Process Rheology Predictions in a Confectionary Extrusion Process

Martin Gram Christensen[1] and Alan Friis[1]

[1] Food Production Engineering, National Food Institute
Technical University of Denmark, Lyngby, Denmark

ABSTRACT

The effect of extrusion process settings on final texture of confectionary products have been investigated using rheology and texture evaluations. The fluid dynamics is validated theoretically inside a single screw extruder and preliminary results show correlation to higher process shear leading to a softer texture of the final product. The product is characterised using the power law model where both the exponent and the consistency index are found to be constant.

INTRODUCTION

The core of modern food industry is prediction and the ability to control your process to create a uniform, repreduceable and consumer percieved product. Especially rheology and final texture are difficult parameters to measure and control.

In this study the rheological behavior of a confectionary base has been investigated to correlate process settings in an extrusion process to final product characteristics, in order to improve process control. Based on experiments conducted in a pilot plant extruder, process rheological behavior has been characterized based on process parameters (pressure, feed, rotation and geometry) by use of mathematical modeling: Qualitative rearrangement of the Pouisouille equation[1] Eq.1 yields the relation:

$$\Delta P \propto \frac{Q^n}{D^{3n+1}} \tag{1}$$

Utilization of the Rabinowitch relation, as determined Youngoon Son[2] Eq. 2 :

$$n = \frac{d(log\Delta P)}{d(logQ)} = \frac{d(\tau_w)}{d(\gamma_a)} \tag{2}$$

And the relation between process parameters and consistency index for power law fluids Eq. 3:

$$\frac{R\Delta P}{2L} = m\left(\frac{3n+1}{4n}\frac{4Q}{\pi R^3}\right)^n \tag{3}$$

Where n is the power law index, m is the consistency index. The variables (shear stress and shear rate) are calculated based on Q (volumetric flow rate), R (radius), in this study the hydraulic radius as experienced by the flowing product, the extruder length and measured pressure drop. Due to spectacular flow characteristics the process flow is based on the axi-circular movement of the product along the extruder screw.

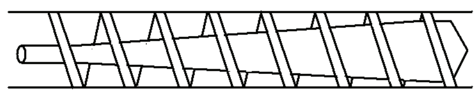

Figure 1. Principle in the single screw extruder annulus.

The product is expected to change character during extrusion concerning texture and rheology, the hypothesis is that higher shear rates yields a softer texture[3]. In the study the wall shear caused by the screw as well as the extrusion chamber is evaluated.

MATERIALS AND METHODS

The final product texture is characterized by measuring the pre processing rheology (storage modulus, yield stress and phase angle) on a HAAKE Modular Advanced Rheometer System (MARS) using oscillation plate-plate methods. For the post process texture measurement slicing, compression (95%) and max slope of compression on a Stable Micro Systems TA-XT2 Texture Analyser is applied. In the texture measurements, the data is normalized by dividing the force with the sectional area of the specimens.

The extruder is a pilot plant single screw extruder (HAAKE PolyLab RheomixOS, ThermoFischer), with pressure transducers mounted along the axis is utilized to monitor the process physics during extrusion i.e. to evaluate the process rheology on-line, by the means of shear rate and pressure drop.

To relate the shear and rheology data to the extrusion process, a mathematical expression for the accelerating helical flow is developed. The extrusion is conducted under different flow rates and temperatures to evaluate the extrusion parameters impact on the final texture of the confectionary product.

The further data analysis and modeling is conducted using Latentix PCA, and PLS modeling to map the correlations and causal textural process factors.

RESULTS

The extrusion process is conducted at 50°C at 30, 60 and 120 rpm. The preliminary results for the extrusion experiments show a softening of the texture when processed under higher shear, Table 1. The fluid dynamics inside the extruder is calculated based on flow rates and pressure drops along the extruder axis and are presented in Table 2.

Due to high uncertainties in the calculations of the specific process flows, and in the experienced geometry no significant differences in the power law fluid dynamics under the different conditions is observed at this point.

Table 1. Texture results.

	τ [Pa]	*γ[1/s]*	*Comp*	*StDev*
30 rpm	7698	25643	12,12	0,70
60 rpm	9712	55370	9,52	0,60
120 rpm	10470	108129	8,71	0,32

Table 2. Process rheology results.

	P [bar]	*Q [m³/s]* 10^{-6}	*n*	*M*
30 rpm	3,49	0,383	0,21	912
60 rpm	4,36	0,827	0,21	980
120 rpm	4,72	1,615	0,21	918

CONCLUSION

The preliminary results show correlation between shear and final texture of confectionary products, leading to a softer texture under higher shear conditions. The fluid dynamics could be evaluated based on proves settings, but does not seem to change markedly. Further experiments will frame the process impact of different extrusion temperatures and a wider shear range to model the final texture based on the process history.

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REFERENCES

1. Levine, L., (2008). “Extrusion rheology”. Food extrusion Master course 2008, Switzerland.

2. Son, Y. (2007), “Determination of shear viscosity and shear rate from pressure drop and flow rate relationship in a rectangular channel”, *Polymer, **48**, 632-637.*

3. Levine, L. (2008), “Introduction to extrusion”. Food extrusion Master course 2008, Switzerland.