LIFE Project Number

**<LIFE13 ENV/IT/000650>**

LIFE+ PROJECT NAME or Acronym

**<LIFE long WASTE-FREE LLWF>**

# FINAL Technical Report

Project Data

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| **Project start date:** | 01/09/2014 |
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| **Total Project duration (in months)** | 36 months |

Beneficiary Data

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|---|---|
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# Summary


The objectives of the project were to reduce waste, moderate the use of chemicals and to contain $CO_2$ emissions using an innovative method of minimal tolerance dehumidification during plastic biomedical bags production.

The current methodology of PVC dehumidification both during the process of compounding and of extrusion is inadequate. The residual moisture during the PVC preparation and production phases creates phenomena of hydrolytic degradation catalysed by the thermo-mechanical forces. These degradations are manifested through the presence of imperfections (double bonds, carbonyl and hydroperoxide groups) also due to the $H_2O$ effect, causing photochemical degradation with removal of hydrogen chloride and formation of sequences of conjugated double bonds.

A remedy lies in the use of stabilising and plastifying chemicals in over quantity (+ 30%) compared to the normalised situation, i.e. without moisture during the cycle.

During this phase, the production of the granule can be partially compromised with waste formation (+ 15%). The compounding phase is followed by the extrusion phase where the presence of moisture can result in processing waste, machine downtime and extraordinary maintenance.

So, the environmental problem addressed was the presence of moisture in polymers and technopolymers, which has detrimental effects on their processability and is responsible for the need of multiple treatments and of the generation of waste or, viceversa, for the need of using plastifying additives to try to recover part of its properties.

Moreover, overtreatment implies than an excess energy is used, and this, for instance in case of hot air based systems, amounts to more than 50%, which becomes 65% in case of microwave assisted treatments, due to their poor efficiency.

The source of this overtreatment is the current impossibility to directly monitor and manage in real time the moisture level of the material under processing, and hence only rough processing parameters are used during de-moisturizing, thus ending with non-homogenous nor reproducible treatment and the consequent raising of the aforementioned environmental problems. Instead, the introduction of an innovative way to measure in real time moisture content of the materials, and to tailor the de-moisturizing treatment from case to case would represent an enormous benefit, able to completely nullify the need for overtreatment and the related problems.

The main innovative aspect is the realization of a de-moisturizing unit which is not based on overtreatment, but on the proper and dedicated treatment depending on the mixtures typology and the features of the input materials. Using the new system, the approach is different: the load properties are measured, the equipment is regulated accordingly and only the strictly required amount of energy is used. In case some part of the load are not treated enough, they are detected at the exit port and conveyed back to the “start cycle”. This can guarantee that no energy is wasted and that no material is thermally damaged during the process, i.e. the efficacy end efficiency are maximum.

A further innovative aspect, which was at the basis of the outstanding performances expected, has been the design and application of a tandem of microwave-based sensors of moisture, which are able to sense and measure the water content directly on the materials to be processed, and not on the air in equilibrium with them. The new sensors can allow on time measurements.

The main result achieved are: a functioning de-moisturizing pilot plant, including moisture measurement sensors, and a control system able to manage the moisture for all the materials that could be treated. Costs and products are compatible with an industrial production, permitting to reach the important environmental and economic benefits expected. The new system is able to immediately adjust the moisture contained in the material and so can be saved most of the thermal energy necessary for dehumidification, allowing to use only the energy strictly necessary to achieve the goal of dehumidification and systems largely less-consuming than current ones, thereby allowing reductions measured between 55 and 60 % of total emissions in relation to the type of raw material processed, i.e. up to 400 tons/year $CO_2$ with the pilot plant for the project saved. Moreover, within the project can be saved about 28-30 tons per year of production waste which can become 45-50 tons considering the troubles created often by the moisture in the materials during extrusion and so when the dry blend is converted into gelled material. In the latter case, other 20 tons/year of CO2 emissions can be saved. So, about 25% of waste, i.e. 50 tons/year, can be not generated on the 200 tons per year treated by the pilot plant. As regard energy consumption, can be said that the new system reached important results consuming only 30 kj/kg for the de-moisturizing unit, not present in the traditional process (ref. 1000kg/day of material treated). This latter data have to be compared with the 1900 kj/kg necessary to recycle 150 kg of waste per day produced without moisture control. Moreover, even if some process phases have been added, the whole process has better performances consuming only 0.14285 Kwh/kg instead of 0.158 Kwh/kg of the traditional process with no de-moisturizing units. Moisture control upstream of the granulation can remove the risk of transforming material that is unsuitable, recovering it intact before transformation and permitting to save raw materials.
The new method can so allow the full recovery of the waste materials making them perfectly compatible with the virgin material thanks to the possibility of homogenising the water gradient with the relative viscosity control. Then, balanced moisture of the materials permits to use only the amount strictly necessary of additives(stabilizers, lubricants, plasticisers, flame retardant, catalysts in general). Several tests with different mixtures demonstrated an average percentage reduction of up to 35-40% (30% on average) i.e. 900 kg of chemical additives usage per year only with the pilot plant, achieving perfect quality products with great homogeneity of granules (standard deviation of moisture: 1%). So, there are numerous results that relate to energy saving, lower emissions, the smart use of raw materials, the minimisation of the production of waste, even if in part recyclable, a reduced use of chemicals and optimisation of the production cycle.

As for economic evaluation, the costs for the production are minor compared to the current technology; the infrastructures are almost the same, the process is different but not more expensive. The variable costs regard mainly the energy necessary to the de-moisturizing unit, not significant. The new technology could permit, so, to maintain almost the same products selling price, object of deep periodical study based on market responses and international competition, but to gain by the lower production costs and so to have a payback time of the investments, if needed. So, the proposed technology has a potential commercial value and the economic issues should not represent a real and significant obstacle to its implementation or replication.

# Introduction

– Description of background, problem and objectives

- Environmental problem/issue addressed

The environmental problem addressed is the presence of moisture in polymers and technopolymers, which has detrimental effects on their processability and is responsible for the need of multiple treatments and of the generation of waste or, viceversa, for the need of using plastifying additives to try to recover part of its properties.

- Outline the hypothesis to be demonstrated / verified by the project

The main innovative aspect is the realization of a de-moisturizing unit which is not based on overtreatment, but on the proper and dedicated treatment depending on the moisture level of the input materials. Using the new system, the approach is different: the load properties are measured, the equipment is regulated accordingly and only the strictly required amount of energy and materials is used. In case some part of the load are not treated enough, they are detected at the exit port and conveyed back to the start of the cycle. This guarantees that no energy is wasted and that no material is thermally damaged during the process, i.e. the efficacy end efficiency are maximum.

- Description of the technical / methodological solution

At the basis of the outstanding performances expected is the design and application of a tandem of microwave-based sensors of moisture, which are able to sense and measure the water content directly on the materials to be processed, and not on the air in equilibrium with them. The new sensors allow on time measurements. The installation of a first sensor on the loading port ensures that the de-moisturizing unit is regulated specifically on the load characteristics, and the installation of the second sensor on the unloading port allows to both verify that the treatment is properly conducted or to intercept possible partially treated or untreated materials, and send them back to processing, stopping the process.

- Expected results and environmental benefits

There are numerous results expected that relate to energy saving, the smart use of raw materials, the minimisation of the production of waste, even if recyclable, a reduced use of chemicals and optimisation of the production cycle and so: lower CO2 emissions, removal of production waste, savings and recoveries of raw material, less waste of additives and constant control and optimal management of the quality of the products.

– Expected longer term results

The project will contribute to the achievement of European environmental objectives because it directly involves the demonstration of the application of a high performance technique to one important step of the recycling of polymers. It will also contribute to update the EU policies for waste management (e.g. Waste Framework Directive 2008/98/EC), and in particular " Waste prevention": reducing the amount of waste generated in the first place and reducing its hazardousness by reducing the presence of dangerous substances in products. The proposed project lies also in the framework of HORIZON 2020 objectives, since it has the potential to contribute to a more efficient use of resources and provide tools of competitiveness for SME. Last but not least, the project will contribute to the EU commitment to reduce CO2 emissions (Kyoto protocol) in its pursuing the minimum energy consumption.
The main stakeholders involved will be the polymer manufacturers and transformers, manufactures of paper-related goods, like food confectionery, paper-based containers and tissues, where the requisites of precise moisture control or levelling is of the great importance and could also benefit from the application of the new sensors, for great transferability issues.

# Technical achievements

## Sensors network

This action aimed to design, realize, implement and test the new sensors used to measure the material moisture level trough the permittivity measurements of a given load geometry, at the microwave frequencies; a novel sensor geometry has been optimized and tested in order to measure its accuracy and response time, as well as the feeding and unloading section of the demonstrative unit, so that the flux of material occur with an almost constant geometry of process, to ensure proper sensor functioning.

The company's core business is the production of biomedical bags for multiple uses, ranging from the collection of blood or infusion treatments to the collection and separation of platelets and plasma, producing internally the granules for the extrusion of the film from a mixture of raw materials which we have researched inhouse. This way, we have the complete control of the most critical and strategic steps.
The line starts with a turbo mixer inside which the raw materials are blended for the production of the granule of desired polymer (virgin polymer powder, plasticisers, additives etc.). A rotary motion is then imparted to a mixer positioned inside it and a certain temperature is applied. This means the different components are mixed together and the resulting powder, known as 'dry blend', has the required characteristics for the next step, i.e. extrusion with tapered counter-rotating twin-screw extrusion system and pelletizing.
Once the turbo mixer processing stage is complete, the dry blend is conveyed to a collection system and then to the extruder.
The moisture problems that can arise and damage the material, usually occur inside the turbo mixer. To remedy this problem, with all the consequences of an environmental nature that it causes, as described in the application, a system needs to be added which measures the moisture content of the dry blend and corrective measures need to be applied upstream and downstream in order to standardise the conditions of the raw materials and prevent faults in the production of the polymer tube.

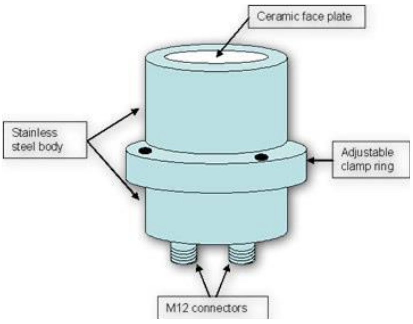
The aim of this first technical action was to modify the dry blend collection system in order to incorporate an innovative microwave sensor for measuring residual moisture content, the sensor being able to interface with the management software system for this production phase, introducing changes to processing parameters in the systems up and downstream.

After the first activities which permitted to change the system of pipelines running to the dry blend collection system, and to prepare a housing for a sensor that can measure the moisture content directly within the storage system, through the partnership with the University of Modena and the linked company that helped us to implement the system, Pertec S.r.l., we ran a first series of tests with a demo sensor, mainly in Pertec establishments, testing different types of materials to process.

Among all these activities, the most important regarded the design, development and set up of the two sensors. The idea of using a microwave sensor for the moisture measurement is based on the strong difference in dielectric properties, at 2.45 GHz, between the polymeric materials of interest (usually real part of dielectric constant less than 3 and imaginary part less than 0.01) and water (real part about 80 and imaginary part about 12). Although the sensitivity may

be increased to 9 GHz, the 2,45 GHz is a frequency ISM free worldwide and is the same of WI-FI and Bluetooth system, for which the electronic components are more easy to find and economic, with important replicability and transferability issues.
The functioning principle derives from the dielectric properties of the material mixtures which follow the forms of the mixtures that depend on the dielectric properties of the individual components of the mixtures, as well as from the way they are arranged mutually in space. For example, in the case of complete miscibility, the rule of mixtures applies as a weighted average of the dielectric properties (real and imaginary part), weighed on the volume fraction of the individual components.

After several suppliers checked and some simulations, the research carried out showed the possibility of exploiting part of the hardware (system of generation and measurement of the signal) of a commercial sensor (Moistron), distributed by Pertec Srl.




The sensor has the advantage of already provide for a layer of ceramic interface (glass ceramic), therefore suitable to withstand the temperatures of the process of the project. The original commercial sensor is too broad (requires a measurement planar surface too extensive, with the risk of strong differences of homogeneity that penalize the repeatability of the measurement) and still too sensitive to temperature variation (coefficient of linear thermal expansion) and also too little heat conductor to ensure that the temperature in the measurement zone is constant. For this reason it was decided to use alumina as a substrate for the creation of the ring resonator, with microstrip technology, since it presents good thermal conductivity, while remaining electrically insulating.
Even the antenna needed to be redesigned, in order to make the microstrip resonant to excitable and measurable frequencies by the Pertec measuring system. So several tests were needed to simulate the microstrip antenna, exposing it (by simulation) to different loads to verify the real sensitivity expected from the sensor. The shape of the antenna has been parameterized and optimized in order to obtain a resonance at a frequency of around 1220 MHz.
On the basis of the simulation, it has been realized a first sensor prototype

The sensor has been then used on a mixture of dry blend, humidified in a controlled manner, to perform the calibration (note the tendency of the product to adhere to the side surfaces of the sensor, while the part of measurement, of alumina, has low roughness and is still brushable even with abrasive systems, for periodic cleaning).

It was found an optimal correlation between moisture and resonance frequency and Pertec was asked to modify the software of control by replacing the normal calibration (two-point calibration, which then assumes a correlation of a linear type) with a polynomial curve of degree 3.

After several test and configuration activities, the right features of the sensors have been determined, in order to use them for the continuous measurement of moisture in solids, granules or powder, with compact and resistant structure to make it particularly suitable for industrial use, even in possible unfavorable environmental conditions, and to find application in processes which need a constant monitoring of the humidity content. The sensors have so been applied in the pilot plant and started configuration in real conditions with final success thank to the work realized in laboratory and with sensors' development. They are able to sense the moisture level in polymer-based materials with a detection threshold of 1000 ppm. The identification down to 100 ppm water in polymers foreseen proved to be not necessary to the aims of the project and the targeted results of 0.01% of moisture content in the mixtures.

*Moisture sensors*

## De-moisturizing demonstrative station

This activity aimed to realize the hardware part of the de-moisturizing unit to ensure proper and efficient water removal from the polymer, based on the information acquired by the sensors network.

Initially, the company has conducted a study aimed to realize a pilot process "out of line" able to treat 1000 kg/day to demonstrate the possibility to treat an amount of compound up to about 15.600 kg/day. To this end have been made, with the cooperation of the specialized company PIOVAN, some technical drawings depicting a possible production scheme for the de-moisturizing process, including centralized supply - dehumidification - storage. To test the drying time were carried out a number of tests of the resin particle size, with determination of the optimal granulometric curve. The compound was tested in the laboratory through an automated sieve and the tests were conducted to determine the optimal time of dehumidification.

*Automated sieve*

The application of hot air was so tested in the compound sieved with the time of dehumidification determined, with good results, but with necessary stop in the production in continuous.

As an alternative to the off-line system, therefore, the company has studied the possibility of managing the optimal dehumidification within the process "in line". Have been so assessed all the variables/causes of the formation and development of moisture within the process. The main source was detected in the reactor turbo-mixer where the inconstancy of parameters (critical is temperature) results in the continued development of vapours and gases.

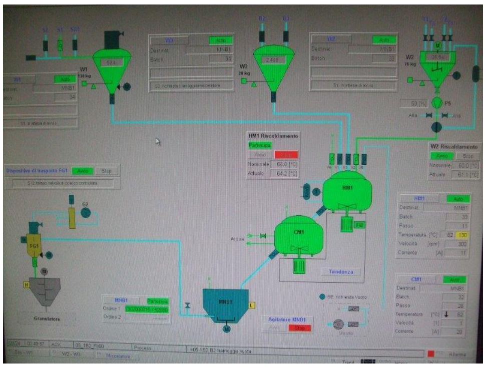
*Vacuum system*

In particular, the new system was born by inserting a cooling circuit within the reactor turbo-mixer sleeve, integrated with the boot process ("start cycle") of the preparation of the compounds. Then, through sensors arranged within the reactor turbo-mixer sleeve has been arranged an exchange with water that would allow to bring the temperature always in the state of "system startup" thus avoiding that the raising of the same temperature busted development of moisture of the mixture inside the reactor turbo-mixer.

*Water exchange system*

Properly the compound is formed by a liquid phase and a solid phase and is polymerized by a cycle of 15 min with a temperature ramp from 45 °C till 105 °C.

The combination of an integrated system between the new process described above and the sensor placed downstream of the storage buffer unit has made possible a continuous production system with the optimal conditions of dehumidification to reach target process.



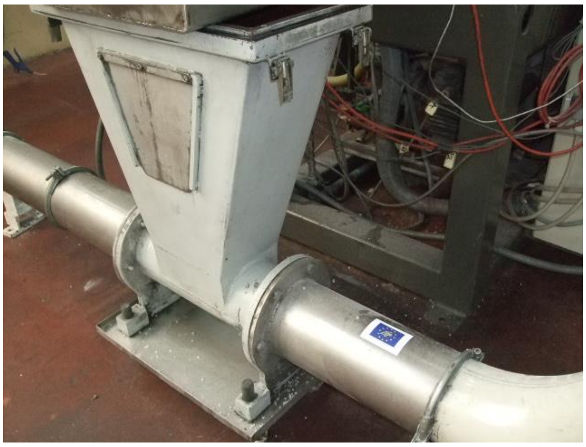
*Control system* *Downstream sensor*

The system has been so validated with several tests and put into security guarantee through the sensors realized that permit to prevent the "cycle start" if the critical temperature parameters within the turbo-mixer and the percentage of residual moisture are not respected.

Were conducted at the scope laboratory tests for the determination of the residual moisture evaluating various reference samples, subjecting them in oven and determining the loss of volatility after an accelerated cycle of drying at 60 °C for 40 min.

*Oven used for testing*

The stabilization downstream of the semi-finished granule, thus conceived has been guaranteed through specific conveying systems and a forced ventilation which ensures the control of the temperatures up to the time of subsequent storage in silos.



*Conveying systems*

The new system is better in industrial mindset because allows to work "in line" thus avoiding to have a high time to set-up which compromises the efficiency and productivity of the plant; therefore the proposed technology is better than that foreseen for the reasons described mainly related to possible future industrializations and productive concepts of industrial and continuous type. So the technological content thought with the preliminary studies for the project is not depleted with the changes developed, but increased, creating an innovative know-how widely transferable to other plants and other sectors.

Summarizing, the drying process developed is linked with the result of the validation of the optimized process. The reference value, assumed as a critical, is the temperature that develops in the turbo reactor. The new sensor placed downstream of the cooler measures the effectiveness of the changes incorporated and integrated in the production process. The so modified system has three values that are integrated into the process, they are:
- temperature probe inserted in the turbo mixer,
- time of vacuum in service to the turbo reactor,
- dehumidification sensor placed downstream of the system.

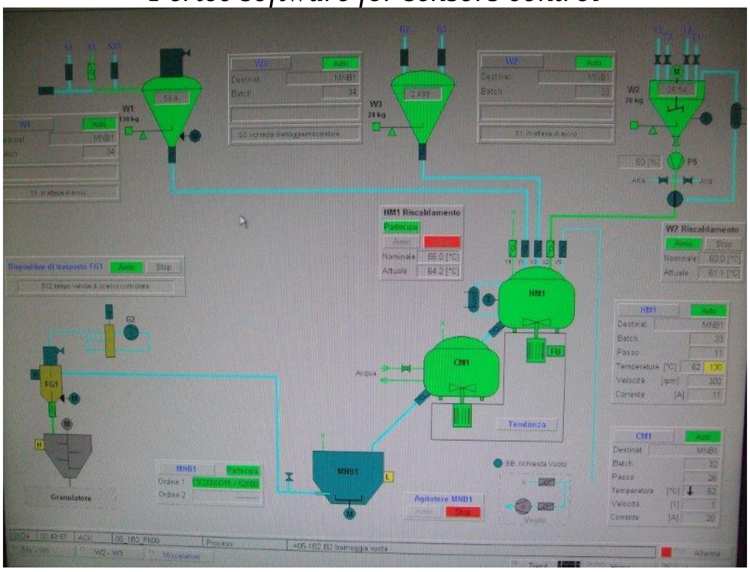
Their interaction start from the temperature probe that reads the temperature inside the turbo mixer and adjusts the consensus of cycle start up. The sensor placed downstream of the system detects the humidity value of the compound, and determines the vacuum time of the compound inside the turbo-reactor.
The analyses carried out on a formulation led to the validation of the formulation compared to an optimal dehumidification value of 0.01% of a "white" sample. Each formulation has so been tested and a similar validation process determined the validated production cycle (target 0,01% moisture) for each mixture.

**Control system**

This activity aimed to provide the necessary on board intelligence to the new system, in order to be able to process any kind of input polymers at any kind of moisture content.
Through the control system, dehumidification must be parameterized on the basis of data collected in the flow of raw material physic-chemical parameters, to the environmental conditions for an immediate answer and a re-modulation of dehumidification cycle also in function, precisely, of the characteristics of the raw materials in transit.

The control unit has been implemented linking the control system of the process with the one that control the sensors' network, realized specifically within Meditalia processing and measurement and modified to meet the common control software for processes like Meditalia one, to have a single control system for the whole process. The aim was to increase the possibility of widespread the technology realized and to contain the applicative and operative costs, as well as, of course, to optimize the process as better as possible.


*Pertec software for sensors control*



*Meditalia software for process validation linked to Pertec software*

The granule control system in relation to the humidity has been integrated into the process control software, resulting in a series of "cycle stop" alarms until it reaches the optimum

conditions to ensure the achievement of the target. The system provides the continuous control of dehumidification that must be parameterized on the basis of data collected in the flow of material in transit, starting from the first sensor installed.
In fact, as a result of the validation process of the new system and of the numerous tests and variations in the operating conditions of the production process, the two humidity meters installed upstream and downstream of the process have clearly highlighted when and where the problem of excess moisture within the process arose.
The standard cycle times of a medical polymer alloy mixture production are 12 min on average and the critical aspect of a medical production is to ensure that the physical and mechanical parameters of the product are consistent. No variations within the production batch are allowed. On the basis of this premise, was made an analysis of all the components of the system in order to understand the onset of moisture formation.
The analysis carried out following the validation process, based on the measurement of humidity at phase 0 (start production) and phase 1 (dry blend production) showed how the problem arose during the turbo mixing phase. A thermal inertia of the turbo and the consequent uncontrolled thermal drift combined with the entry sequence of the solid and liquid components, the same injection times of liquids into the solid component, caused the process instability and humidity formation.
We have so discarded the idea of building a self-adaptive humidity control system connected to phase 1 sensor (production of dry blend) and we have tried to self-adapt all parameters that could contribute to the elimination of humidity; all the basic mixtures have been taken as a reference in the validation process and grouped together in the product code families that make up Meditalia's offer, creating a validation process for each able to take into consideration the humidity issue.
To each of the blends was so assigned a specific work programme and found the best working conditions for the process, determining the validation of the production data sheet for each of the mixtures.
The basic concept of operation of the new process is based on the control of the turbo-mixer temperature and the sequences and times of entry of the solid and liquid components into the turbo mixer, modulated and controlled to ensure a production in constant quality assurance. Probes were then inserted into the process integrated with the production software to ensure process homogeneity. Each process has therefore been customized according to the 5 product families, modulating the reception times of raw materials, the injection times of liquids and controlling in an adaptive way the temperature at the beginning of cycle and at the end of cycle of processing inside the turbo mixer.
For each mixture we have assigned about 30 processing phases defining and customizing the working parameters, assigning and appropriately recording the material, the nominal value (kg), the actual value (Kg), the start of the dosing (min.), the end of the dosing (min.), the allocated part of the plant (W1, W2, W3, W3), the assigned source (T3, B3, SA1 etc.....).
In addition, we have also included in the production program a window for the temperature control of the turbo mixer during the entire production phase, making the operator visible to the system's self-adaptivity during the entire production phase.
The maintenance of optimal parameters within the process was made possible by interfacing each production phase within the production plc with sequences definition, in terms of time, working temperatures, processing phases, controlling in this way the humidity creation.
The process is kept under constant control in relation to working temperatures and to the vacuum phase; the process variables are thus governed and neutralized due to the effect of precise restrictions inserted in the production programs of each product family, making the process stable and in guarantee of constant quality over time: for each processing phase, the processing time, temperature, turbo reactor revolutions, vacuum times were assigned.

**Demonstrative line continuous testing and LCA**

The activities carried out permitted to test the demonstrative unit in continuous operation, in order to reach the steady state conditions and perform reliable LCA balance.
The action ended with forming tests, in order to verify on the field the effective lack of any degradation or the no longer need of plasticizer additions. Subsequent tests included not only forming of the film, but also its process, like further thermoforming and RF-welding, in order to have confirmation on the field about the lack of any degradation or the no longer need of plasticizer additions also in different conditions and to verify directly on the field all the possible treatments to be made on the products. These tests helped also for future scale-up and replication of the technology and as benchmarking with current productions; no issues arose and no degradations were shown.
So, after the connection of the demonstrative line to materials hopper and continuous feeding of the line with real materials, both the hardware and software systems were tested in continuous to solve possible critical issues raised during the extensive testing activities. Then standard working cycles have been defined for each materials to treat and each products to obtain. Continuous testing trials for each one of them in steady state feeding conditions were performed and subsequent LCA assessment were realized.
Several testing campaigns have been carried out for all the product families work cycles in order to obtain the process validations necessary to produce with the new system. In Annex 14 can be found a summary of the quantities of the materials treated and the tests realized, even if not all the tests were formalized and registered. The first step of the validation process took lower quantities treated and was addressed to measure and define the process parameters to control temperatures and humidity values, as well as the quality of the products obtained. Then, in the final stage of the project, once defined the final operating parameters, the pilot plant was tested, with this action activities, at the maximum capacity of 1500 kg/day using the same materials several times and stressing the system as much as possible with the parameters identified, which proved to be well defined. Monthly efforts were defined, taking up to 5 test per day, with 5, 15, 25, 50 kg of materials treated, in the early stage and 1-2 test per day in the final stage with higher quantities.
The film has been quite ever reached, after extrusion process, and then trashed, while very few times have been produced the bags since not necessary and since is a process very environmentally controlled and so to not jeopardize the normal production. However, forming tests of the treated polymers were performed to assess product final quality and project aims achieved.
The work cycles determined are all documented within the program developed for the management of the mixtures. On tests of the incorrectly dried materials, the parameter was measurable directly on the machine and the effect was visible due to continuous burns and downtime caused by excess of humidity.
With the pilot plant, the material can be put into processing on monday mornings and continue without interruption of the process until the shutdown on friday evening. The saving of stoppages due to the continuous burning of the material in the extrusion process has allowed to significantly reduce the process waste and the time lost for the continuous shutdowns and restarts of the production line.


no waste after granulation stage

The LCA study for the project performed by an external expert assistant as UNIPD staff of industrial engineer department allowed the quantification of the impacts associated with the categories analyzed and the identification of the most impacting contributions of the supply chains of the new and of the traditional process.
The main data from primary source concerned the consumption of raw materials and energy. The main data from secondary source concerned the processes to produce the materials used (obtained from international databases) and the composition of the Italian energy mix.
The results calculated using the ReCiPe 2008 method highlighted that the main impacts of both the traditional product and the new product are due to the utilization of PVC and additives. The comparison between the traditional product and the new product reveals that the new product presents lower impact than the traditional one for all of the categories analyzed mainly thanks to the lower energy consumption. For instance, for the category climate change the traditional product presents higher impacts mainly due to the higher consumption of energy, which causes the emissions of carbon dioxide and methane, which cover the 87% and 8% of the total emissions, respectively. The environmental advantages of the new product were also confirmed by the application of an alternative impact assessment method namely CML-IA baseline.

## Environmental benefits

The project has been executed in line with what was foreseen in the application and the technical variations that occurred did not affect the achievement of the expected results.
The testing phase progressed according to the schedule of the project and provided important results.
The main result is a functioning de-moisturizing pilot plant, including sensors, conveying systems and de-moisturizing unit: costs and products proved to be compatible with an industrial production, permitting important environmental and economic benefits.
There are numerous results that relate to energy saving, the smart use of raw materials, the minimisation of the production of waste, even if in part recyclable, a reduced use of chemicals and optimisation of the production cycle:
- The new system is able to immediately adjust the moisture contained in the material and so can be saved most of the thermal energy necessary for dehumidification, allowing to use only the energy strictly necessary to achieve the goal of dehumidification and systems largely less-consuming than current ones, thereby allowing reductions measured between 55 and 60 % of total emissions in relation to the type of raw material processed, i.e. up to 400 tons/year $CO_2$ with the pilot plant for the project saved. This data is even more important if compared to the energy consumption necessary to recycle production waste estimated in 1900kj/kg (150 kg per day wasted in a production capacity as the pilot plant one without moisture control).
- The incorrect or ineffective dehumidification actions lead to irreversible damage in the intrinsic qualities of the raw materials that are transposed as such even in the finished product where it will be mapped, causing - in all cases - product waste. The latter is transformed into an additional cost to the production cycle, when it does not become a true rejection and precisely to landfill. In current processes this translates into a more than 25% difference that the new system will make it possible to eliminate totally. Waste amount is never lower than 285-300 tons/year in business perspective for only the overtreatment of the materials with consequent abnormal emissions of CO2 equal to 116 tons/year that will be avoided if waste will be eliminated. Within the project can be saved about 28-30 tons per year of production

waste which can become 45-50 tons considering the troubles created often by the moisture in the materials during extrusion and so when the dry blend is converted into gelled material. In the latter case, other 20 tons/year of $CO_2$ emissions can be saved. So, about 25% of waste, i.e. 50 tons/year, can be not generated on the 200 tons per year treated by the pilot plant.

- As regard energy consumption, can be said that the new system reached important results consuming only 30 kj/kg for the de-moisturizing unit, not present in the traditional process (ref. 1000kg/day of material treated). This latter data have to be compared with the 1900 kj/kg necessary to recycle 150 kg of waste per day produced without moisture control. Moreover, even if some process phases have been added, the whole process has better performances consuming only 0.14285 Kwh/kg instead of 0.158 Kwh/kg of the traditional process with no de-moisturizing units.
- Moisture control upstream of the granulation can remove the risk of transforming material that is unsuitable, recovering it intact before transformation and permitting to save raw materials. The new method can so allow the full recovery of the waste materials making them perfectly compatible with the virgin material thanks to the possibility of homogenising the water gradient with the relative viscosity control.
- Less waste of additives: the additives (stabilizers, lubricants, plasticisers, flame retardant, catalysts in general) are the first to be volatilised due to problems of drying in the event of over dehumidification and this therefore requires a superabundant and prudent use. Balanced moisture of the materials permits to use only the amount strictly necessary of additives. Several tests with different mixtures demonstrated an average percentage reduction of 30% in use of chemicals additives, achieving perfect quality products with great homogeneity of granules (standard deviation of moisture: 1%). Considering that per kg of material treated on average 0.65 kg are main resins and 0.35 kg are additives and that 0.015 kg of the latter are additives that can be saved with the project up to 35-40% (30% on average) get 900 kg of chemical additives usage saved per year only with the pilot plant on average.

So, there are numerous results that relate to energy saving, lower emissions, the smart use of raw materials, the minimisation of the production of waste, even if in part recyclable, a reduced use of chemicals and optimisation of the production cycle.

# Economic benefits

The research into new products, less expensive, with large environmental benefits and therefore marketable as true innovation is becoming increasingly frequent, given also the crisis that has been stifling the European economy for some years. The sector has several products that are wholly similar in intended use, shape and made with the same features and systems. International competition is very wide and fierce especially from those countries that cannot contain the cost of the labour market and thus apply prices that are not sustainable by European producers for products with low added value and therefore not very differentiated. Innovation could ensure sustainability and economic benefits for European producers for the future because it could differentiate the product and gain advantages over the competition and replace all the similar products ensuring ample revenue for European companies for many years.

The proposed approach is more economical than the current one. The main economic results concern the direct economic value generated (about +10% estimated) mainly reached thank to the reduction of energy costs and the increase of productivity (less waste) and company image on the market. The minor production cost can be attested of about 9%; considering the improvement of company image that impact the selling price can be estimated a 10% of added economic value.