LIFE13 ENV/IT/001238

The K-12 Project Mid-term event

Pont Canavese, 18th May 2017
K12- PU Disruptive technology to dramatically improve Energy Efficiency of Household Appliances

K12: A REAL LIFE PROJECT
V. Parenti, A. Gasparoni, M. Corti

With the contribution of the LIFE financial instrument of the European Community
THE LIFE+ K12 PROJECT

The LIFE+ K-12 project aims to demonstrate the feasibility and effectiveness of an innovative Polyurethane (PU) technology offering significantly improved thermal insulation and, thus, energy efficiency of households cold appliances, contributing to the European Community’s goals of creating an energy efficient economy while mitigating the threat of global warming.
The Home Appliance Industry Challenges

- Innovation
- Cost
- Policies
- Market Needs
- Environment
Background: EU climate & energy package

2020:
- 20% cut in greenhouse gas emissions (from 1990 levels)
- 20% of EU energy from renewables
- 20% improvement in energy efficiency

The targets were set by EU leaders in 2007 and enacted in legislation in 2009.

2030:
- 40% cuts in greenhouse gas emissions (from 1990 levels) – at least
- 27% share for renewable energy – at least
- 27% improvement in energy efficiency – at least

The framework was adopted by EU leaders in October 2014.

Reduction target for Emissions trading system (ETS) and non-ETS sectors.

The European Union, United States and China collectively produced 45% of global annual emissions of GHG in 2010.

**China - peaking emissions by 2025 or 2030**
- 2030: 15.3 Gt CO$_2$e
- 2030: 13.8 Gt CO$_2$e

**US - 28% below 2005 by 2025**
- 3.8 Gt CO$_2$e

**EU - 40% below 1990 by 2030**
- 3.2 Gt CO$_2$e

Source: ESRC Centre for Climate Change Economics and Policy - Grantham Research Institute on Climate Change and the Environment (May 2015)
Background: Energy Consumption

- Residential sector account for 30% of total energy supply, distributed over 140M households.
- Cold appliances account for 14,5% of total household energy consumption.
- Between MDA, cold appliances account for 37% of total household energy consumption.

Residential electricity consumption breakdown in the EU-27, 2009 (source JRC)

Share of fleet energy consumption by product groups (2010-2014). Source: GfK Retail and Technology Panel
Background: Energy Efficiency

Energy Label  New Technologies

Average energy consumption trends by product groups in Western EU (2010-2014). Source: GfK Retail and Technology Panel

Draft for Energy labels rescaling (Source CECED)

Energy efficiency classes of refrigerators-freezers in the EU (21 countries), 2004-2014. Source: topten.eu from GfK
BACKGROUND: THE MARKET

- The cold appliances market is characterised by a high level of substitution of old appliances rather than by an increase of the existing stock.
- Refrigerator stock reached the saturation level with penetration rates of around 100% in almost all EU-28 countries.
- Market trends of refrigerator-freezers are towards models with a larger capacity.
- The higher energy classes have larger capacities.

(Source: JRC Report Energy Trends 2000-2014)

Figure 12. Factors influencing the choice of refrigeration appliances (source: GMJ/Mintel “Fridges and freezers – UK”, April 2014, in “Energy efficient products – helping us cut energy use”)

An highly efficient refrigerator, with larger capacity and environmental friendly manufacturing can be a real winner on the market!
The K12 projects objectives and expected results

- Refrigerator manufacturing process demonstrated at pilot scale with optimized foaming parameters and new injection equipment
- A 25-30% improvement in foam thermal conductivity performance of the new PU foam, compared to the best in class solutions
- Up to 20% reduction in the energy consumption of cold appliances, with respect to the current best in class OR trade off between energy/capacity
- Feasibility of applying the novel insulation material with a zero ODP (Ozone Depletion Potential) and minimum GWP (Global Warming Potential)
- Reduce environmental footprint over the value chain based on a “cradle-to-gate” LCA approach
- Create an industrial showcase that supports policy makers to further push the use of energy efficient home appliances
- Development of a market introduction impact scenario
Domestic Refrigerators: insulation material

Why Polyurethane?

Comparison of thermal efficiency:

- 2.5 cm rigid PU foam
- 4.0 cm poli-styrene
- 4.5 cm fiber-glass
- 5 cm cork
- 12 cm wood
- 40 cm bricks
# EU Energy Labeling for Domestic Refrigerators

<table>
<thead>
<tr>
<th>EEI</th>
<th>EN - supplementing Directive 2010/30/EU of 28 Sept 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>A+++</td>
</tr>
<tr>
<td>33</td>
<td>A++</td>
</tr>
<tr>
<td>42</td>
<td>A+ (* A+)</td>
</tr>
<tr>
<td>44</td>
<td>A</td>
</tr>
<tr>
<td>55</td>
<td>B</td>
</tr>
<tr>
<td>75</td>
<td>C</td>
</tr>
<tr>
<td>90</td>
<td>D</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

**Energy Efficiency Index (EEI)**

$$EEI = \frac{AEc}{SAEc} \times 100$$

- **AEc** = Annual Energy Consumption
- **SAEc** = Standard Annual Energy Consumption (average of the specific category)

**Timeline:**
- Only class A+ (42) or better from July 2014
- Ban of class A
- Only class A or better from June 2010

**Today:**
- A++
Why K12 Project?

**K12 project objective:**

Demonstrate the feasibility of a novel PU insulation technology for the domestic appliance industry able to improve the refrigerators energy efficiency up to 20% 
By  
Developing a microcellular PU foam with cell size \( \leq 10 \mu m \) blown with CO\(_2\) as sole Blowing Agent  
To  
Reduce consistently the Carbon Footprint in the production and use of the domestic refrigerators, enabling easier insulation filling material Recycling within the frame of Circular Economy
K12 would allow one step change in Energy Efficiency

**EU: average energy consumption of refrigerator sales in 2014**

Data: GfK, Graph: Topten.eu
How a refrigerator is injected with PU foam?

Most conventional injection technology:
Injection from the compressor side—door up
Available PU technology solution in the market with various Blowing Agents

\[ \text{k-factor} \]

\[ \text{Gel time} \]

\[ \text{PASCAL}^{\text{TM}} \text{ is a Tradename of The Dow Chemical Company} \]
Non-PU available alternate solutions in the market with CO₂ or No-Blowing Agents technologies

### k-factor @10°C (mW/m.K)

- **Dow Xenergy™**
- **K12**

**Xenergy™** is a Tradename of The Dow Chemical Company
Thermal insulation by VIPs + PU foam

### Fumed silica typical VIP physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>170-210</td>
</tr>
<tr>
<td>Thermal Conductivity at mean temperature of 22.5°C (72.5°F) (W/m.K)</td>
<td></td>
</tr>
<tr>
<td>@ 1 mbar</td>
<td>≤0.005</td>
</tr>
<tr>
<td>@ ambient pressure</td>
<td>≤0.019</td>
</tr>
<tr>
<td>Rated Value (W/m.K)</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Source: Porextherm web site

\[ \lambda_{Wall} = f(\lambda_{VIP}, \lambda_{PU \text{foam}}) \]
PU Foam Thermal Conductivity

\[ \lambda_{\text{Foam}} = \lambda_{\text{gas}} + \lambda_{\text{solid}} + \lambda_{\text{radiative}} \]
How can we reduce the PU foam Thermal Conductivity?

- Smaller cell size → reduce the radiation contribution
- Lower foam density → reduce the solid contribution
- Low gas thermal conductivity ($k$) → reduce the gas/blowing agent contribution

*however, combination of all these options must be considered and gauged, for example...*

- Reduced density will decrease the solid conduction contribution, but will also increase the radiation contribution due to thinner cell walls

*K-12 Project is active in all these aspects and works on reducing all heat transfer contributions and to maximize thermal insulation, thus energy efficiency*
Energy Efficiency Impact of PU insulation

- Fast reactivity
- Modified fixture
- Foaming under vacuum
- Blowing Agent

- Current process
- PU injected into the refrigerator
- Blowing Agent

- Microcellular foam
- CO2 blowing agent
- Lowest GWP
- Long term sustainable solution

PASCAL™

ENERG-ICE

LIFE08 ENV/IT/000411

LIFE13 ENV/IT/001238
Towards K12: Microcellular foam upscale

←Low Magnification - High magnification→

Process Optimization T, P and Output effect

↓

PU R&D Lab → Cannon Pilot Plant → Whirlpool prototype
K12 Gantt Chart and action program

1. Lab Development and Testing
   Done/Ongoing:
   • Autoclave Lab development
   • Collaboration with Core R&D and CNR/Naples Eng. Univ. for PU fundamentals and formulations dev.

2. Pilot plant runs
   Plan/Ongoing:
   • Design/construction of the pilot plant
   • Realization and testing prototypes
   • Technology validation indoors and cabinets

3. Project impacts
   Plan/Ongoing:
   • Environment/LCA
   • Market and Socio-economic impact

4. Communication
   Plan/Ongoing:
   • Web site
   • Layman’s report

5. Whole management
   Plan/Ongoing:
   • Networking
   • After LIFE

Project start date: 2014 June
Project end date: 2017 November → Extension 2018 November

Cell size 100-120 μm

Cell size 10-40 μm

Cell size 30-60 μm

Bimodal cells

Elongated cells
Scaling up from Lab scale to Semi-industrial application

First phase activities: CO₂ dispersed in vein of the polyol stream

Design and production of a special mold for testing the expansion of the foam with CO₂ dispersed into the polyol stream

A special flat mould has been studied, designed and constructed in order to test the expansion of the PU foam under pressure with gaseus CO₂
Specific mixing head provided with a CO2 injection valve

First phase activities: CO₂ dispersed in vein of the polyol stream

Preparation of a specific mixing head provided with a CO₂ injection valve.

The test was performed by using an FPL 10 mix-head provided with a special valve to inject liquid CO₂ in the vein of polyol stream

The valve recirculates the CO₂ (in liquid phase) and insert/mix it into the polyol stream before mixing it with the isocyanate
Metering units

First phase activities: CO₂ dispersed in vein of the polyol stream

Liquid CO₂ metering unit

Metering unit:
to handle the new
types of formulation
with direct injection
of CO₂
First in-mold studies

First phase activities: CO$_2$ dispersed in vein of the polyol stream

4 different campaigns were performed c/o Afros R&D Lab with the aims to:

- Test the PU chemicals and their expansion behaviour
- Measure the foam cell sizes obtained and the foam performance including the percentage of open cells, with different formulations and foaming process parameters.
Pilot Plant to realize fine and stabilized CO₂ dispersion

Following the indications derived from the first series of tests in very small scale by DOW and the Naples Engineering University, we decided to realize a special pilot plant able to repeat in full size the expansion situation.

**Polyol metering group**

**Special container rated for 160 bar to mix and fine disperse CO₂**

**Module for dispersing CO₂ and Polyol + module to meter the dispersion to the mixing head**

**Isocyanate metering group**

**Module for mixing the reactive mixture and injecting it into the mold**

**Mixture metering system**
K12 Pilot Plant in operation

Test and trials with the Pilot plant assembled and fully operative
Pilot plant: Polyol and Isocyanate metering module

The module for metering the polyol and the isocyanate in high pressure installed and properly working.
Pilot plant control: New operator interface and software

The control of the whole pilot plant has been developed with a new software and logic.

It controls the different functions by blocks, particularly the **new operator-interface** is based on the visual schematization of the functioning of the different parts through specific animation of the movements.
Components of the new K12 Pilot Plant

Module to efficiently store and disperse polyol and CO₂ with high efficiency mixing

+ Module to meter the dispersed fluid to the high pressure mixing head
K12 Pilot plant: sealing of the mix heads

The **LN 10** mix head has been specifically designed and set to maintain a delta pressure of around 70 bar between the POLYOL and ISO grooves.

Any leaking from the grooves can block completely the mix head.

This achievement is the result of several months of tests and it’s an important result for future applications. It has been applied also to the FPL type mix-head.
The transfer module is composed of a special cylinder and its ancillaries.

It can accumulate the reactive mixture during its reaction, maintain the mixture under pressure and release it at a certain phase of the reaction.

It can expel the complete mixture before it becomes solid.
Upon the completion of the first part of tests into the brett mold, the tests have been transferred to the flat mold.

It can maintain the mixture under pressure and then upon release of the pressure to complete the foam expansion.

The tests are still ongoing and results are quite good in terms of fine cells size.
Conclusions

A new and important milestone has been achieved through the pilot plant modules in terms of fine dispersion of CO$_2$ and polyol and in term of capability to meter it to the mixing head in any pressure conditions.

The use of the system showed that it is possible to disperse the CO$_2$ up to 40% in the polyol.
K12 trials continue with a new device

Actually we are running tests of the expansion in high pressure conditions (up to 160 bar)

We use a special spherical container adapted from an hydraulic accumulator.

Test and trials are ongoing with increasing quantities of CO₂
Today the by Pilot Plant it is possible to produce dispersion of polyol and CO$_2$ in any pressure conditions up to 160 bar and to dose and mix them into a high pressure mixing head properly sealed.

To test the expansion in pressure conditions up to 160 bar by means of a special spherical container adapted from an hydraulic accumulator.

Test and trials are ongoing.
Next action: begin the prototyping phase

The **K12 project** will continue with the application to a prototype refrigerator.

In the meantime we will set up the type of chemicals and the type of expansion conditions that can further improve the reduction of the cells size and the control of the filling of the mold.
Thank You