Replacing fossil-based foams with (potato) carbohydrate based foams

VerPAK TIND121009

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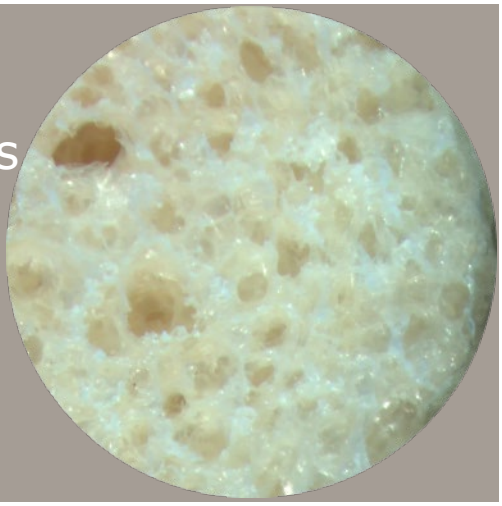


WAGENINGEN UNIVERSITY & RESEARCH

Public Summary

Introduction

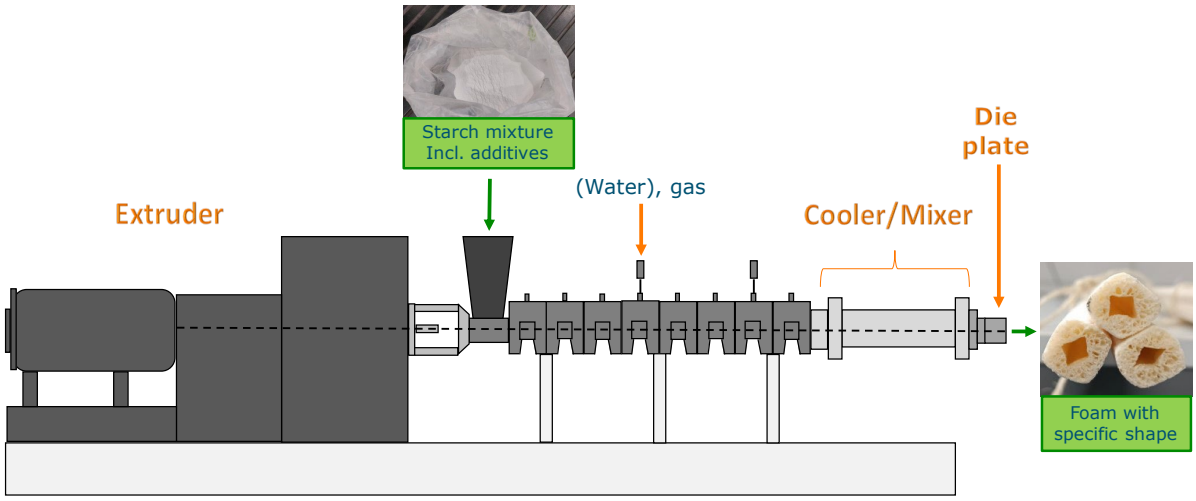
In December 2021, the project VerPAK (in Dutch: *Vervang Piepschuim door (Aardappel) Koolhydraat gebaseerde materialen* - Replace expanded polystyrene by (potato) carbohydrate-based materials) was granted by the RVO (Netherlands Enterprise Agency) in the framework of the Top sector Energy industry subsidies under the topic "Closing industrial chains", project number TIND121009. The project had a duration of two years and one month, starting on January 1st, 2022 till January 31st 2024. PaperFoam bv commissioned this project and applied for the subsidy together with ProSuMe. The project activities executed by Wageningen Food & Biobased Research (WFBR) and Centro di Servizi Metrologici Avanzati (CeSMA) and University of Naples Federico II (UNaples) were subsidized by RVO, the three days external trials at the commercial pilot line (Sulzer, Switzerland) were prepared by the consortium and sponsored by Paperfoam bv. Simulations and die design and manufacturing for this project were performed by a PhD student employed and supported by personnel from the Centro di Servizi Metrologici Avanzati (CeSMA) and the Department of Chemical, Materials and Production Engineering, University of Naples Federico II.

The goal of the project was to do industrial research and experimental development of a prototype of a biobased and innovative alternative for EPS-based packaging materials and the process to produce it. WFBR, CeSMA/UNaples and PaperFoam worked together with the aim of finding the right production system and process parameters, die-designs and recipes to mass produce extruded starch/fibers mixtures towards foamed products suitable for packing of heavy products (white, grey and brown goods).

The results of the project contribute to the long term goals of the Dutch Top sector Energy by closing industrial chains, namely: "In 2030, greenhouse gas emissions from production processes and the waste sector will be reduced to approximately 36 Mton CO_2 equivalent" (and) "bio-based raw materials are seen as standard."

Summary

Foaming of polymeric materials requires a delicate balance between raw materials, blowing agents and equipment. They have an important effect on the end properties of the product. During this project, the behavior of the raw materials based on starch/fibers mixtures and water as blowing agent was investigated by means of offline rheological measurements, providing data for process development. Furthermore, three essential parts of equipment were investigated: 1) the extruder, 2) melt cooling and mixing systems, and 3) die plates. Equipment with specific requirements is needed to get to a stable extrusion foaming process using water as blowing agent. A continuous process generating foamed profiles with different cross sectional shapes could be obtained. A sketch of the process is shown below.



Main results and conclusions

Three essential parts of equipment have been identified as crucial for a stable extrusion foaming process of starch/fibers mixtures and water as blowing agent:

- Extruder with a screw design suitable for processing starch and enough power to plasticize the starch without degrading it.
- A cooler and mixer or a cooler/mixer combination to ensure homogeneous melt temperatures and high enough pressures at the die.
- Dies designed with specific cross sections that will result in the desired uniform well-defined shapes. Use of a pin can result in hollow profiles, they are interesting to decrease bulk density and increase recovery properties.

Two different processes were studied: at a commercial pilot line and at a modular line at WFBR. A three days trial was done at a commercial extrusion foaming line with the goal to obtain symmetrically shaped, centimetres thick foamed profiles with sharp edges and low densities. A stable production of two different well-defined shaped foamed profiles (rods and square profiles) could be established at this commercial pilot foaming line. A feasibility trial was done at WFBR by combining a modular extruder with a cooler/mixer combination equipment. A stable extrusion process resulting in homogeneous foams could be demonstrated for starch mixtures with this equipment. In both processes as tested up to now, it was shown that combinations potato starch and fibers result in a more stable process under the current settings in comparison to mixtures in which for example tapioca starch is used. Foams with densities of around 100 g/L are possible with the studied process and with a maximum recovery of 70% at 20% compression. Mechanical properties of analysed foams correlate linearly with the density of the foamed profiles. Compression strength increases with increasing density but recovery decreases with increasing density. Densities are not yet as low as those of commercially available fossil based foams (around 30 g/L).

Various experiments were done to understand the viscoelastic properties of starch/fibers mixtures. This was very important for developing simulations that could predict the behaviour of the mixture during the processing and through the die (exit of the extruder that defines the shape of the final product). Special emphasis was put on being able to obtain reliable data of the full formulation at fixed moisture contents. Measuring starch/fibers mixtures at high moisture contents at temperatures above 100°C is quiet challenging. Accurate moisture control and a system where minimum water loss can be guaranteed are needed. During this project, it was worked with the closed cavity rheometer (CCR), and it was demonstrated that the generated data is dependent on many parameters such as sample origin.

Die design plays a crucial role in the foaming extrusion process, first steps in moving away from empirical optimization of die design towards educated die design were done during this project. Four dies were designed, manufactured, and tested for this project: one rod die and 3 square dies. They were tested with a pin inside. The flow of the mixtures based on the measured viscoelastic properties was simulated in order to predict velocity profiles (shape of the profile) and pressure drop. However, the assumptions made in the model and the limited rheological data available have a large influence when matching experiments with simulations, resulting unfortunately in a bad match for square dies.

The results of this project have shown the huge potential of combining the knowledge on biobased materials such as starch/fibers mixtures and the equipment and technologies available for polymer processing. The combination of this knowledge with die design and modelling offers the opportunity to design foamed products with improved properties.

Description of the contribution of the project to the goals of the subsidy scheme

This project has contributed to strengthen the knowledge positions of WFBR and PaperFoam bv in the area of extrusion foaming of starch-based mixtures. This project has delivered a number of new building blocks that bring the replacement of the current EPS material and production process with biobased alternatives one step closer. The feasibility study helped to complement a business plan to invest in a melt cooler and mixer for foaming of biobased materials at WFBR. To our knowledge, there are no lab or pilot extrusion foaming facilities to support the Dutch industry in the Netherlands.

Research output

Publications

- Alvarado Chacon, F. (2023, March 1-2). *Latest developments on thermoplastic starch processing and characterization* [Invited talk]. 3rd Annual Bioplastics Innovation Forum, Brussels
- Esposito, C., Tammaro, D., D'Avino, G., Schennink, G., Huisman, J.W., Geerts, M, Alvarado Chacon, F, Maffettone, P. L. (2023, May 22-26). *Validated Modelling of Complex Geometry Dies for Extrusion Foaming of Starch-Based Mixtures* [Conference presentation]. 38th International Conference of the Polymer Processing Society, Olma Messen, St. Gallen, Switzerland. https://www.pps-38.org/documents/7430410/0/Book+of+Abstracts.pdf/1c1488ea-b634-4069-acc7-2ee964680007
- Esposito, C., Tammaro, D., D'Avino, G., Schennink, G., Alvarado Chacon, F, Maffettone, P. L. (2023, July 29- August 4). *Rheological characterization and modelling of starch-based mixtures aiming at the optimization of the extrusion foam process* [Conference presentation]. International Congress on Rheology, Athens, Greece. (https://edepot.wur.nl/644819)
- Hilhorst, M., de Beukelaer, H.J., Chu, S.S.M., Alvarado, F., Esposito, C., Tammaro, D., van Polen, T.H.J., Huisman, J.W. (2023, December 12-13) *Extrusion foaming of starch-based materials* [poster presentation]. European Bioplastics Conference, Berlin, Germany. (https://edepot.wur.nl/644820)

Exhibitions

Presentation of preliminary project results in booth at K-fair, Dusseldorf Germany (2022, October 19-26). Participation of Fresia Alvarado, Herman de Beukelaer, Marieke Hilhorst, Gerald Schennink and Martin Zijlstra.

Availability

The public report can be found in the public depository of Wageningen University and Research under number https://doi.org/10.18174/657298.

Other remarks

More information

More information about the project can be obtained by contacting any of the following persons:
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