Final Publishable Summary
Project duration 39 months: 01.10.2013 – 31.12.2016

HiPerDry

Executive Summary

The SME-AG consortium of HiPerDry aims (i) to extend the knowledge to overcome technical barriers associated with drying of hygroscopic polymers, especially those derived from bio-based materials, establishing sustainable production patterns across the European plastic processing industry and (ii) to develop a novel microwave-enhanced superheated steam process in continuous operation for high performance drying of hygroscopic polymers, which has a promising potential to help strengthen the competitiveness of European plastics processing SMEs through the improved energy efficiency permitting up to 50% reduction in energy consumption compared to the current state-of-the-art systems. Drying is accounted for up to 20% of the overall energy consumption, making it the most energy intensive step within the processing chain of hygroscopic polymers. Annually, over 10 million tons of hygroscopic polymers, both fossil- and bio-derived, are processed into technical thermoplastics used in the European automotive, aerospace and the electronic goods sectors. Towards more environmentally responsible and sustainable products, biopolymers are estimated to gain market shares of 10% in the packaging as well as in the consumer goods sectors, and even up to 40% in the sector for automotive interior components in 2020. Despite the increasing importance and market demand, processing characteristics of thermo-sensitive bio-derived polymers are not fully understood and explored. Energy reduction in drying of plastics must be implemented to cope with the rising energy and commodity prices and cost-effective and continuous concepts for drying of plastic granules are urgently required to overcome the limitations in the manufacturing of bio-based hygroscopic polymers. Databases and best practices in drying of hygroscopic polymers, especially bio-derived polymers, will help to achieve the reliable production efficiency and exploit the benefits of bio-based plastics through their eco- and resource-efficiency. This technology innovation and know-how build-up will help strengthen the competitiveness of European hygroscopic polymers manufacturers and thus meet the pressure through upcoming overseas markets.

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Project Context and Main Objectives

The HiPerDry-consortium consists of a trans-European partnership of 5 SME-AGs, 2 SMEs and 1 LE from 5 Member States, and has recognised the problems on energy intensity and technical limitation associated with drying of hygroscopic polymers, thermal sensitive polymers such as biopolymers, and recycled materials. Hygroscopic polymers like polyamide or PET play an important role in several European key industries including automotive, aerospace and the electronic goods sectors as well as technical applications. Due to their physico-chemical properties these polymers bind water internally, and therefore need to be dried before processing. The drying process currently has a share of 10% to 20% in overall energy consumption within the process chain (see: Kent, R. (2008): Energy Management in Plastics Processing), making it the most energy intensive step in pre-process material handling. Moreover, current technologies for drying have been developed for conventional fossil-based polymers and are not suitable for up-coming bio-derived polymers like PLA, posing the risk to damage them through thermal degradation. Accordingly, main objectives of HiPerDry are to develop a novel microwave-enhanced superheated steam drying (MW-SHSD) process for continuous operation. Based on earlier experiences with other applications with superheated steam OR microwaves, a reduction of 30% to 50% of energy consumed in comparison with current inefficient drying systems based on hot air technologies was originally expected for the project. Consequently, for each ton of hygroscopic polymer granules dried with the proposed technology, a potential reduction in energy consumption of 110 kWh per ton can be achieved, corresponding to savings on energy costs of €15 per ton and decreases in CO_2-eq emission of 22 kg per ton. Energy consumption is an important competitive factor for European plastics manufacturing SMEs, as they nowadays find themselves facing several socio-economic developments due to the increasing scarcity of resources. Energy prices have continually risen within the last years and will rise more and more. Thus, energy-related costs are becoming a crucial limiting factor for operational profits. Approximately 50% of the total energy consumption in plastics manufacturing is non-productive. Additionally, the threatening shortage in oil will, in the medium run, force the polymer market to switch to an alternative feed-stock. Raw materials for fossil-derived polymers are decreasing. Consumption patterns are changing towards more environmentally responsible and sustainable products. The development and processing of bio-based polymers, though still a niche market, have recently gained a crucial importance with Europe in a leading position in this area. The innovative process developed in this project will not only provide a gentle means to remove moisture from temperature-sensitive hygroscopic polymers, avoiding partial degradation of the polymer, but also enable significant energy and time reduction in drying. The main objective of HiPerDry is the development and implementation of a novel microwave-enhanced superheated steam process for high performance drying of hygroscopic polymers in order to improve the overall energy efficiency, thus facilitating economical production of hygroscopic polymers.

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Main S&T results/foreground

The HiPerDry project has successfully achieved a number of valuable scientific and technical results.

In order to identify which hygroscopic polymers are most significant for the industry in regard to drying, an online-survey has been set up and spread among SMEs in the European plastics processing sectors via the SME AGs. From the results as well as from current literature a selection of five materials to be tested within the project was made. Furthermore, drying process specifications for the new technology were deducted from a benchmark of current practices and parameters just like throughput requirements etc. The results of this were the basis for a process design well suitable to industry conditions. In a further step, focus was set on the scientific characterisation of fossil- and bioderived hygroscopic polymers. This encompassed i) the selection and testing of the physic-chemical properties with more relevance to drying and processing, ii) the aging behaviour of bio-polymers due to heat exposure will be analyzed and compared to that of fossil-derived polymers. The results were interpreted in regard to the dependence of thermo-sensitivity to processing conditions, and iii) the determination of criteria and requirements for material specific gentle drying that derived as a guideline for the MW-SHS process design. The evaluation of physic-chemical properties and processing characteristics of polymer granules dried with the microwave-enhanced superheated steam enabled a deeper understanding of the whole process, especially with respect to the drying of bio-derived polymers. Following current state of the art, drying temperatures and drying times for hygroscopic polymer pellet drying often are chosen following standard recommendations (e. g. 80°C for 4-8 hours) with no further validation. In order to obtain a more efficient production and prevent materials and machinery from taking damage from either thermal stress due to aggressive drying or hydrolysis due to insufficient drying, it is important to make reliable predictions of the drying process. Therefore, a thermodynamic model has been developed that describes the drying process in dependence on variables such as the temperature of dehumidified hot air and the polymer mass introduced into the dryer.

Analytically, the drying process can be described in four main stages:

1) heat convection from drying air to polymer pellets;
2) heat conduction within the polymer pellets from the surface to the center of the particles;
3) diffusion of moisture from to the polymer pellet surface; and
4) convective drying at the surface and migration of moisture to the drying air.

The model has been programmed with the numerical computation platform MATLAB®, describing the process of heat conduction and moisture migration from pellets to the air. The model was validated via a series of practical experiments.

Prior to the development of a process layout for the MW-SHS drying unit, design parameters and process conditions for the microwave-enhanced superheated steam drying (MW-SHS) of hygroscopic polymer granules have been determined using extensive theoretical knowledge and prior experimental experience of the project partners. Various arrangements of microwave coupling in drying process of polymer granules were studied in order to ensure complementary interactions between microwaves (MW) and superheated steam (SHS) and thus in order to avoid local and/or surface overheating of hygroscopic polymer granules. Following the detailed theoretically findings, a pilot-scale MW-SHS unit has been designed according to the parameters and process conditions determined for the microwave-enhanced superheated steam drying (MW-

SHS) of hygroscopic polymer granules. Main specifications for the unit were elaborated according to ensure best combination arrangement of microwave-enhanced superheated steam drying process in terms of energy efficiency and output quality. A piping and instrumentation diagram (P&ID) has been set up, as well as circuit and wiring diagrams for closed-loop control system. The MW-SHS unit has been assembled, commissioned and intensively tested and further optimized. Not only should the MW-SHS drying unit fulfil the desired functionalities, but also the requirements from safety aspects. Thus, verification and commissioning of subsystems and process instruments had to be carried out with respect to the associated risk assessment. After successful commissioning, the pilot plant was tested at the University of Stuttgart in regard to its drying performance and energy consumption in comparison to a State of the Art dryer. Screening tests were carried out in order to define an operational mode. Temperature and drying time were varied in a series of main tests. The results showed a reduction of drying times and energy consumption for low drying temperatures with the pilot plant. For a better evaluation of actual saving potentials of the HiPerDry pilot plant, the pilot plant was also operated only with dehumidified air and therefore in the same mode as a SoA dryer. With only dehumidified air, drying of polyamide 6 was much slower than with microwave application. Based on this test, saving potentials of 64 % in time and 34 % in energy consumption were identified for microwave drying, when all other conditions remain the same. Further constructive improvements allowed again for an increased performance.

After all the tests and the corresponding optimization, the commissioning phase of the MW-SHS drying unit was successfully finished. The system had met all the requirements as described previously. The system was transferred to and assembled at Faperin and tested for different materials from their production. The dried materials were then used for injection molding and the resulting parts were compared to parts from conventionally dried material. Using the MW-SHS dryer showed that the plastic parts produced with the dried material provided good results without any defects.

Accompanying the technical achievements, focus of the project was on the economic, environmental and social impacts of the MW-SHS drying process compared to state-of-the-art (SoA) benchmark systems for drying polymers. The results of this analysis showed, that the main advantage of the MW-SHS drying technology is the reduction in energy use for drying. Further effects were identified:

- A higher quality – which is difficult to quantify
- Less drying time – leading to an economic advantage of 7.500€ per year for plastic converters producing more plastics, requiring a switch in the production.
- More instruments to ensure quality; the possibility to get (more) feedback on the quality when using the MW-SHS drying system.

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Potential Impact, Dissemination & Exploitation

Potential Impact

The developments reached in the HiPerDry project provide a significant socio-economic impact as summarized in the following:

Significant results:

Economic effects of the MW-drying system

Table 1: Economic effect of the MW drying system

	Conventional (SoA)	New
Assumptions		
▪ Energy use	0.165	0.033
▪ Depreciation	1,800	2,500
▪ Calculated interest	540	750
▪ Maintenance	900	1,250
▪ Insurance	36	50
▪ Labour	1,875	1,875
▪ Electricity	5,301	1,060
▪ Drying costs per tonne	38.71	27.72
Difference in drying costs		
▪ Small companies (throughput 400 tonne/ year)	2.200 € per year	
▪ Medium companies (throughput 1.600 tonne/ year)	8.800 € per year	
▪ Big companies (throughput 4.000 tonne/ year)	22.000 € per year	
IRR for different Member States with different energy prices		
▪ EU-28	55%	
▪ Italy	76%	
▪ United Kingdom	72%	
▪ Germany	70%	
▪ Spain	52%	
▪ France	42%	
▪ The Netherlands	36%	

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- The implementation of the MW-drying technology reduces the costs of drying.
- To what extent the costs will be reduced depends on mainly two factors: (1) the age of the dryer that has to be replaced and (2) the energy prices.
    - Compared to the older types of hot air dryer systems, the reduction of the costs is much higher than compared to the newest types. Compared to the older types the reduction of the costs will be 35%, while the reduction of the costs when replacing newest types is much less: 2.5%. One can assume that mainly older types will be replaced.
    - The higher the electricity prices, the higher are the financial advantage that can be obtained when using the MW-drying technology. For example with the high Italian electricity prices the advantage of HiPerDry is much higher (24 € per tonne plastic) than in the Dutch situation where electricity prices are low compared to other EU-countries (12€ per tonne plastic).
- For all polymers considered in this study (PLA, PET, PA6 (1) and PA6 (2) it is profitable to switch to the MW-drying technology.
- In the case of PLA the NPV for EU-28 is € 3,808 and the IRR 23% whereas the payback period goes to 3.8 years. For the Netherlands, having the lowest electricity price of the considered countries, the NPV will then be € 218, the IRR 11% and the payback period 5.9 years. So for PLA the advantages of the MW-drying technology are small and will become disadvantages in more countries, compared to PA6(1), if the investment for the MW-drying technology would be double of the SoA technology. This effect is stronger if the functionality of PLA, compared to PET, is taken into account. On the other hand the economic effects will be more positive in the case of PA6(2) and PET because of their higher energy requirements for drying.
- For a small holder company (throughput of 400 tons/year), only applying the drying and a simple molding, the reduction in costs when applying the MW-drying technology will be a considerable share of its total costs: 2,200€ per year for small plastic converters to 22,000€ per year for big plastic converters (throughput of 4,000 tons/year).
- Even though drying is responsible for 10 to 20 % of total energy consumption in processing (see above), the share of the costs for drying in the total cost price for plastic products is small, about 2% on average. This is due to the fact that material costs have the biggest share in total costs. Therefore the effect of HiPerDry on the total cost price of hygroscopic plastics is rather low.
- The effect of the MW-drying technology on the cost price of biobased plastics (PLA) is by far the least. For PA6 and PET it's the most profitable.
- On EU-level the total cost reduction could be 110 million € for the European plastics industry, assuming an average energy reduction of 11€ per tonne and 10 million tonnes of product per year.

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Environmental effects of the MW-drying system

- The implementation of the MW-drying technology reduces the specific use of energy for drying with 80% (based on the reductions realized in WP5 and under the assumptions specified in D6.4).
- MS-drying helps companies to meet the directives and energy goals of the government and energy agencies.
- The reduction of environmental effects from the use of MW-drying instead of state of the art technology is less than 1% in the case of PA6 and about 3% and 2% for PET and PLA, respectively.
- On EU-level the total energy reduction could be 2000 GWh electricity. This corresponds to the average electricity use of 400,000 EU citizens, based on 5,000 kWh average per EU citizen (incl. electricity use by industry, services, etc.), or about one third of the electricity use of the city of Brussels.

Social effects of the MW-drying system

- There is no extra noise to be expected.
- The effect on health and safety is very limited.
- The effect on food security can be neglected; HiPerDry partners don't expect a switch from fossil based plastic production to bio plastic production because of the introduction of the MW-drying system.

Dissemination & Exploitation

A widespread dissemination of the project was ensured mainly through the SME-AGs. There is a high number of international events where the project and its results were presented. Different project partners attedned K' fair 2016, the World's No. 1 Trade Fair for Plastics and Rubber as well as Fakuma in 2015, the International trade fair for plastics processing, to name just two important trade shows. A lot of workshops and events have been organized by the SME-AGs for their members as well as interested companies.

Additionally a project video was prepared to easily explain the projects idea as well as to show the final demonstration unit. The video can be reached through the projects website www.hiperdry.eu.

The exploitation of results will be organised through a joint ownership agreement, defining rights and obligations of partners concerning all four project results.

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For further information, please visit the coordinators website:
https://www.igb.fraunhofer.de/en/research/competences/physical-process-technology/heat-and-sorption-systems/drying-and-torrefaction/projects/hiperdry.html

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