NEW ENVIRONMENT FOR THE SIMULATION, OPTIMISATION AND CONTROL OF FOOD PROCESSING

E. Balsa-Canto[1], C. González[1], J. Mora[1],
J. R. Banga[2], A. A. Alonso[2]

[1]*CIMNE: International Centre for Numerical Methods in Engineering, UPC, Campus Nord, Gran Capitan s/n, C-1, 08034 Barcelona, Spain*
[2] *Process Engineering Group, IIM-CSIC, C/Eduardo Cabello 6, 36208, Vigo, Spain*

SUMMARY: Computer aided process engineering techniques have been successfully used for the simulation, optimisation and control of many industrial processes. However, in the case of the food industry, the complexity of the mathematical models of food processing, plus the often complex geometries of foodstuffs, makes the solution of this type of problems very complicated. The development of a new tool based on the combination of GID with suitable numerical methods is presented here as a new software package for the complete study of the most relevant food preservation techniques (sterilization, pasteurisation, and freezing, among others). This new tool will consist of a user friendly, ease to use environment allowing users from food companies to improve their processes in an effective way. As a consequence, they will be able to design better processes which will guarantee safety and quality of foodstuffs, with less cost, reduced energy consumption and minimum environmental impact.

KEYWORDS: Food preservation, simulation, optimisation, control, finite elements, GID

INTRODUCTION

One of the major concerns of the food industry is offering high quality and safe products to the consumers. Food safety and quality control ensures that the desirable characteristics of food are retained throughout the production, handling, processing, packaging, distribution and preparation stages. Food spoilage is a gradual process occurring because of enzymatic and/or chemical reactions, improper temperature control or microbial growth, resulting in undesirable changes in the colour, flavour, odour and/or texture.

It is well known that the use of adequate preservation techniques ensures a longer shelf life of the product. Food preservation through processing is an extremely broad area in food technology, including processes like refrigeration, freezing, pasteurisation, sterilization, fermentation, and drying, among others. Although the basic idea behind all these techniques is to either slow down or eliminate the activity of the bacteria causing spoilage, not all these processes are suitable for all types of food. Moreover, operating conditions must be carefully selected in order to guaranty a safe product with the maximum possible content of nutrients.

The increasing demand from industry of tools for the design of better processes and the computation of optimal operation policies has lead to extensive research in several areas related to food processing such as modelling, simulation, optimisation and control (e.g. see Teixeira et al, 1969; Banga et al, 1991; Fryer, 1994; Alonso et al., 1998, among others). The use of these techniques allows the reduction of cost and time if compared with traditional approaches usually based on extensive experimental work and "trial-and-error" procedures. However, regardless of all the advances in this field in the academic world, the use of these methodologies in industry is still very limited, with the absence of user friendly software environments being one of the main reasons. Moreover, although there is a number of commercial tools that allow quite easy simulation of many relevant food processes, this is certainly not the case for the solution of dynamic optimisation and control problems.

The objective of this work is to present a new, easy to use software tool (CALISO) which combines a library of numerical routines for the simulation, optimisation and control of a number of relevant food preservation processes, with the pre/post-processing capabilities of GID and a user-friendly graphical interface.

MODELLING AND SIMULATION OF FOOD PRESERVATION PROCESSES

Modern process systems engineering methods rely on mathematical models based on sound first principles, considering heat, mass and momentum transport phenomena, plus the corresponding expressions for the kinetics and thermo-physical properties. Moreover most of the relevant variables (e.g. temperature and moisture content) depend on both the position inside the food load and time. Therefore, the resulting mathematical models consist of usually highly non-linear sets of partial differential and algebraic equations (PDAEs) whose solution usually relies in numerical techniques. Most of these numerical approaches are based on the discretisation of the spatial domain, such as the finite differences approach, the numerical method of lines (NMOL, Schiesser, 1991) or the finite elements method (Zienkiewicz and Taylor, 2000; or Datta, 1998 for applications related in food processing).

DYNAMIC OPTIMIZATION OF FOOD PRESERVATION PROCESSES

Dynamic optimisation involves the calculation of time-varying control profiles (e.g. the heating temperature profile in a sterilization process) that optimise (minimise or maximise) a desired objective functional (usually related to cost, quality of final product, energy consumption, etc.) subject to the system dynamics and a number of constraints (e.g. microbiological safety). During recent years, dynamic optimisation methods have been successfully applied to a number of relevant processes from the food industry, such as thermal sterilization (Banga et al, 1991; Silva et al 1993; Durance, 1997) or drying (Banga y Singh, 1994).

CONTROL OF FOOD PRESERVATION PROCESSES

In order to implement these optimal operating policies obtained through the solution of the dynamic optimisation problems, it is necessary to use adequate control methodologies, usually based in the model predictive control scheme. This type of controllers has been applied to several food processes such as extrusion (Nikolau, 1996), drying and refrigeration (Trelea et al, 1998) and thermal sterilization (Alonso et al, 1998; Chalabi et al, 1999).

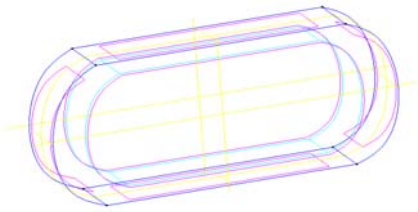
CALISO CAPABILITIES

CALISO will remedy some of the current software limitations providing tools non only for simulation but also for both optimisation and control. It will consist of three main elements:

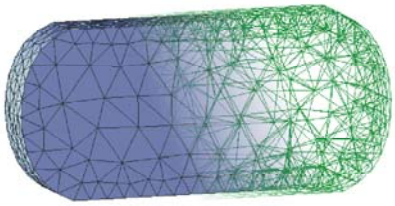
- A user friendly interface: in order to make work very simple, it will provide information regarding the modelling of different preservation processes, geometries, plus simulation, optimisation and control capabilities.
- Pre-postprocessor: GID will provide different mesh generation options, adaptability to simulation codes and visualization facilities, such as temperature distributions, animated sequences for dynamic analysis, graphics related to quality of products, etc.
- New modules with suitable and efficient numerical techniques will ensure the rapid solution of the simulation, optimisation and control problems.

The capabilities of CALISO may be shown through an example, the case of sterilization of canned foods. CALISO will allow the implementation of the can geometry, the simulation and the dynamic optimisation in order to maximize the nutrient contents inside the food while guarantying a level of sterility, that is safety. Figure 1 illustrates the process:

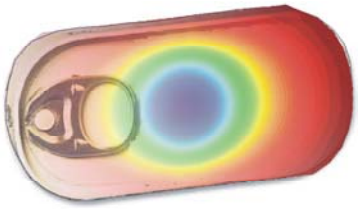
a) Can to be sterilized



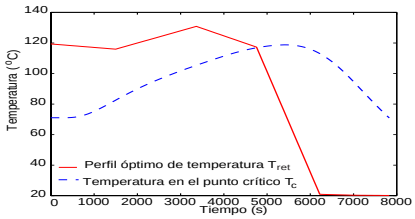
b) Geometry representation



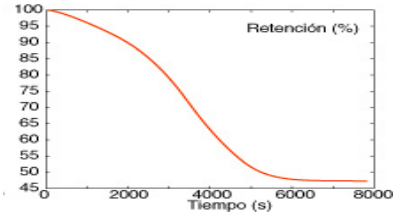
c) GID: Mesh generation



d) Temperature distribution at final time



e) Optimal operating conditions and temperature in the coldest point



f) Volumetric nutrient retention

Figure 1: CALISO solving approach

Moreover, for some very complicated cases the computational effort may be too large for the solution of dynamic optimisation and control problems. However, the use of reduced order models allows the efficient solution of these type of problems (Balsa-Canto et al., 2001 I,II). Therefore, CALISO will also include an appropriate module for the automatic generation of reduced order models.

CONCLUSIONS

Although there are a number of simulation tools based on the finite element method which could be somehow programmed to simulate food processing operations, this is not the case for dynamic optimisation and control. CALISO is a new, user friendly, easy to use environment which will allow the systematic application of computer-aided process engineering techniques to food preservation processes. This new tool will allow the modelling and simulation of highly complex food preservation processes and geometries, plus the possibility of computing their optimal operating conditions and designing closed loop controllers. This software environment will allow the food industry to improve both the performance of their processes and the quality of their products.

REFERENCES

1. Alonso, A. A., Banga, J.R. and Martín, R.I.P. "Modeling and adaptive control of a batch sterilization process", Comput. Chem. Eng. 22(3):445-458, 1998.
2. Balsa-Canto, E., Alonso, A.A. and Banga, J.R. "A novel, efficient and reliable method for the thermal process design and optimisation. Part I:Theory", J. Food Eng. , in press.
3. Balsa-Canto, E., Banga, J.R and Alonso, A.A. "A novel, efficient and reliable method for the thermal process design and optimisation. Part II: applications", J. Food Eng., in press.
4. Banga, J. R.; Perez-Martin, R. I.; Gallardo, J. M.; Casares, J. J. "Optimization of the thermal processing of conduction-heated canned foods: study of several objective functions", J. Food Eng. 14(1): 25-51, 1991.
5. Banga, J. R. and Singh R. P. "Optimization of the air drying of foods", J. Food Eng., 23:189-211, 1994.
6. Chalabi, Z.S, L.G. van Willigenburg and G. van Straten. "Robust optimal receding horizon control of the thermal sterilization of canned foods", J. Food Eng, 40(3):207-218, 1999.
7. Datta AK. "Computer-aided engineering in food process and product design". Food Technol-Chicago 52 (10): 44-52, 1998.
8. Domínguez, N. and Soler P. , "GID User Manual", Ed. CIMNE, Spain,1999.
9. Ribó, R., de Riera, M. and Solano, E., "GID Reference Manual", Ed. CIMNE, Spain, 1999.
10. Durance, T.D., "Improving canned food quality with variable retort temperature processes", Trends In Food Sci. & Tech. 8(4):113-118, 1997.
11. Fryer P, "Mathematical-Models In Food-Processing", Chem Ind-London (13): 515-518, 1994.
12. Nikolaou, M., "Computer-aided process engineering in the snack food industry", Chemical Process Control (CPC-V) Conference, January 7-12, Tahoe City, CA, 1996.
13. Schiesser, W. E. " The numerical method of lines". Academic Pres, New York, 1991.
14. Silva, C. L. M., Oliveira, F. A. R. and Hendrickx, M. "Modelling optimum processing conditions for the sterilization of prepackaged foods", Food Control 4(2): 67-78, 1993.
15. Teixeira, A.A., Dixon, J.R., Zahradnik, J.W. and Zinsmeinster, G.E. "Computer optimisation of nutrent retention inthermal processing of conduction heated foods". Food Technol., 23:137-142, 1969.
16. Trelea, I.C., Alvarez, G. and Trystram, G., "Non linear predictive optimal control of a batch refrigeration process", J. Food Process Eng. 21:1-32, 1998.
17. Zienkiewicz, O.C. & R. L. Taylor (2000), "The Finite Element Method", 5ª Ed. Butterworth-Heinemann, 2000.