Impact of Frictional Heat Generation upon Temperature of Sesame Paste Flow through Screw-expeller

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INTRODUCTION: In past literature on flow through screw expeller, in general, no-slip condition was assumed to prevail at all boundaries and viscous heat dissipation was taken as the major heat source to model temperature of the flow [1]. When no-slip condition is relaxed [2], friction at contact surfaces and the resulting heat generation shall be considered. Frictional heat generation at the paste/barrel interface was modelled for the first time in this study. Model developed was simulated using COMSOL Multiphysics®.

COMPUTATIONAL METHODS: Screw-expeller used consisted of a rotating tapered screw and a constant-inner-diameter stationary barrel. Since screw diameter was much larger than the sesame paste thickness, an unwrapped model was employed with Cartesian coordinate x taken parallel to the barrel surface, y taken perpendicular to screw flights and z taken from screw root to barrel. Steady, fully developed, incompressible, creeping flow was assumed. Sesame paste was observed to exhibit shear thinning behaviour described by $\mu = K\,[(\check{D}:\check{D})^{½}]^{n-1}$, where μ is viscosity, K is consistency coefficient, n is power-law index, $[(\check{D}:\check{D})^{½}]$ is shear rate and $\check{D}$ is strain tensor expressed in terms of the gradient of flow velocity ($\bar{U}$) as $½\,[\nabla\bar{U} + (\nabla\bar{U})^T]$. Mass, momentum and energy balance equations available in the computational fluid dynamics (CFD) module of COMSOL Multiphysics® were used. In the past literature, no-slip was assumed at the paste/barrel and paste/screw interfaces and viscous heat generation, given by $Q_V = 2\mu\check{D}:\nabla\bar{U}$, was taken as the major heat source. In this study, slip at the paste/barrel interface and the resulting frictional heat generation at the said interface (Q_F) were considered. Q_F is given by $\int\int (\pi\ \lambda\ p_{barrel}\ \beta\ D_b\ N)\ dy\ dx$, where λ is coefficient of friction at the paste/barrel interface, p_{barrel} is the pressure acting at the paste/barrel interface, β is the slip factor at paste/barrel interface (β = 0 for no-slip condition and β = 1 for total slip), D_b is the inner-barrel diameter and N is the screw rotational speed. Owing to the reduction in sesame paste thickness along x-direction, choice of mesh was crucial to the accuracy of the temperature field simulated and therefore a user-controlled mesh was used. Extra fine-sized free triangular mesh was created on the barrel surface boarded by extremely fine-sized mesh on either sides and they were swept down to the screw root surface through 20 fixed number of elements so that the reducing thickness of the sesame paste was adequately represented for numerical simulation. The choice of mess was guided by sensitivity analysis. Taguchi method [3] was utilised to design the simulation study on the impact of β, K and n upon the maximum temperature of flow.

RESULTS: A 4-factor and 3-level Taguchi experimental design was used to study the impact of p_{exit}, β, K and n upon the simulated maximum temperature of the paste. Results are depicted in Figure 1. At β = 0, Q_F was zero and Q_V raised the flow temperature to a maximum of 0.7˚C above the inlet temperature. As β was increased from 0 to 0.3, Q_F increased, almost linearly, to its highest at 13 W. Maximum temperature also increased, almost linearly, to its highest at 65.9˚C. As the temperatures recorded during the laboratory experiments (subjected to a maximum of 57˚C) were below 65.9˚C, investigations were not extended beyond β = 0.3. Simulation results showed that Q_F and, hence, the maximum temperature were more sensitive to β than to p_{exit}, K and n.

CONCLUSIONS: When working with highly viscous flow such as polymer flow, viscous heat would be of considerable quantity and, therefore, would be adequate to explain the temperature rise within the material flow. Viscous heat was totally inadequate to explain any temperature rise in the sesame paste flow since its viscosity was not as high as that of polymer flow. Simulations of the model developed successfully predicted temperature rise in the flow. This study, therefore, clearly demonstrated the importance of including slip at the boundaries and Q_F when modelling sesame paste flow and other similar low viscous flow through screw-expeller.

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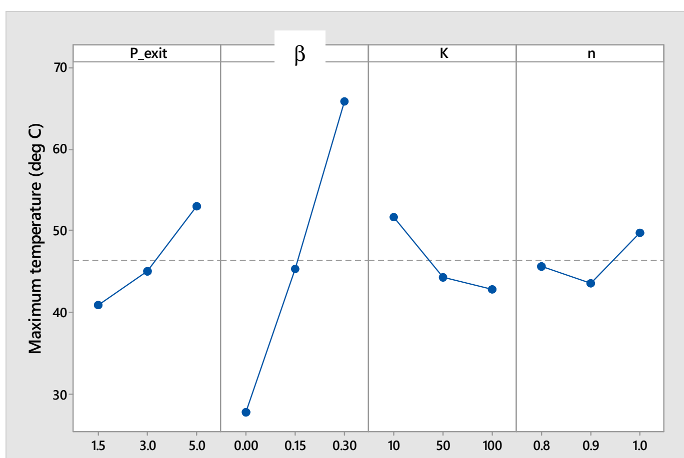

Figure 1. Data means of maximum temperature at levels of factors: exit pressure (p_{exit}, in bar), slip factor (β), consistency coefficient (K, in Pa.s^n) and power-law index (n). Pressure and temperature at the inlet were 1.0 bar and 27˚C, respectively.

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