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APPLICATION NOTE

No. LR-78

The influence of extrusion conditions on the processability of starch compounds

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Keywords
Food extrusion, twin-screw compounding, process optimisation

Introduction

Starch is a base material that is widely used in the food industry for snack foods, cereals and pet food products. The processing of starch with twin-screw extruders offers great flexibility in process design and in the final products derived from it.

Carefully choosing extruder parameters like screw set-up and processing temperature, as well as the liquid-to- solid ration of the raw materials enables the operator to greatly influence the resulting product properties.
This application note showcases the different process parameters that play an important role in influenand their influence on the final product quality.

Experiment

The Thermo Scientific™ Process 11 "Hygienic" Parallel Twin-Screw Extruder was used for extrusion experiment.

Figure 1: The Thermo Scientific Process 11 "Hygienic" Parallel Twin-Screw Extruder.

The extruder itself is built of hygienic grade steel and is therefore perfectly suited for the processing of food-based materials.

A 30 mm sheet die with a gap height of 1.0 mm was attached to the extruder.
The extruded starch sheet was taken off by a small conveyor belt.

To avoid any loss of sample humidity, 20 mm discs were immediately cut from the extruded sheet, and the rheological properties were determined without further delay.

Sample material

- Extrusion System:
  Process 11 "Hygienic" Twin-Screw Extruder (see Figure 1)

ThermoFisher SCIENTIFIC

- Cooling Circulator:
  Thermo ScientificTM Polar Series Accel 500 LC Recirculating Chiller
- Feeder for Premix:
  Gravimetric MiniTwin MT0 for Process 11 Extruders
- Feeder for Liquid:
  Thermo ScientificTM Masterflex P/S Pump Systems
- Extrusion Die: 30 mm Sheet Die
- Take-Off System:
  Mini Conveyor Belt for Process 11 Extruders

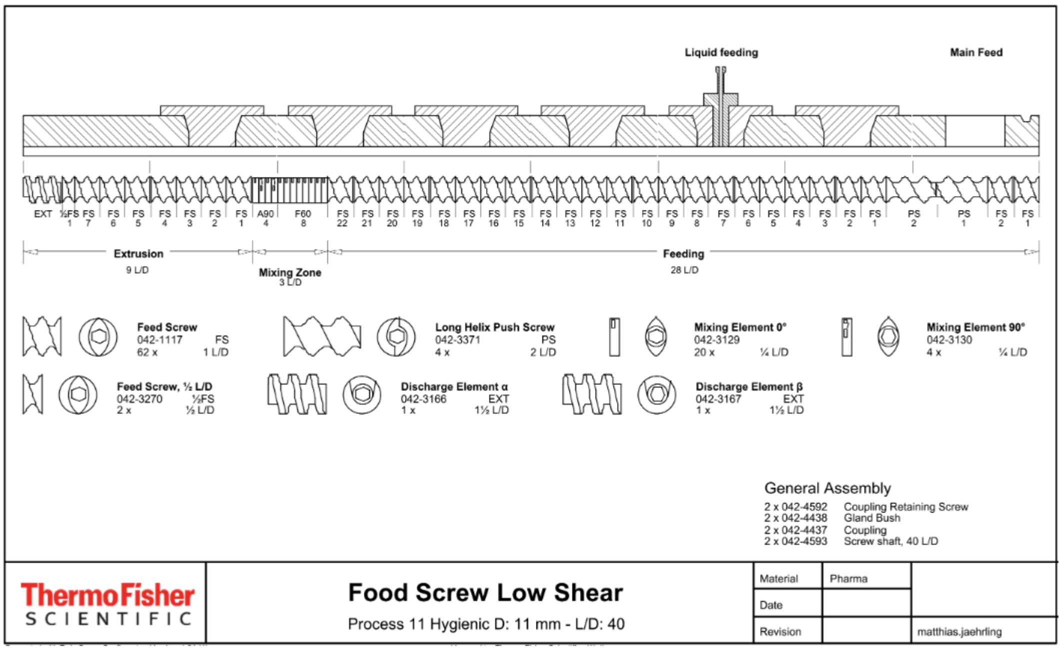
Rheology equipment

- Rheometer:
  Thermo Scientific™ HAAKE™ MARS™ 60 Rheometer
- Temperature control: Peltier temperature module
- Measuring geometry: 20 mm Parallel plates

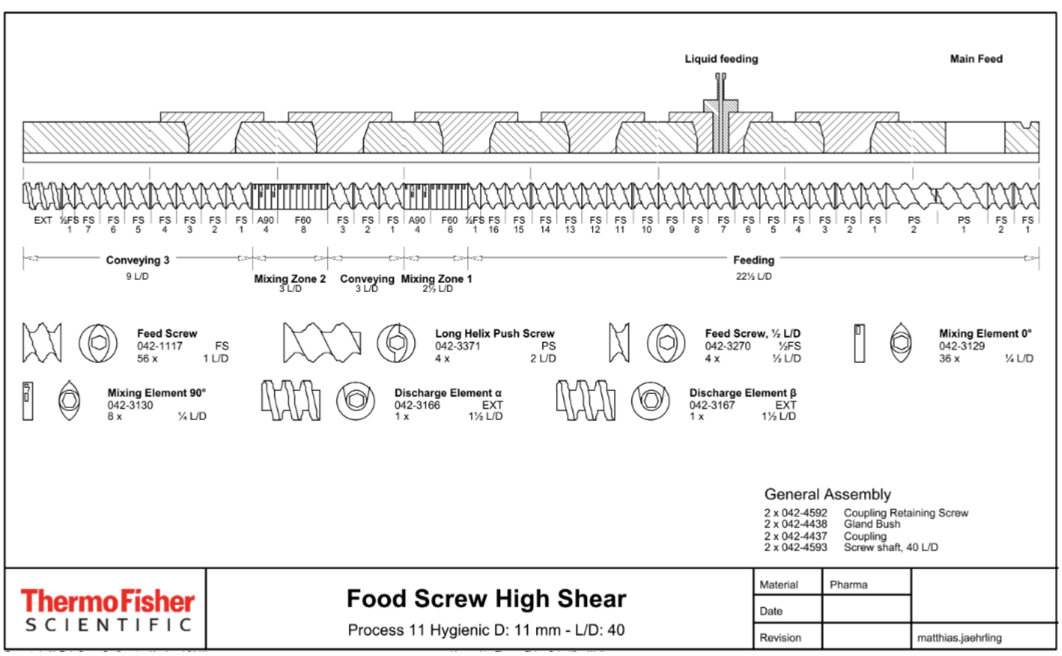
Extrusion conditions

Variable 1: Screw-Configurations

a) Low shear screw ("LS"): One stage mixing



b) L High shear screw ("HS"): Two stage mixing



Variable 2: Temperature profiles

Table 1. Low Temperature Profile (“80 °C”)

Barrel Temperature Profile “80 °C“									
Zone	Die	9	8	7	6	5	4	3	2
	80°C	80°C	80°C	80°C	80°C	70°C	70°C	50°C	50°C

Table 1. Low Temperature Profile (“120 °C”)

Barrel Temperature Profile “120 °C“									
Zone	Die	9	8	7	6	5	4	3	2
	80°C	90°C	120°C	120°C	120°C	70°C	70°C	50°C	50°C

Variable 3: Speed extruder screws

a) 200 rpm
b) 400 rpm

Variable 4: Feeding rate

a) 540 g/h
b) 960 g/h

Process 11 Hygienic									
Sample No.	Screw config.	Speed [rpm]	mp [g/h]	Extrusion Temp.	TM [°C]	P [bar]	TQ [%]	RT [sec]	|η*| 10 Hz [Pa*s]
1	Low	200	540	80°C	87	31	24	95	15040
2	Low	400	540	80°C	94	25	25	78	12170
3	Low	200	960	80°C	93	41	33	58	15900
4	Low	400	960	80°C	99	33	28	47	12830
5	Low	200	540	120°C	113	35	26	99	20990
6	Low	400	540	120°C	117	32	28	91	20680
7	Low	200	960	120°C	107	50	28	63	24020
8	Low	400	960	120°C	115	48	27	51	29090
9	High	200	540	80°C	86	33	37	110	12960
10	High	400	540	80°C	98	24	32	92	9194
11	High	200	960	80°C	93	39	44	70	13970
12	High	400	960	80°C	99	31	39	56	12250
13	High	200	540	120°C	113	33	28	110	17300
14	High	400	540	120°C	119	38	27	75	13160
15	High	200	960	120°C	103	44	36	68	16830
16	High	400	960	120°C	115	37	32	57	15840

Figure 2: Test-Matrix and results of the extrusion tests.

Discussion of the extrusion results

a) Residence time

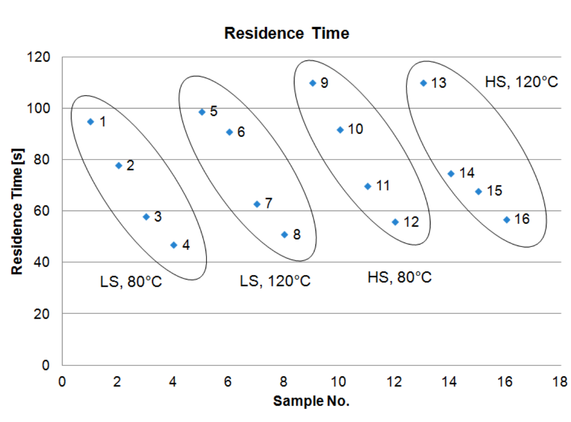


Figure 3.

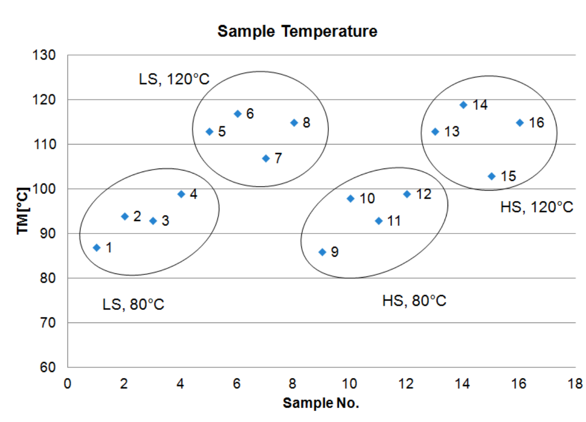


Figure 4.

The residence time was measured by means of a color tracer that was added into the main feed port. The time was stopped until a color change could be seen on the extruded sheet.

Figure 3 shows the results of the residence time measurements.
It can be clearly seen that the residence time gets shorter- with increasing screw speed and with increasing feed rate,

whereas the effect of the higher feed rate proved to have a much larger effect on the residence time.

It also can be seen, that the extrusion temperature had nearly no effect on the residence time. Finally, the effects of the different screw configurations are not very significant.

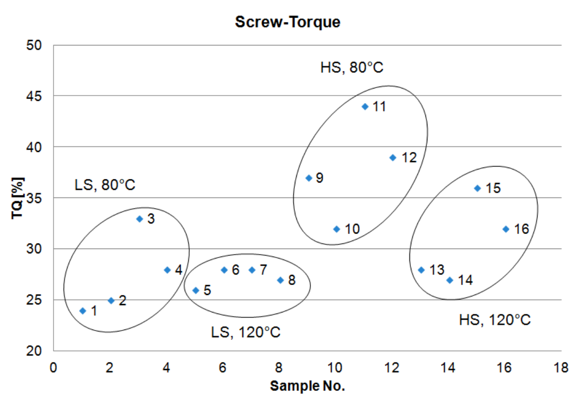
b) Sample temperature

The sample temperature was measured with a melt thermocouple, which was placed at the die adapter at the end of the extruder.

As expected, Figure 4 shows that the sample temperature increased, with a higher extruder temperature. In addition, the higher screw speed resulted in a higher sample temperature. The different screw configurations seemed to have no significant effect on the sample temperature.

c) Extruder torque

Figure 5.



The measurement of the extrusion torque showed a clear increase in torque when using the high shear screw configuration with the two mixing zones. It also can be seen that the torque is higher at lower temperatures. Higher feed rates with the same screw speed generate a higher torque where- as an increase of the screw speed decreases the torque.

d) Sample viscisity

The measurement of the sample viscoelastic behavior gave some interesting and unexpected results. The highest sample viscosity could be found with samples extruded at 120 °C with the low shear screw configuration. The viscosity measurements at 80 °C with the low shear screw configuration showed no significant difference to the samples prepared with the high shear screw at 80 °C and 120 °C. A possible ex- planation of this result may be that the sample wasn't yet fully gelated at 80 °C, but it was over-sheared with the high shear screw configuration so the structure already suffered a structural damage.

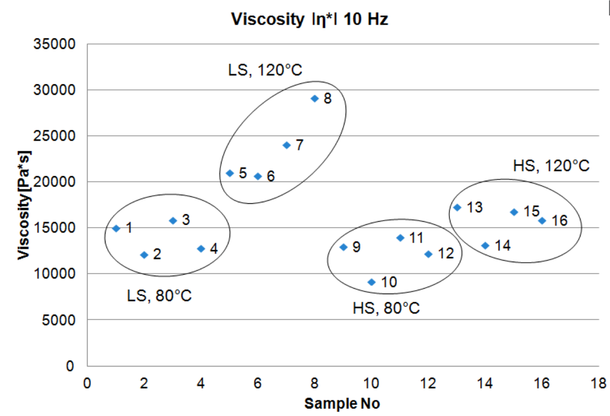


Figure 6.

The test results indicate that extrusion with the low shear screw configuration, at 120°C, at the high feed rate, and at the high screw speed delivered the best gelation of the product.

Rheological results

Rheological tests were performed on the samples with a HAAKE MARS 60 Rheometer with a Peltier temperature module. All tests were conducted at 20 °C with a parallel plates measuring geometry: P20/Ti. All samples collected from the extruder were measured immediately. Test spe- cimens were cut out of the extruded sheet with a 20 mm punch hole. First an amplitude sweep from γ 0.5 to 50% at 1 Hz was performed to determine the linear viscoelastic range.

It is obviously in Figure 7 that linear viscoelastic range extends to a deformation of about γ = 10%. For all the successive frequency sweeps, a deformation of γ =2% was the set value for the tests with a frequency range of 0.02 to 46 Hz. To were repeatability, two fresh test specimens extruded at 80 °C were measured.

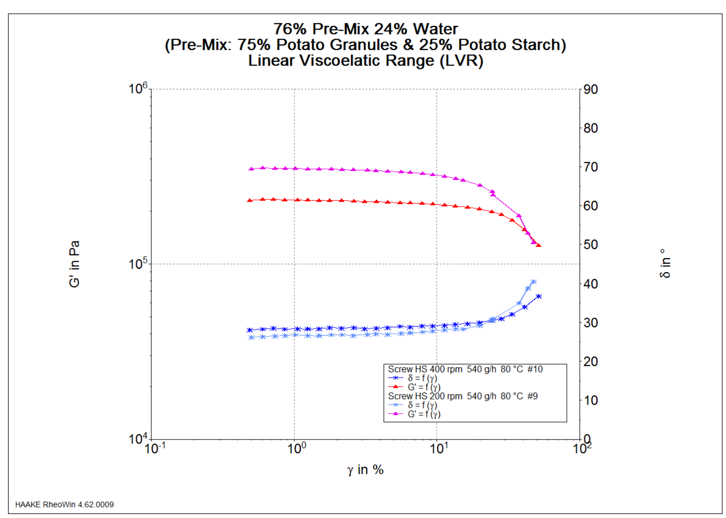


Figure 7: Determination of the linear viscoelastic range. High shear screws, feed rate 540 g/H at 80 °C.

In Figure 8 the results of the two tests are plotted and show a reasonable repeatability. All test specimens show the same viscoelastic behavior; the elastic component G' is always higher than the viscous part G". In the frequency dependence of the complex viscosity |η*| a shear thinning of the sample is visible. This is also the typical trend of thequantities for all the other tests.

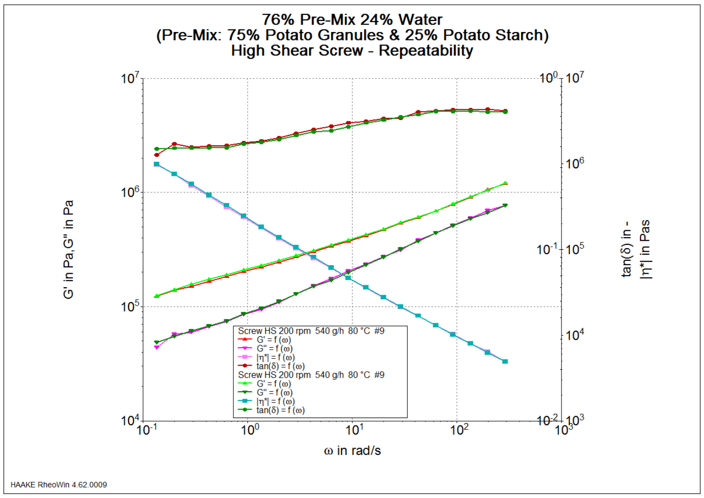


Figure 8: Frequency sweep repeatability. High shear screws, feed rate 540 g/H at 80 °C.

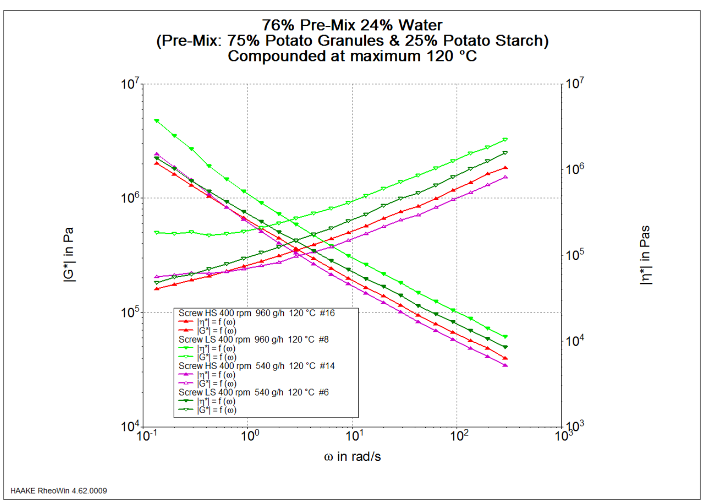


Figure 9: Frequency sweep - high shear screws, different feed rates at 120 °C.

The four tests of the samples with low shear screws and the different feed rates at 120 °C are plotted in Figure 8. The complex viscosity |η*| and modulus |G*| of the samples with a feed rate of 540 g/h is almost independent of the screw speed. With an increase of the trough put to 960 g/h, the values increase and the expected effect the of higher screw speed is visible. High feed rate and high screw speed of the low shear screws result in the highest viscosity and modulus which is an indication of the best gelation (see also Figure 6).

Conclusion

The gelation of starch is a complex process that is dependent on several variables. For water concentrations between 20% and 60%, the degree of gelatinization shows a strong dependency on the processing temperature [1]. The higher the temperature, the more complete the gelatinization is.

This effect can be observed in Figure 6 where, using a liquid content of 26%, the viscosity is highest at 120 °C. Under the same conditions, the higher shear energy introduced into the system by the screw setup with two mixing zones degrades the three-dimensional network during the gelatinization process.

In summary, using twin-screw extrusion for production of a starch matrix offers a range of processing variables that enables the user to more adeptly design a starch matrix to required product properties. Twin-screw extrusion offers the user the ability to influence texture, stability and further processability of the final product. Combining extrusion with oscillatory rheology allows for defined, precise analysis of the end product and thus provides a workflow that enhances capabilities in today's food design.

Reference

1. Fechner, Petra M. „Charakterisierung pharmazeutischer Hilfsstoffe“ 2005; Dissertation at Martin Luther Universität Halle-Wittenberg

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