A Library of Software Components for the Operation of Thermal Food Processing Plants

C. Vilas, M.R. García, J.R. Banga and A.A. Alonso

Process Engineering Group

Instituto de Investigaciones Marinas (CSIC)

Eduardo Cabello, 6 36208, Vigo (Spain)

Keywords: Hybrid Systems, Dynamic Simulation, Food Processing, User Friendly Environment.

Abstract

In this work, we present a library of software units for the simulation, optimisation and control of thermal processes in the food industry. The *Ecosimpro*® environment has been selected as the programming tool. The reason is twofold: On the one hand it allows working with hybrid systems as it is the case of food processing plants and, on the other hand it is equipped with a graphical user interface (GUI) which allows users to handle models in an intuitive way (by means of icons). Although this work is focused on processes of the canned food industry, new units dealing with other processes can be added without modifying the existing. Finally, the models have been validated in a pilot plant installed at the IIM-CSIC.

INTRODUCTION

Traditionally, in the food industry, no systematic approach to the design of the plant operation policy has been employed. The characteristic parameters of the process such as the temperature or the time of the treatment, have been usually selected by the plant workers taking into account several factors such as the quantity of product to be processed or the current legislation on food safety, among others. Usually, this approach may lead to unnecessary food quality losses and the increasing of processing time and production costs due to the selection of a suboptimal operation policy.

In order to systematise and optimise the design of such processes, many alternatives have been proposed among which the most successful are those based on the use of mathematical models (Banga et al., 2003). A complete survey of works dealing with the modelling of the different processes in the food engineering area can be found in Bruin and Jongen (2003); Wang and Sun (2003); Bimbenet et al. (2007).

However a critical obstacle to the use of models is the requirement of an extensive mathematical and programming expertise. To avoid this inconvenient a number of key tools have been developed. Among those one must remark the Graphical User Interfaces (GUI) which allow users to handle models in an intuitive way (by means of icons), and the paradigm of object oriented programming (OOP) which makes easier the inclusion of new models or the modification and improvement of the existing. There exist several environments for the simulation of food industry processes, see for instance Datta (2002); Ötles and Önal (2004). Other simulation environments not included in these revisions are: *Pro-Food*¹

¹<http://www.cimne.com/profood>

or *Kratos*² for food conservation processes. All these environments were designed either without taking into account the paradigm of OOP or they are closed. These inconvenients cause that the inclusion of new units or the modification of the existing to be a tedious, or even impossible, task for a person unconnected with the programming team.

The aim of this work is to present a library of components, constructed in a GUI and using the OOP paradigm, for the simulation of thermal processes in food processing plants. Due to the special features of this kind of plants the library was constructed in order to be able to deal with non linear dynamics with coupled transport phenomena, spatial distributed components and hybrid systems, i.e., systems that combine processes with continuous dynamics (such as, sterilisation or freezing) with discrete events (such as controller actions) (Alonso et al., 1998). It is worth mentioning that although *EcosimPro*® is the main simulation environment in which the library has been constructed, other software tools like Matlab® or C/C++ have been employed so as to add new powerful capacities to *EcosimPro*®. In this regard, the linkage of *EcosimPro*® with the other software allows the library to be equipped with tools for control, optimisation, partial differential equation solution, real time prognosis or information analysis, among others. In order to illustrate the predictive capabilities of the library, the results obtained with this simulation tool were compared with measurements obtained from a real plant installed in the IIM-CSIC. Other examples illustrating possible uses of the simulation environment involve the selection of the appropriate equipment for a given plant or the optimal design of the operation policy.

MATERIALS AND METHODS

For the model validation a pilot plant, whose schematic view is shown in Figure 1 (a), was employed. The steam coming from the boiler is passed through a reducing valve to

Figure 1: (a) Schematic view of the pilot plant installed in the IIM-CSIC. P corresponds with the pressure sensors while T and TC represent the temperature sensors. (b) Extensions of the tool to the general structure of the plant.

keep the pressure of the inlet steam constant. The retort temperature and pressure are mea-

²<http://www.cimne.upc.es/kratos/food.asp>

sured by means of different devices located inside the vessel. In this way, the temperature is measured by means of *PT100* sensors (*T*) and thermocouples (*TC*) while the pressure sensors are of type *Teleperm Transmitter K*. Besides, an OPC server (*Labview*®) collects, stores and distributes the information (see Figure 1 (b)). Temperature and pressure signals collected through the plant devices are sent to the OPC server through a data acquisition external module. The simulator and the additional tools are connected using the *Labview*® options for the communication with external programming languages (for instance *Ecosim-Pro*®). The sensor, simulator and additional data tools are stored into a database which generates the pertinent reports. The clients can communicate with the OPC server through either a local area network or internet. In this way, they have access to the database and the rest of information collected in the server. This structure allows the remote manipulation of the plant, simulator and/or additional tools.

The mathematical models of the different components are constituted by sets of equations describing the inherent characteristic of processes, units and auxiliary equipment such as retorts, heat exchangers, cooker vessels, boilers, controllers and valves or pumps, for instance. Mathematically, these components are expressed by coupled sets of non-linear algebraic and partial or ordinary differential equations (DAEs, PDEs and ODEs, respectively). Formally, the different classes of PDAES (Partial Differential Algebraic Equation Systems) are of the form:

$$\frac{\partial x}{\partial t} + \vec{v} \cdot \sum_{i=1}^n \vec{n}_i \frac{\partial x}{\partial \xi_i} = \sum_{i=1}^n D_i \frac{\partial^2 x}{\partial \xi_i^2} + f(t, \xi, x, u) \quad (1)$$

$$\frac{dx}{dt} = f(x) + g(x)u \quad (2)$$

where x is the vector of states (or simply the field) which, for instance, might represent the temperature or mass product distribution in a solid or fluid. $\vec{v}$ and D represent the fluid velocity and the diffusivity, respectively. Equation 2 represents a typical set of non-linear ordinary differential equations in affine form with u being both in Eqns (1) and (2) the control actions. Finally, f and g are possibly nonlinear functions which may include for instance the reaction rate or degradation kinetics among other aspects. For more details on the particular structure of the different unit models see Vilas et al. (2008) and references therein.

Different numerical techniques have been implemented in the environment to deal with equations of the form 1. In this regard, our tool is equipped with the classical finite difference method (Schiesser, 1991), employed in simple geometries, and the finite element method (Reddy, 1993) more useful when considering complex geometries. In general, and specially in 2D and 3D spatial domains, these methods translate into a extremely large number of ODE systems to be solved, what makes the approach unsuitable for real time simulation or optimisation. We overcome such limitation by taking advantage of the dissipative structure of the PDE systems (Christofides, 2001) which allows the extraction of a low dimensional dynamic manifold capturing the relevant dynamic behavior of the system. Different techniques such as Laplacian spectral decomposition (Vilas et al., 2007) or Proper Orthogonal Decomposition (Sirovich, 1987), widely employed in the context of process engineering, have been currently implemented on an automated basis in our simulation environment. The code employed by *EcosimPro*® to solve the systems of DAEs en ODEs

is DASSL (Petzold, 1982) which is based on the backward differentiation formula (Ascher and Petzold, 1998).

On the other hand, different software tools were employed for the mathematical model implementation. The heart of the simulation environment is *EcosimPro*®. Nevertheless other software like *Matlab-Femlab*® and *C/C++* were employed to add new powerful capacities to *EcosimPro*®. In this regard, *Matlab-Femlab*® is employed to deal with partial differential equations and optimisation problems while *C/C++* is the bridge between *Ecosimpro*® and *Matlab*® and it also is employed as the programming language for some numerical methods like to solve eigenvalue problems, singular value decomposition or matrix multiplication, among others. The communication from *Matlab*® to *Ecosimpro*® is carried out by means of the *Matlab Engine* (<http://www.mathworks.com>) in combination with the *EcosimPro*® procedure for calling *C/C++* routines. The communication from *Matlab*® to *EcosimPro*® is carried out through the *Matlab*® tool for calling generic dll's (<http://www.mathworks.com>).

RESULTS AND DISCUSSION

The final structure of the simulation environment and the library of components is shown in Figure 2 (a). The different units and equipment are selected from a library

Figure 2: (a) Example of a pilot plant constructed in the GUI. As shown in the figure, each component have associated its own mathematical model. (b) Evolution of the temperature measured in the pilot plant (circles) and that computed by means of the model (line i) as a response of different steps in the in the steam (line ii) and bleeder (line iii) valves.

(left hand side) and dragged to the workspace. Once there, the different components are connected using the EcoDiagram connector (right hand side). The component parameters can be modified with a mouse click over the component. It should be remarked that this library can be connected to other designed by different authors provided that they were constructed following the same criteria.

The model validation

The first step is to construct a model for the pilot plant (Figure 1) using the GUI. As a result, the model presented in Figure 2 (a) is obtained. The characteristic parameters of the plant which are not available in the bibliography, such as the retort transfer area or the valve

size among others, has been estimated from experimental data (*model calibration*). The validation experiment consisted on comparing the measurements taken in the pilot plant with the simulation results. It should be remarked that the calibration and validation stages were carried out in different conditions. In Figure 2 (b) we can compare the experiment (circles) and simulation (line i) temperature evolution when different steps in the steam (line ii) and bleeder (line iii) valves are introduced. As shown in the figure, the model is able to reproduce the experimental behaviour.

Comparison among different scenarios

In this example, the simulation environment will be employed so as to compare, on the basis of economic cost and total time, different scenarios in the sterilisation of a given amount of canned tuna fish to be processed. The plant consists of three retorts which operate in parallel. The auxiliary equipment is composed by one boiler, *PI* controllers, different types of valves and three kinds of cylindrical cans (*RO85*, *RO1000* y *RO3900*). As shown in Figure 3 (a), the plant can be constructed using the simulation environment. The duration

Figure 3: (a) Schematic view of the pilot plant employed for comparing the different scenarios. (b) Organization chart of two different scenarios.

of the sterilisation process is fixed on the basis of the can size. Typically in the industry, when the sterilisation temperature is about 116°C , this process lasts around 50 min for *RO85* cans, 215 min when using *RO1000* cans and 270 min for *RO3900* cans. With these parameters the product satisfies the legislation requirements. The load and unload time is 8 min .

Among the different possibilities for sterilising the tuna using this equipment, we have selected eight to be compared. In the first and second scenarios all the product is sterilised using *RO85* and *RO3900*, respectively. In the remaining scenarios (six) the tuna is sterilised using four sterilisation cycles for *RO85* cans, three for *RO1000* cans and for *RO3900* cans. For illustration purposes, Figure 3 (b) depicts the organisation charts of two different scenarios. Each white rectangle represents the sterilisation cycle for the type of can indicated inside. The black rectangle between the cycles symbolises the load and unload time. Besides, Figure 4 shows the evolution of the temperature and the fuel cost for the retort 1 on the first scenario of 3 (b). The other scenarios show the same qualitative

Figure 4: (a) Typical output plot showing the evolution of (i) the retort temperature and (ii) the fuel cost. (b) Comparison between the different scenarios. Black bars represent the fuel saving while the white bars indicate the total processing time.

behaviour but with different numerical values. Apart from the variables represented in the figure, the evolution of other representative variables such as pressure or lethality among other can be followed online. In this way one can take decisions concerning the sterilisation parameters.

Once the simulations were carried out, the results can be compared. In Figure 4 (b) the percentage of fuel saved in each scenario in comparison with the worst (scenario 2) is represented. As shown, the appropriate selection of the operation policy can reduce the fuel consumption around an 18% as compared with the worst alternative. Furthermore the scenario with the minimum fuel consumption is the scenario with the lowest processing time.

CONCLUSIONS

A library of components programed for the simulation of thermal processes in the food industry has been presented. Such library has been constructed in a GUI (*Ecosim-Pro*©) and using the paradigm of OOP. A non expert user can employ it, in an intuitive way and by means of icons, to analyse for instance the effect of alternative technologies in the production or new production policies among other things. The software architecture allows the inclusion/exclusion, improvement and modification of the components according to the user's requirements. It is able to deal with hybrid systems as well as nonlinear distributed processes. Besides, the library is included into a web management scheme that allows the access to the general information structure of the plant. The mathematical models have been validated using a pilot plant installed at IIM-CSIC. Finally, some advantages of having this tool have been highlighted through an illustrative case study.

ACKNOWLEDGEMENTS

The authors acknowledge financial support received from the Spanish Government (MEC Projects PTR1995-0884-OP-02-01 & DPI2004-07444-C04-03) and SUPERA contract.

References

- Alonso, A. A., Banga, J. R., and Martin, R. I. P. (1998). Modeling and adaptive control for batch sterilization. *Computers & Chemical Engineering*, 22(3):445–458.
- Ascher, U. M. and Petzold, L. (1998). *Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations*. SIAM, Philadelphia, USA.
- Banga, J. R., Balsa-Canto, E., Moles, C., and Alonso, A. A. (2003). Improving food processing using modern optimization methods. *Trends in Food Science and Technology*, 14(4):131–144.
- Bimbenet, J. J., Schubert, H., and Trystram, G. (2007). Advances in research in food process engineering as presented at ICEF 9. *Journal of Food Engineering*, 78(2):390–404.
- Bruin, S. and Jongen, T. R. G. (2003). Food process engineering: The last 25 years and challenges ahead. *Comprehensive Reviews in Food Science and Food Safety*, 2(2):42–81.
- Christofides, P. D. (2001). *Nonlinear and Robust Control of PDE Systems: Methods and Applications to Transport-Reaction Processes*. Birkhäuser, Boston.
- Datta, A. K. (2002). *Computational Techniques in Food Engineering*, chapter Enabling Computer-Aided Food Process Engineering: Status and Needs, pages 3–14. International Center for Numerical Methods in Engineering (CIMNE), Barcelona.
- Ötles, S. and Önal, A. (2004). Computer-aided engineering softwares in the food industry. *Journal of Food Engineering*, 65(2):311–315.
- Petzold, L. (1982). A description of dassl: A differential/algebraic system solver, rep. 82-8637. Technical report, Sandia National Labs.
- Reddy, J. N. (1993). *An Introduction to the Finite Element Method*. McGraw-Hill, 2nd edition.
- Schiesser, W. E. (1991). *The Numerical Method of Lines*. Academic Press, New York.
- Sirovich, L. (1987). Turbulence and the dynamics of coherent structures. Part I: Coherent structures. *Quarterly of Appl. Math.*, 45(3):561–571.
- Vilas, C., García, M. R., Banga, J. R., and Alonso, A. A. (2008). Desarrollo de una librería de componentes en ecosimpro para la operación de plantas de procesamiento térmico de alimentos. *Revista Iberoamericana de Automática e Informática Industrial (RIAI)*, 5(1):51–65.
- Vilas, C., García, M. R., Banga, J. R., and Alonso, A. A. (2007). Robust feed-back control of distributed chemical reaction systems. *Chemical Engineering Science*, 62(11):2941–2957.
- Wang, L. J. and Sun, D. W. (2003). Recent developments in numerical modelling of heating and cooling processes in the food industry - a review. *Trends in Food Science & Technology*, 14(10):408–423.