HEO project

Final Report

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Author(s)	:	**Santacatterina Gianpiero; Andrea Mazzoleni, Andrea Gasparoni**
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1 Executive summary

HEO -Highly Efficient Oven- was a 36 months demonstrative project involving four European partners and co-financed by the LIFE Environment Programme. Started in June 2012, the long-term general goal of the project was to contribute to the main European environmental policies, by addressing the issues of energy efficiency, over dependence from fossil fuels, GHG emission, chemicals and waste.

The objective of the HEO project was to showcase a mix of environmental friendly technologies for manufacturing a new class of domestic electric ovens using up to 50% less energy in the production process, avoiding use of toxic substances and with an improved efficiency of about 30% during the use phase, if compared to state-of the art ovens. In this regard, the specific technical targets of this project to achieve the above results can be summarized as a follow: i) substitution of a steel enamel cavity with a stainless steel cavity with increased reflectivity; ii) a new sol-gel coating applied to avoid deterioration of the ovens metal cavities; iii) oven heating system upgraded to increase the quantity of energy transferred directly to the food.

Therefore the first environmental aspect targeted by the HEO project was related to the Energy consumption in the cavity production process. In the typical enamel process the low carbon steel is cured at 830°C to apply the traditional enamel. In the innovative HEO process, demonstrated through a pre-industrial production line, the stainless steel is cured twice at about 230°C for 30 minutes to apply the new coating, allowing to save up to 63% in terms of energy. This value is much better than the targeted one! The saving in the thermal energy also compensates the higher embodied energy of stainless steel versus low carbon steel. This new coating is also avoiding the use of toxic substances, such as nickel and cobalt.

Additionally the project was targeting an energy consumption reduction during normal use of the oven. Traditional ovens are among the most inefficient appliances with an energy efficiency of around 10-12% with respect to the input power. The new concept applied to HEO project is taking the energy efficiency of the innovative oven up to a 30% higher than traditional ovens, mainly thanks to the increase of radiation contribution of the cavity wall to the total heat exchange with food and to the adaption of the heating system.

According to Commission Delegated (EU) N.65/2014 supplementing the Directive 2010/30/EU with regard to the labelling of domestic oven and range hoods, the HEO project was targeting an EEI lower than 82 (class A+ or higher) and finally resulted compliant to A++ energy class. To achieve the above-mentioned results, a number of cavities and prototypes have been realized and the energy used to manufacture a sol-gel coated stainless steel cavity has been evaluated, in comparison to the energy used to manufacture an enamelled steel cavity. Similarly, tests about energy efficiency – targeting the brick test method – have been carried out on the final HEO prototype to assess the improvement in energy efficiency in use in comparison to a conventional oven. The assembled prototype is fully code compliant (temperature, condensation and packaging tests were approved) and energy to cook has been evaluated 20% less in comparison to a black enamelled cavity. A life test has been performed (5 years of product simulated) and performance were guaranteed over time.

The activities carried out and the results achieved during the HEO project have been actively disseminated through a dedicated project website as well as newsletters, workshops, lectures, conferences and scientific articles. In particular, the results achieved throughout the project have been presented in two high-level conferences held respectively on October 2013 and May 2015.

2 The Project

In order to obtain the desiderated results, the project has been divided in different phases. Main activities and results for each phase are hereafter summarized.

- **Preparatory actions:** The objective of the preparatory actions was to prepare the ground for the following demonstration activities. Specifications, parameters, measurements, procedures, testing methodologies and targets have been defined either for what concern the pilot line as well as the prototypes.

  The main mechanisms of heat and mass transfer to food in a traditional oven have been studied as well as possible strategies to increase the heat transfer to the food with the scope to reduce the overall product consumption.

  The basic idea identified in the HEO project to improve the energy consumption of the oven is to exploit the contribution of components of heat transfer that are usually unused. In particular traditional ovens use the convection as main vector of heat transfer to the food while the radiation is not giving a significant contribution due to the dark enamelled cavity. The use of reflecting cavity wall to recovery heat lost due to not optimal view factors was identified in the HEO project as the best solution to increase the radiation mechanism in a oven and to reduce the oven energy consumption.

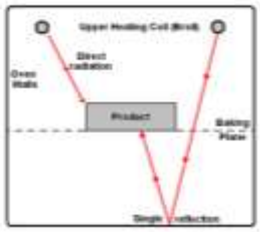

Figure 1 HEO principle

  Therefore the surface reflectivity of material to realize the cavity was one of the key parameter determined and kept under control.

  Different ferritic stainless steels have been compared to identify the best substrate for the application. To select the best substrate chemical composition, was important to define the worst case working condition mainly driven by the high temperature function (about 450°C), the compatibility with a transparent coating and the best trade-off between cost and quality.

  Different solutions of transparent coatings have been evaluated and the characteristics of the best ones are summarized in the following table. Finally a specific sol-gel coating has been selected as the only transparent coating that can withstand temperature without degradation and that present either an extremely high chemical resistance performance as well as an industrial friendly process.

	PECVD (SiOx)	Sol-gel general	Sol-gel HEO
Technical characteristics & key benefits			
Temperature resistance	● (green)	● (green)	● (green)
	Over 400C theoretical possible but specific process development should be engaged and implemented.	theoretical possible : ex. sol-gel from Liebniz Institute (D)	OK
Scratch resistance	● (green)	● (green)	● (green)
	OK	OK	OK
Chemical resistance (discoloration-damage)	● (green)	● (green)	● (green)
	OK	OK	OK
Aesthetic characteristic			
Appearance	● (orange)	● (green)	● (green)
	Iridescence	OK	OK
Industrial production implementation suitability			
Process timing - energy efficiency	● (orange)	● (red)	● (green)
	long process deposition time	curing @ 500C for 24 hours	OK
Mass production compatibility	● (orange)	● (red)	● (green)
	batch process	the only known example of sol gel coating able to withstand temperature over 500C is that from INM Liebniz Institute that require curing at 500C for 24 hours.	OK

Figure 2 Characteristics of the different solutions of transparent coatings evaluated

In a reflective oven, the selection of the correct heating element configuration is important to have the best compromise between overall product performance and the reduction of energy consumption. The main problem to be solved was related to the positioning of the bake element. Therefore great attention was paid to the study of the best heating elements configuration in order to achieve the targeted results.

To achieve a better cavity walls reflectivity and the best heating configuration, a set of studies has been conducted and some prototypes of increasing complexity were realized, starting from the application of an aluminium panel-foil creating a high-reflectivity proxy in a traditional cavity oven and arriving to early versions of coated stainless steel cavities assembled and tested.

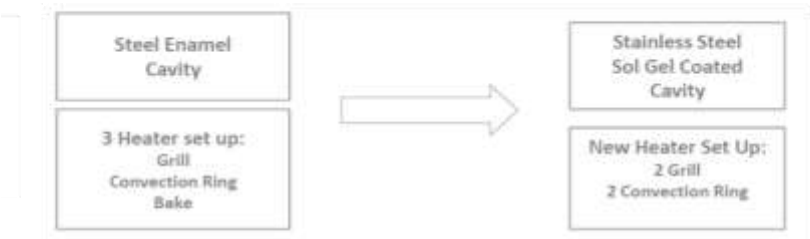

Figure 3 HEO technology in comparison to a conventional oven

Finally prototype design has been finalized and design guidelines, tolerances and test procedures were defined to evaluate the energy consumption and the respect of the specifications defined. The technology was validated according to the new oven label scheme proposed by the European Commission (Commission Delegated (EU) N.65/2014).

Figure 4 Comparison between the usual steel enamel cavity with a stainless steel cavity

From the manufacturing process point of view, different processes have been compared in order to obtain a sol gel transparent coated cavity wall and the most suitable one chosen and applied during the implementation phase.

A detailed calculation of energy saving based on selected process, substrate and coating has been performed. The possibility to achieve the quantitative target of reducing by 50% the energy consumed in the manufacturing application process for a sol-gel stainless steel cavity compared to a traditional enamelled low carbon steel cavity has been demonstrated.

- **Implementation actions:** This set of actions was the core of the project intended to engineer and realize the pilot line and the prototypes as well as to evaluate their performance in terms of energy efficiency.

In particular, the selection of the best combination of coating material, stainless steel and technology for the process has been done.
The selected coating material technology was a sol-gel double layer system able to ensure the right adhesion to the metal substrate as well as temperature resistance, chemical resistance and mechanical resistance. The coating is applied in double layer system: the first layer is applied directly on stainless steel and then cured while the second layer is applied on the first one and then cured to get the final protected surface. A set of quality check have been performed to evaluate the characteristics of the selected coating.
Stainless steel material has been selected as the best trade-off between performance and cost. Because the target product is an oven, the stainless steel has to provide the suitable resistance against sensitization (intergranular corrosion) and corrosion resistance. To achieve these multiple targets ferritic and/or superferritic stainless steel has been considered and the best one used for the final prototypes realization.
Coating technology process identification and selection: since the oven cavity is characterized by a large surface and complex geometry, the chosen technology was a pre-coating process. The reverse roll coating has been selected as the best technology trade-off to manage a low viscosity fluid as the sol-gel coating and to control in the robust way the coating thickness. At the end of the process, a pre-coated stainless steel ready to be used to

produce the oven cavities has been provided. To ensure the best quality standards, the process parameters were defined and monitored.
Based on the oven cavity design defined in the preparatory phase, all the necessary tools for cavities formability and welding were created.

Figure 5 HEO-Pilot line

Finally 50 cavities and 12 complete prototypes have been realized and a set of tests on the assembled prototypes carried out to evaluate their performances. In particular, tests about energy efficiency – targeting the brick test method – have demonstrated the possibility to increase the efficiency of about 30% in comparison to a conventional oven. The assembled prototypes are fully code compliant (temperature, condensation and packaging tests were successfully done) and the energy to cook standard food has been evaluated on average 20% less in comparison to a black enamelled cavity. A Life test has been performed (5 years of product simulated) and performance were guaranteed over time.

Figure 6 HEO Final Prototype

Test type	Methodology	Status	Results
Energy test	CEI EN 50304-60350/A1/A11	Approved	Increase of the efficiency of about 30% in comparison to a conventional oven.
Cooking performance	Whirlpool Internal Procedure	Approved	Energy to cook 20% less in comparison to a black enamelled cavity.
Codes test: • Condensation; • Temperature; • Packaging;	Whirlpool Internal Procedure for condensation and packaging test and IEC EN 60335 for temperature test	Approved	The assembled prototype is fully code compliant.
Life Test	Whirlpool Internal Procedure	Approved	5 years of product life has been simulated. Performance guaranteed over time.

Table 1 Test on assembled product

- **Monitoring of the impacts of the project actions:** this set of actions was intended to evaluate and monitor the innovative HEO process and prototype from a technical, as well as environmental and social impact perspective. During this phase, to assess the environmental impact of the HEO technology and to quantify its potential environmental and economic benefits in comparison to a conventional oven, a Life Cycle Analysis and a Life Cycle Costs Analysis have been performed by the School of Chemical Engineering and Analytical Science of the University of Manchester. The unit of analysis of the study was defined as the "manufacture and use of 1 domestic electric oven cavity over a lifetime of 19 years".

110 use cycles per year have been assumed for the use stage over a lifetime of 19 years either for HEO as well as for conventional oven. The analysis was carried out at two levels: for a single oven and for the whole EU28 market. The results suggest that, over the lifetime, the savings in the global warming potential (GWP) from the HEO relative to conventional ovens range from 9-61%, depending on the assumptions. Other environmental impacts are reduced by 24% to 62%. The equivalent savings in the life cycle costs range from 41%-61%.

At the EU28 level, the results of the study, suggest that replacement of conventional domestic electric ovens by highly-efficient models would lead to significant environmental and cost savings ranging from 0.5-5.2 Mt CO_2 eq./yr and €0.5-1.96 bn/yr, respectively. Most of the latter would be direct consumer savings because of lower energy consumption. Assuming an uptake rate of 5% per annum, it would take 20 years to achieve these benefits. At 10% annual uptake per year, these savings would be realised in half the time while at 3% it would take 33 years. Therefore, policy makers should consider measures to encourage the uptake of energy efficient ovens, including financial incentives and 'choice editing' through legislation.

In terms of the potential social impact of the project results, the sol-gel coating allows to reduce the energy requirement during manufacturing as well as to avoid toxic substances contained in traditional enamel. This latter result, may potentially contribute to improve human health as well as to reduce welfare costs in EU28.

As previously mentioned, the HEO project has demonstrated the possibility to improve the energy efficiency of a domestic electric oven of about 30% during the use of a oven in comparison to conventional oven. This result could be translated into a relevant socio-economic benefit: according to the study carried out by the School of Chemical Engineering and Analytic Science of the University of Manchester, an **increase of only 20% of the electric ovens efficiency would mean a saving of around 5 TWh of electricity per year in Europe.**

- **Communication and Dissemination actions:** the objective of the communication and dissemination actions was to promote the achievements to stakeholders and general public. An After-Life+ communication plan has been prepared as a part of this action.

In particular, the activities and the results of the project have been disseminated by the HEO partners. A website has been created, developed and made available since the first months of the project (http://www.highefficientoven.eu/). According to the technical development of the project, 4 newsletters, addressed to the stakeholders, general public and to the most widest audience of interested in, have been published on the website. Communication materials (i.e. flyers, brochures, posters) have been prepared and distributed during conferences, workshops and other dissemination activities. In addition, Life + Notice Boards have been accurately positioned.

Two high level conferences have been organized: a Mid-Term conference has been held on 29 October 2014 in Varese, Ville Ponti as a part of a large event titled “Technological innovation for the quality and sustainability of everyday life”. The Final conference has been held on 22 May 2015 in Varese, at Whirlpool Europe premises in Cassinetta di Biandronno (VA). This event has also included the final conference of the CIP-Eco Innovation SPRAY project. Alongside the previous activities, Whirlpool has been invited as keynote speaker at the event “Milano-Mass Customization Workshop 2013” held in Milan on 5-6 February 2013. Lastly, the project coordinator has presented the HEO objectives and achieved results in a lecture held on 4 December 2014 at the Free University of Bozen entitled “Home appliance Whirlpool innovation process”.

Figure 7 HEO-Final Conference

The research carried out during the project has been described and disseminated through the following scientific articles and conference proceedings:

- David Amienyo, John Doyle, Davide Gerola, Gianpiero Santacatterina and Adisa Azapagic "Sustainable manufacturing of consumer appliances: Reducing life cycle environmental impacts and costs of domestic ovens" - invited paper for the Industrial and Engineering Chemistry Research journal for the special issue on "Sustainable Manufacturing".

- Poster on Environmental benefits of eco-innovation: development of high-efficiency ovens presented by David Amienyo at the 2014 ChemEngDay conference, Manchester, April 7-8, 2014.

- Adisa Azapagic, *"Sustainability considerations in the energy-water-food nexus"*? article presented as conference proceedings at the 2014 ChemEngDay conference, Manchester, April 7-8, 2014.

Moreover, the HEO project has been included in the database of the GELSO (GEstione Locale per la SOstenibilità ambientale) project. The GELSO's project responds to the need to have a database on best practices for sustainability available to public administration, environmental groups, engineer, environmental consultants, citizens and all those are interested about innovation in sustainability.

Networking with other Life+ and EU funded project has been established. Whirlpool has structured links with internal and external funded initiatives dealing with the reduction of the environmental impacts and a more efficient use of the resources. Confidentiality issues towards competitors and categories associations (e.g. CECED) have been taken into account. 6 projects were identified for networking:

- ✓ 3 Life+: K-12 - LIFE13 ENV/IT/001238; ENERG-ICE - LIFE08 ENV/IT/000411; CRESIM - LIFE11 ENV/IT/000095;

- ✓ 3 other EU financing programmes: SPRAY - EU Instrument: ECO-INNOVATION; GREEN KITCHEN - EU Instrument: FP7 Marie Curie; HEECS - EU Instrument: ENIAC JU.

The home page to the project is: http://www.highefficientoven.eu/

3 Conclusions

The HEO project has demonstrated the production feasibility of a domestic electric oven with a stainless steel sol-gel cavity able to achieve 63% in energy saving in production process and about 30% savings in use-phase, as well as to eliminate enamel from production process. A set of cavities and prototypes based on European configuration have been built. Tests about energy efficiency – targeting the brick test method – have demonstrated how the HEO final prototypes are complaint to A++ classification.

4 Summary table

Summary table	
Project location	Cassinetta di Biandronno (VA) Italy
LIFE Project Number	LIFE 11 ENV IT 103
Project acronym	HEO
Project full title	Highly Efficient Ovens through eco – friendly energy efficient sol-gel enamelling process
Project start date	01/06/2012
Project end date	31/05/2015
Total project duration	36 months
Coordinating beneficiary	Whirlpool Europe s.r.l.
Project coordinator	Gianpiero Santacatterina
Telephone	0332-75-89-67
E-mail	gianpiero_santacatterina@whirlpool.com

Table 2 Summary Table

5 The Consortium

Partners	Role in the consortium
Whirlpool Europe s.r.l. – WHR	**Coordinator** WHR was in charge of the overall project's management of the activities, realization of prototypes and dissemination of the project results;
Whirlpool R&D s.r.l. – WHRD	**Associated beneficiary** WHRD activities were mainly linked to communication and dissemination as well as management;
University of Manchester – UNIMAN	**Associated beneficiary** UNIMAN was responsible for the development of the Life Cycle Analysis and Life Cycle Costs environmental analysis;
SCAMM s.r.l. – SCA	**Associated beneficiary** SCA was responsible for achieving the molds and assembling the cavities;

Table 3 HEO-Partners

6 References

Amienyo, D., Doyle, J., Gerola, D., Santacatterina, G., Azapagic, A., "Sustainable manufacturing of consumer appliances: Reducing life cycle environmental impacts and costs of domestic ovens" - invited paper for the Industrial and Engineering Chemistry Research journal for the special issue on "Sustainable Manufacturing";

Bertoldi, P., A. Ricci, A. de Almida (Eds.) (2001). Energy efficiency in household appliances and lighting. Springer-Verlag, Berlin.

Fonseca, P., A. de Almeida, N. Feilberg, G. Markogiannakis, C. Kofod (2009). Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations. ECEEE 2009 Summer Study.