FOOD PACKAGING OPTIMIZATION BY MEANS OF INTEGRATED CAD/CAE AND STATISTICAL TECHNIQUES

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ABSTRACT

Packaging innovation, finalized to configure food in terms of product/service, is crucial in satisfying consumers' needs: pleasure, practicalness, health.

Furthermore, also in such sector, time reduction between the R&D activity and the industrial exploitation of the results becomes more and more strategically important.

In such scenery, "Steam Pack", an innovative disposable pack, has been developed for pressure cooking of food in microwave ovens.

The development in short times of "Steam Pack", winner of the Oscar dell'Imballaggio 2005 ("Technology" section) and of a World Star Packaging Award 2005, was possible thanks to integrated CAD/CAE and statistical techniques.

The study has been carried out according to a DOE of FEM analyses aimed to optimize the geometry of the membrane spring, the geometry of the steam vent and the thickness of the bowl walls.

The use of integrated CAD/CAE and statistical techniques made possible the simultaneous handling of several parameters, enabling optimization in short times. This allowed to realize prototypes and start the testing stage after just two weeks from the beginning of the design activity.

DEVELOPMENT OF "STEAM PACK", A DISPOSABLE PACKAGE FOR MICROWAVE COOKING

Steam Pack is realized in polypropylene and consists of two parts (Figure 1) :
- an oval-shaped bowl subdivided into two concentric compartments, to keep food components separated until use;
- a valve, which characterizes the pack and acts also as a plug for the central compartment. By means of such valve, through a cyclic "open/close" process, the outflow of the steam generated during the cooking process is optimized, with a remarkable reduction in preparation times.

Figure 1: sectional view of the bowl (blue) of the valve (green) and the finished package

The bottom of the central chamber features a spring membrane (3), which lifts the valve (1) when such valve desengages from the dispenser (2) due to the build up of steam generated during cooking. The valve performs open and close cycles dragged by the thermowelded film (4) inflating and deflating thanks to the steam. Such device represents the key element for the correct performance of the pack.

The development of Steam Pack called for optimization in terms of costs, functionality, practicality of use and handling.

As the product needs to be industrialized, further limitation derive from the production process, logistics, and needs resulting from the packaging of the final product.

The entire optimization process can be simplified in the following steps:

- brainstorming, to evaluate all factors contributing to obtain satisfying results for all requirements
- factor screening to individuate the most influential factors for each individual requirement. Regarding this last issue we referred to a DOE performed using reduced factorial plans and trough the analysis of the related Pareto diagrams and ANOVA tables
- full factorial plans and response surface method performed on the most influential factors for each requirement with the aim of researching optimal values for each factor (goal driven optimization)

Following is a report on the most critical aspects, with regards to the optimization of the spring-valve, the exit hole diameter and thickness of the bowl wall.

Optimization of the spring-membrane

Following the factor screening performed on the membrane operation, the three most influential factors have been pointed as being: radius, height, thickness (Figure 2).

Figure 2: parameters influencing the geometry of the spring membrane (radius, height, thickness)

We analysed, in particular, the influence of the three parameters on the value of the third buckling mode, needed to deform the membrane during packaging. The first and second buckling mode have been overlooked as they are considered not influential during product packaging.

The referred load environment and the three buckling modes are shown in Figure 3.

Figure 3:1°-2° buckling mode, 3° buckling mode, load environment

With the benefit of previous experience in designing and adopting the principles of hybrid modelling, the target was set for the 3rd buckling mode, for the goal driven optimization, with relation to the value of the buckling mode multiplier for a previously created product. During analysis we considered the non-conservative buckling nature.

Design of experiment and results

The parameters manager of Ansys Workbench Simulation 9.0 and the integration betweeen Ansys Workbench and the modelling software used (Autodesk Inventor Series 10) allowed for the rapid implementation of a full factorial plan 3^3 (Table 1), performed during advanced optimization of the three influential parameters for the 3rd buckling mode identified during factor screening (radius, height and thickness).

Table1: Parameters and levels for full factorial

Parameter	Low Value	Center Value	High Value
Radius (mm)	25	27.5	30
Height (mm)	5	7.5	10
Thickness (mm)	0.4	0.6	0.8

Following is the response surface for the 3rd buckling mode with relation to height and thickness (Figure 4).

Figure 4: response surface of 3rd buckling mode in function of height and thickness of the full factorial DOE

Assigning a value of 60, resulting from the buckling analysis performed with Ansys Workbench Simulation 9.0 on a existing membrane with similar features to the desired ones, to the 3rd buckling mode load multiplier ,as the target of optimization , and imposing as desirable conditions of the 3 examined factors, values resulting from considerations of economic and functional nature, we managed to determine a set of optimal values of the three factors (radius = 28.5 mm, thickness = 0.56 mm, height = 8.4 mm).

Optimization of the exit hole diameter

Determining the optimal diameter of the exit hole is very important as it determines the level of the pack internal pressure, directly influencing the final results in terms of preservation of the nutritious substances and cooking time. In addition it's important to determine the existing relation between the diameter and the generated internal pressure, to be able to choose the best diameter for each food product.

A stationary fluidodynamic analysis has been arranged, which boundary conditions are shown in picture 5.

In order to reduce the computational effort, the pack symmetric properties have been exploited.

Boundary Conditions
Fluid: Water Vapour at 100°C
Inlet: Mass Flow Rate = 0.303 gr/sec
Outlet: Relative Pressure = 0 mbar

Figure 5: boundary conditions for fluidodynamic analysis

The values of the boundary conditions parameters result from simple thermodynamic evaluations, together with the results of a cooking test in a microwave oven performed using a simplified prototype of the packaging.

Test in a Microwave Oven Using a Prototype

STARTING DATA
Pack Content: 150gr water
Microwave Oven Power: 600W
Test Duration: 4 minutes and 30 seconds
Initial Water Temperature: 20°C
Exit Diameter: 3mm

DATA READ DURING TEST
Steam flow starts after 1 minute and 45 seconds from the beginning of the test

DERIVED DATA
Actual steam flow duration: 4:30 – 1:45 = 2 minutes and 45 seconds (165 seconds)
Energy Supplied by the Microwave: 600W x 4min30sec = 162000 J
Energy needed to heat the water from 20°C to 80°C: 4186 (J/kg/K)x 0,15 kg x (100-20)°C= 50232 J
Remaining Energy to generate steam: 162000 J – 50232 J = 11768 J
Vaporization heat of water at 100°C = 2260 kJ/kg
Generated Steam: 111768 J / 2260 kJ/kg = 50 gr
Inlet Steam Flow: 50gr/165sec = 0.303 gr/sec

Using a parametric CAD file, having as a sole parameter the diameter of the steam exit hole, various fluidodynamic analysis have been performed for different values of the diameter. Finally, the flow of the average pressure in relation to the diameter was outlined. (Fig. 6)

Internal pressure (mbar) = 268,4282*exp(-0,799*vent diameter)

Figure 6: diameter-pressure chart obtained through fluidodynamics simulations

Optimization of the wall thickness

Once the pack internal pressure had been established, the optimal thickness of the pack walls was determined. Determination of minimum wall thickness of the oven bowl is fundamental to make the pack as light as possible (improving cost cut and recyclability), compatibly with needs of production by means of injection molding and the admissible deformations during cooking (positive internal pack pressure) and in a cooling off phase (negative internal pack pressure), for a correct operation.

To evaluate deformation we used Ansys/Workbench Simulation 9.0, using the parameters manager to vary the only used parameter: the wall thickness.

To evaluate compatibility of the wall thickness with the production process, we used a program simulating the injection molding process, considering different thickness of the pack.

Analysing results from the different analysis performed , we determined the desired thickness.

In Figure 7 the load environment considered through the study of deformation with Ansys Workbench Simulation 9.0 and the the results for fill analysis for injection molding process.

Figure 7 : load environment of simulations with Ansys Workbench 9.0 and CAD model for injection molding process simulation

The optimal wall thickness resulted in 0.8 mm.

FURTHER FEM APPLICATIONS FOR STEAM PACK

FEM analysis have also been performed, to determine the strength needed to keep the film and the dish together during operation in order to individuate an optimal film and to determine the optimal geometry of the snap fits keeping all the pack components together. (Fig. 8)

Figure 8 : contact pressure analysis between the film and the bowl (on the right) and the snap fits optimized through FEM analysis

REFERENCES

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