle,°
1	1.5	26.5
2	2.0	14
3	2.5	0

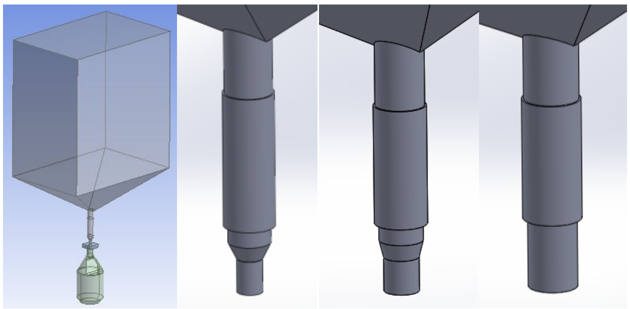

Fig. 1 The dispenser and three different shapes of nozzles

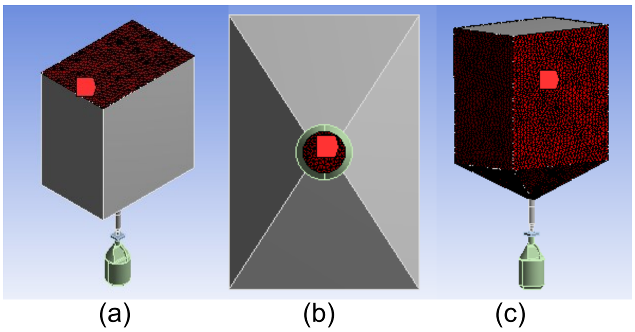

Fig. 2 The boundary conditions (a) inlet (b) outlet (c) wall

3. Results and Discussion

3.1 The chili sauce flow

The chili sauce flow simulation for filling at different time and temperatures are illustrated in Fig. 3 Based on the results obtained, it is shown that the chili sauce at the highest temperature of 80°C has the highest velocity

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compared to the other temperatures. The bottles are filled quicker compares to other temperature. This is because the value of yield stress and viscosity are high at low temperature. Temperature drop will increase the value of yield stress and viscosity resulting more viscous effect occur.

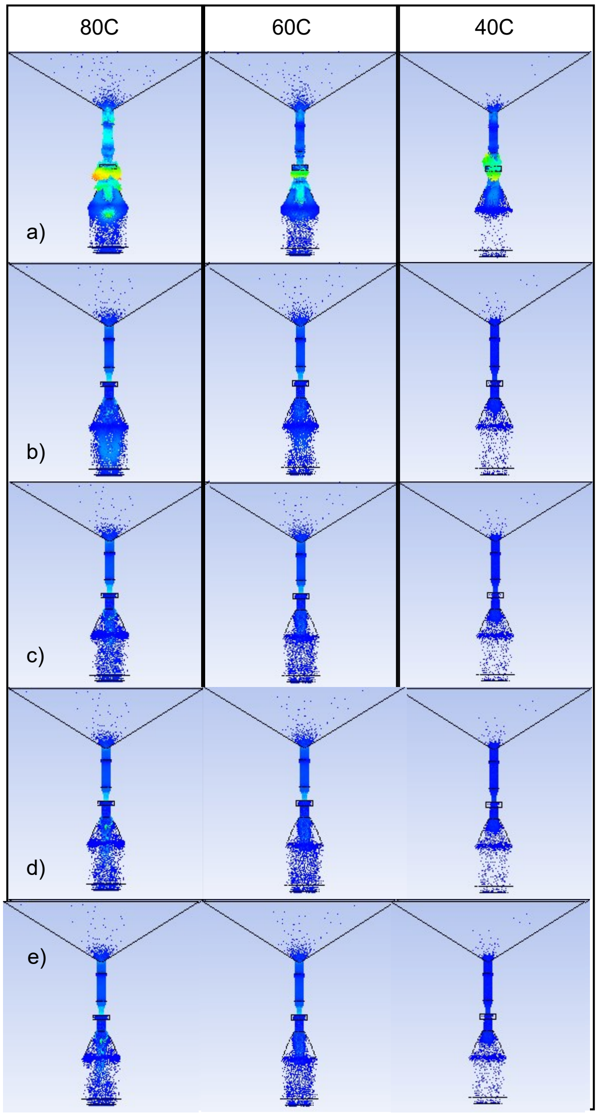

Fig. 3 The flow simulation at 40°C, 60°C and 80°C from 0.15 s to 1.5 second (a) 0.15 sec (b) 0.45 sec (c) 0.75 sec (d) 1.05 sec (e) 1.50 sec

Packaging time is directly proportional to a temperature drop. In other words, longer time in packaging process will increase difficulty during the packaging process. The Fig. 4 shows the velocity of the chili sauce against time at different temperatures of 40°C, 60°C and 80°C. The results show that the hottest sauce has the highest velocity and viscosity is decreased with temperature drop. This is because as the time increased, the hot chili sauce begin to cool due to heat transfer convection phenomena with a surrounding. As a result, they become more elastic and develop solid properties. This resulting the tendency to returning again to the original viscoelastic range. In other words, it will increase a viscosity, and make the packaging process much difficult.

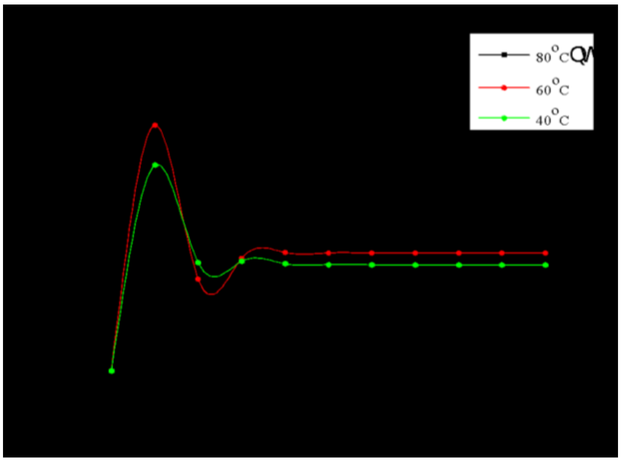

Fig. 4 The flow behavior of chili sauce at different temperatures.

3.2 The effect of geometry shape of nozzles to filling process

The shape of nozzle plays an important role in order to minimize the viscosity effect during packaging process. Fig. 5 shows the velocity vector and pressure contour during filling process. Based on the result obtained, it is shown that the variation of shape of nozzle can influence the behavior of chili sauce movement. Long-time in packaging process will cause the temperature drop to occur. The temperature drop can increase viscosity of chili sauce.

It can be seen that nozzle 1 have a higher in velocity and pressure compared with two other nozzles. This is because nozzle 1 has the biggest conical angle thus give more energy and pressure to the chili sauce. Therefore, the filling time is shorter compared to other nozzles. It is because that non-Newtonian fluid has varying viscosity and the apparent viscosity is not constant at a given temperature and pressure and dependent on the shear rate changes. It is well known that chili sauce has the shear thinning fluid property. As the pressure and shear rate increase, viscosity is decrease due to the shear thinning behavior. Higher of velocity means that more shear rate changes will occur in the nozzle resulting the decreasing of viscosity. Fig. 6 shows the viscosity of the chili sauce in terms of time and temperature. It can be seen that the viscosity is vary with time and temperature. The graph shows that the viscosity is proportionally decreasing with time and temperature drop. This phenomena is occur due to the Brownian motion of the chili sauce that increased with the temperature, resulting in a less developed structure at higher temperatures, which explains the lower values or viscosity of chili sauce at high temperature.

4. Conclusion

The computational fluid dynamic simulation for unsteady flow of chili sauce successfully was carried out. It is observed that the temperature and time of chili sauce packaging process can significantly affect to the flow phenomena especially the viscosity. It is clearly can be stated that viscosity is inversely proportional with temperature drop and time. The geometry shape of nozzle also can significantly affect to the flow behavior of chili sauce. The biggest conical angle is the best shape to give the shortest time to fill the bottle. Thus improve the packaging process and increase the production rate. This research will further help on identifying the required parameters in designing most appropriate equipment that can be used to improve the chili sauce production and packaging process.

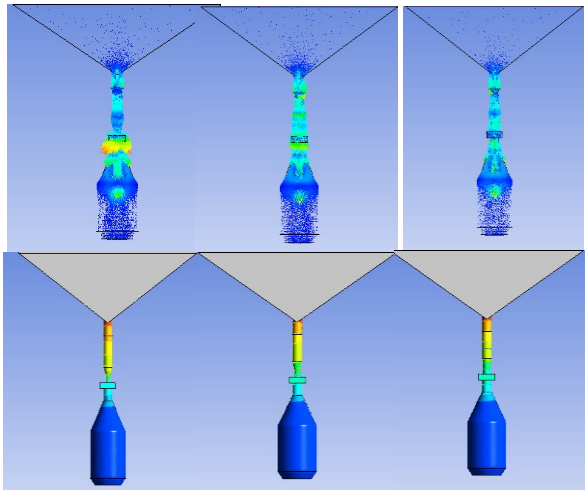

Fig. 5 (a) Velocity vector and (b) pressure contours in a nozzle and bottle at 80°C

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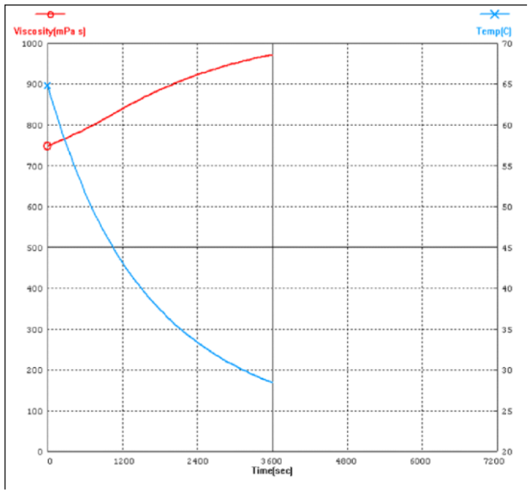

Fig. 6 Viscosity of chili sauce in term of time and temperature

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