Fuzzy traceability: A process simulation derived extension of the traceability concept in continuous food processing

Skoglund, Tomas; Dejmek, Petr

Published in:
Food and Bioproducts Processing

DOI:
10.1205/fbp07044

2007

Fuzzy traceability - A process simulation derived extension of the traceability concept in continuous food processing

Tomas Skoglund[a*,b] **and Petr Dejmek**[a]

[a]Department of Food Technology, Engineering and Nutrition, Faculty of Engineering, Lund University, P.O. Box 124, SE-221 00 Lund, Sweden
E-mail: Tomas.Skoglund@tetrapak.com (*Corresponding author)
Telephone: + 46 46 222 9806, fax: + 46 46 222 4622
[b]Tetra Pak Processing Systems, Ruben Rausings gata, SE-221 86 Lund, Sweden
E-mail: Tomas.Skoglund@tetrapak.com
Telephone: + 46 46 362399, fax: 46 46 362970

Abstract

Liquid food production often involves continuous processing. This leads to problems in traceability systems due to mixing zones and therefore indistinct batch identities causing difficulties with regard to withdrawals or recalls. This article outlines the possible use of the concept of dynamic simulation to improve the handling of batch identities in continuous production of liquid food, a concept we call *fuzzy traceability*. The concept is illustrated with a realistic example from a real dairy process line.

Keywords: traceability, internal traceability, fuzzy traceability, dynamic simulation, dispersed flow, continuous production, virtual batch, food safety

1. Introduction

Large-scale food production in a global market poses a potential threat to society due to the potential large-scale public health consequences of unsafe food reaching retailers and consumers. This health and safety aspect is the foundation of legislation concerning traceability in the food industry, where the aim is to establish means of limiting the consequences of food of unacceptable quality. The need for the development of food traceability is clearly demonstrated by the outbreak of bovine spongiform encephalitis (BSE, "mad cow disease") leading to New Variant Creutzfeld-Jakob Disease in humans (Loader & Hobbs, 1996; Palmer, 1996).

In 2002, European Union enacted Regulation 178 which is primarily concerned with this public health aspect of traceability. It requires all food businesses to be able to identify for each of their products the immediate business supplier and the immediate business customer. The legislation thus covers only one aspect of traceability, chain traceability in the terminology of Moe (1998). This is a well studied subject.

The other aspect, *internal traceability*, concerns the the ability to trace a batch within the business. Moe (1998) provides a list of seven advantages of internal traceability. One of them is the possibility of avoiding uneconomic mixing of high- and low-quality raw materials. Another is that it provides better grounds for implementing IT solutions to control and management systems. This is important for

[*] Corresponding author: E-mail: Tomas.Skoglund@tetrapak.com

the market communication by the ability to respond quickly and transparently to the public in case of food with unacceptable quality.

The advantages of internal traceability are not confined to food and related areas, for example Peyret & Tasky (2004) demonstrate the feasibility of a traceability system for asphalt quality parameters from the plant to the asphalt-pavement site.

One cornerstone in all current traceability systems is the definition of a *batch*. Kim et al. (1999) define a *traceable resource unit* (TRU) as a unit with unique characteristics that no other unit can have, from a traceability point of view, in a batch process. However, as Moe (1998) states, when dealing with continuous processing, defining a TRU is difficult. This applies to both processing conditions and material TRUs.

For example, in continuous processing of liquid food, e.g. milk production in a dairy, it is difficult to claim that two final products, based on different raw materials (source TRUs, e.g. silo tanks with milk from different farms), should be considered as two separate batches (TRUs) when they are produced sequentially by *change on the fly*[1]. It would be even more difficult to claim that only a minor part of the final product is a separate TRU due to different processing conditions during a period of production (e.g. unintentional temperature variations during pasteurization or intentionally adjusted set-point of fat content in milk). In case of withdrawal or recall the two original batches would most certainly have to be considered a single batch after packaging due to the uncertainty in mixing in the production system. This problem will remain even if an IT solution (enterprise quality management, EQM) is implemented in accordance with Deasy (2002) to monitor the integrity data.

Depuy et al. (2005) are discussing intentional dispersion in a sausage production, whereas we address *unintentional dispersion* in mixing zones in connection with continuous liquid food production. For example, one silo tank of milk, intended for one batch of consumption milk, may unintentionally appear in three batches of consumption milk due to mixing at the interfaces of the preceding and succeeding batches when the milk is pumped through the system of pipes, valves and other processing equipment. With the terminology of Depuy et al. (2005), the intended *downward dispersion* is 1, but unintentionally it becomes 3 even though the level of cross contamination is very low.

Thus we propose that for not critical use, the traditional deterministic approach be complemented with *fuzzy traceability*. By *fuzzy traceability* we mean recognition of the fact that there is a certain probability that an unintended source material may be present in a product, and we must learn to live with the consequences. This means we should concentrate on quantifying the probability of finding an intended or unintended component in a product. A more straight-forward interpretation of this is to calculate the unintended dispersion-caused composition of finished product.

Below it is shown how dynamic simulation can be used to predict and analyse system behaviour, particularly concerning mixing zones, and thus provide the necessary information for the *fuzzy traceability* concept. The dynamic simulation can be used as an integral part of traceability systems with the aim of optimizing the management of batch separation concerning the size of TRUs, costs, market communication and health aspects.

[1] With *change on the fly* we mean that a product (source TRU) is changed to another directly without any flush or cleaning between. In other words, the succeeding product chases the preceding product out of the system.

2. Batch identity

Processing of food involves equipment cleaning in order to maintain a high hygienic standard. In the case of liquid food, cleaning is normally performed by pumping water and detergent through the production equipment, i.e. cleaning-in-place (CIP). Cleaning between two product batches is taken to mean that the batches cannot contaminate each other. Therefore, in batch tracing systems, cleaning is used as a distinct separator between batch identities, which according to Cocucci et al. (2002), is “of primary importance”.

This means that if/when food of an unacceptable quality has been discovered, its corresponding batch identity, or TRU, can be established by means of the traceability system, leading to reprocessing, withdrawal or recall of all the items belonging to that batch. In the simplest kind of traceability system, each individual consumer package in a batch need only have one common batch identifier, and information about *when* in the batch it was packed, early, late or by ordinal number, is not available. However, in reality each consumer package is, or can fairly easily be made, identifiable by for example a time stamp.

Production parameters such as silo changes, temperatures, pressures and compositions can be logged, and if a way can be found to correlate the production parameters as a function of time along the processing line to the product in the package, variations in the quality of food from the same batch can be traced and related to variations in the production parameters. A traceability system capable of this could be used to minimize rejects or withdrawals from *the same batch*. Thus, using the terminology of Kim et al. (1999), the batch will consist of many TRUs.

A special case of this is the variation of composition due to mixing between two batches or products that are produced in sequence without being separated by cleaning or water flush. For example, the production of a certain amount of consumption milk may require that two or more silo tanks (source TRUs), containing milk with different origin, are run through the process line sequentially, without any interrupt for intermediate cleaning or water flush. Then a system that can predict the actual composition in each consumer package would be valuable from a traceability point of view.

Cleaning is costly since it occupies the production equipment and requires cleaning agents, energy and manpower. Hence, there is an incentive to clean as seldom as possible. However, this implies that withdrawals or recalls will be large due to large production batches (produced from many source TRUs) between cleanings. Therefore, if batch sizes ─ with cross-contamination criteria defined in the traceability system ─ could be kept small and well controlled, from a traceability point of view, even without cleaning between production batches, this would be a great advantage. Thus we introduce the conception *virtual batch* (see Figs. 1a-c). For example, the cross-contamination criterion for a *virtual batch* X of consumption milk could be defined as the collection of all packages that contain pasteurized milk with a composition of ≥ 99.0 % of not pasteurized milk from silo tank Y. Thus, a system that can predict the composition during batch changes would help the traceability system to keep track of such virtual batches when no physical batch separation (cleaning or water flush) has taken place.

In contrast to “guaranteeing product identity” as stated by Cocucci et al. (2002), this is an alternative where more flexible criteria are used in order to maintain high production efficiency while still having a good control of the traceability.

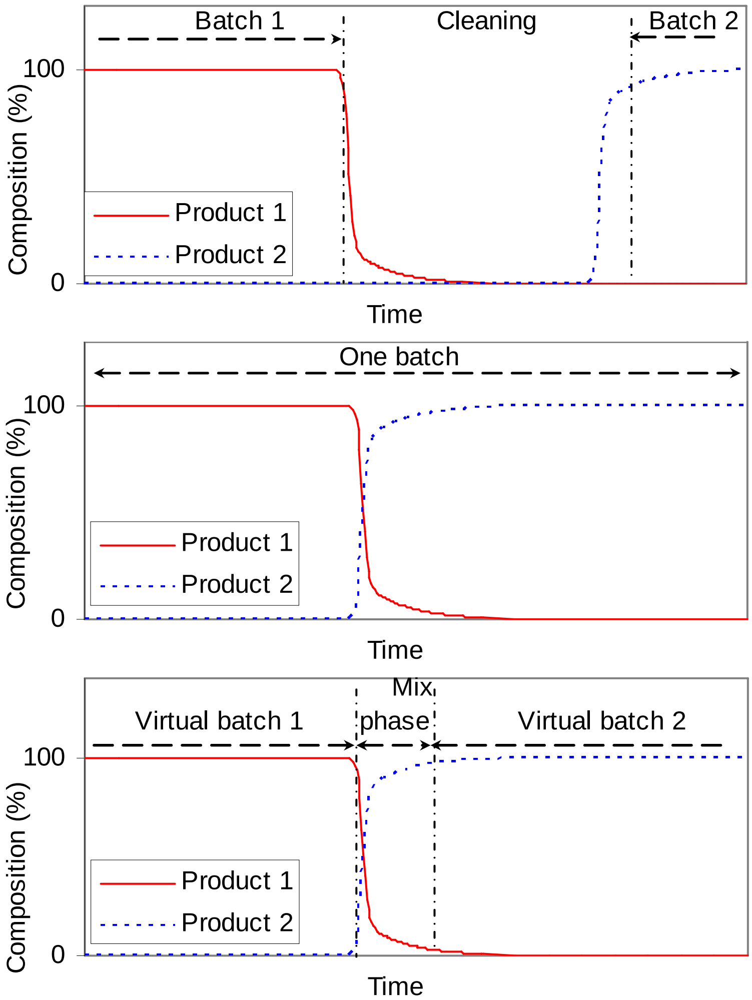

Fig.1. Different ways of production where "different" products (different source TRUs) are separated in different ways and considered as a) two batches, b) one batch or c) two *virtual batches*.

- **a)** (top figure) The two products are processed as two separate batches, distinctly separated by a cleaning.
- **b)** (middle figure) The two products are processed as, and considered, one batch. The production is changed "on-the-fly" without any separation between the products.
- **c)** (bottom figure) The two products are processed as in Fig. 1b, but considered as two separate *virtual batches* and a mixing phase between of product that not fulfils the criteria of cross-contamination levels.

3. "Fuzzy" batch separation by simulation

Beside the characteristics of continuous food processes described in the introduction above, such processing of liquid food, e.g. milk and juice, often leads to problems with indistinct batch separation. In many of these processes, the food from different batches undergoes final processing just before it is packed, e.g. UHT[1] pasteurization of milk without an aseptic buffer before packaging. Changing batch means that the source (a tank) is changed by activation and deactivation of valves. The consequence is that the food from the first batch will be pushed through the system by food from to the second batch. During this product changeover, a mixing zone will develop between the two fluids with different batch identities. The mixing zone will gradually increase due to dispersion, i.e. turbulent diffusion, as the fluids are pumped through the system. In the final packages this fluid transition will manifest itself as a mixture with a gradually changing composition from the 100 % of the first batch to 100 % of the second. Possible hold-up volumes in the system will cause further expansion of the mixing zone.

System integration makes data from the process control system available in the traceability system (Moe, 1998), and measurement of the composition could be a means of following a transition of a mixing zone. However, products with measurable differences are normally separated by CIP. In most cases where there is no CIP between batches the products have similar or identical specifications, i.e. the products are difficult or impossible to distinguish by means of online sensors as they (the sensors) are not sufficiently fast or sensitive.

An alternative to measurements is *simulation*. In a previous study, Skoglund & Dejmek (2006), we described how a dynamic model library was created and could be utilized for the simulation of complex liquid food production lines. We have also described a method of performing simulations of dispersion and mixing zones in large flow systems with reasonable computational effort, Skoglund & Dejmek (2007).

Motivated by early research (Levenspiel & Smith, 1957; Serpemen & Deckwer, 1974) the dynamic models of fluid channels (pipes etc) that were implemented are based on the axial-dispersed plug flow (ADPF) model according to Eq. (1) which describes the concentration, *C*, of substance as it propagates with an average velocity, *v*, and a turbulent dispersion, *D*.

$$\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} \qquad (1)$$

The variables for time and axial direction of propagation are *t* and *x* respectively. To efficiently handle *large flow systems*, e.g. a pasteurization line, the models were modified according to Skoglund & Dejmek (2007). The core of the model principle is to replace in an optimal way each ordinary control volume with a combination of a plug flow part and an ideally mixed volume. The model describes how the model parameters are derived from the known physical parameters. By this the model could be implemented in dynamic models of pipes, heat exchangers etc. to be used for simulation of the axial-dispersed plug flow in whole process lines with reasonable computational effort.

As case study of the *fuzzy traceability* concept, the dynamic models were used to configure and simulate the batch transition in a real process line[2] used for the

[1] Ultra-high temperature
[2] The modelled milk sterilizer is a commercial product, Tetra Therm® Aseptic Flex, designed and manufactured by Tetra Pak Processing Systems, Lund, Sweden.

production of UHT pasteurized milk, as shown in Figs.[1] 2a and 2b. The batch transition is initiated when the changeover valve, V1, is activated to change source tank. Using information obtained from such simulations it would be possible to reduce withdrawals. Figs. 3a and 3b show the product composition in the pipe at the filling machine (Fig. 3a) and in the packages (Fig. 3b) from two successive batches, for example milk with different fat contents or the same fat content but from different sources. In Fig. 3a is also displayed results from validation measurements on the real process line.

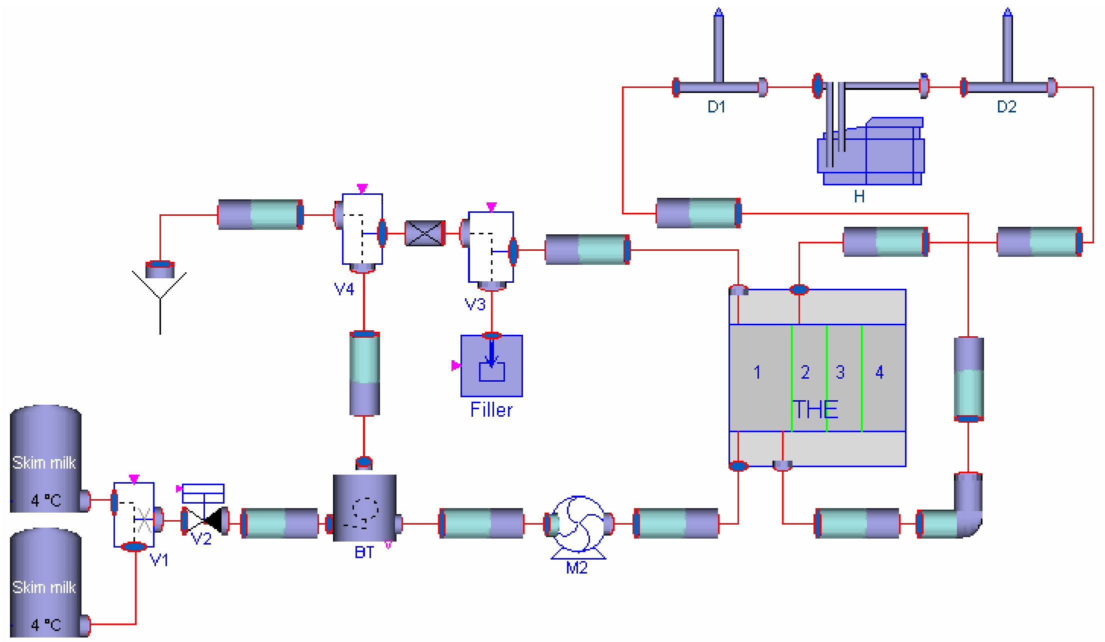

Fig. 2a. Simplified flow chart of a skim milk sterilization line with the following major components: two source tanks ("Skim milk"), a changeover valve (V1), a balance tank (BT), a pump (M2), a tubular heat exchanger system (THE, see Fig. 2b), a homogenizer (H) with two pressure dampers (D1 and D2) and a packaging machine (Filler). The batch transition commence when the changeover valve, V1, is activated to change source tank.

[1] Figs. 2a and 2b are simplified and details (e.g. flow path, pipe geometries, heat exchangers configuration) are left out due to commercial reasons.

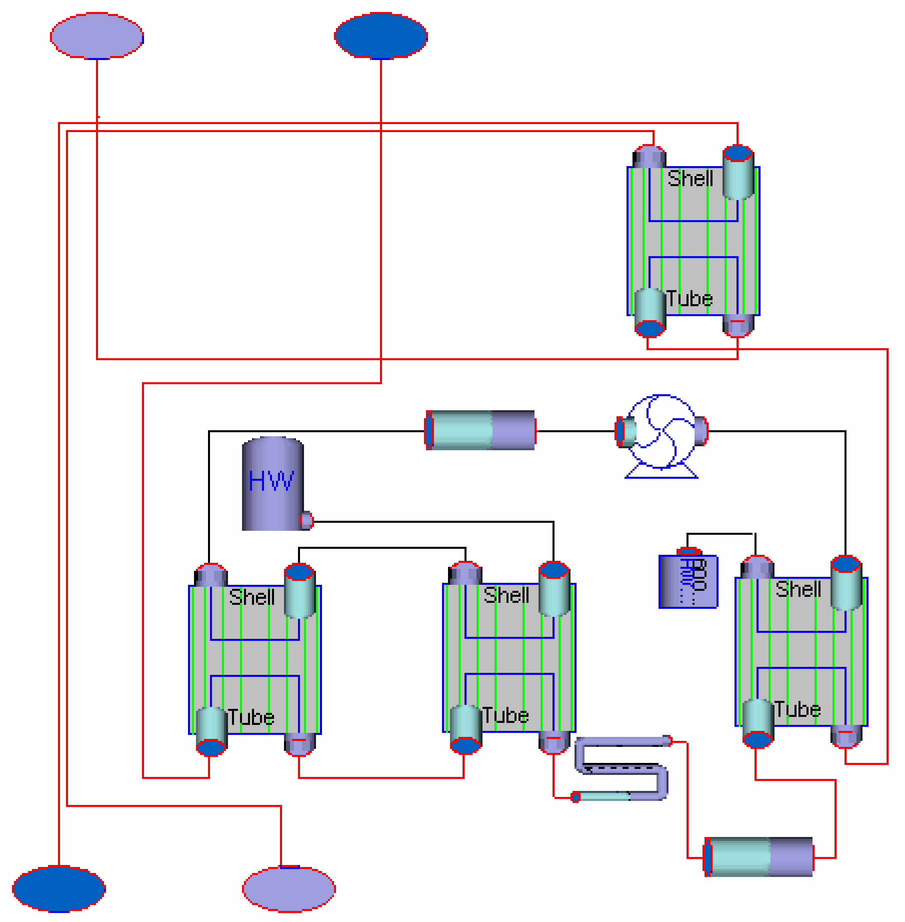

Fig. 2b. Flow chart of details of the tubular heat exchanger system, THE, in Fig. 2a.

Depending on the situation the virtual batches mentioned in section 2 could be defined appropriately. It means that limits for acceptable product mix can be drawn at desired compositions. For example, if a maximum of 20% of *Product 2* in *Product 1* and 5% of *Product 1* in *Product 2* is acceptable, then the product to be rejected or withdrawn will be found in packages 735 to 774 for a system with medium level in the balance tank (BT) during the product change over ("Medium level in BT" in Fig. 3b). With an improved system with lower changeover level in the balance tank, the unacceptable packages will be 740 to 761 ("Low level in BT" in Fig. 3b).

Based on the simulation result showed in Fig 3b, a direct computation could be performed to calculate the cost of product rejection or withdrawal as a function of the virtual batch definition, i.e. contamination level. Fig. 4 shows the results of such calculations where the production cost is set to 0.5 € per litre product. Implementation of this kind of *fuzzy traceability* enables efficient responds on eventualities, to minimize damage while retaining consumer confidence.

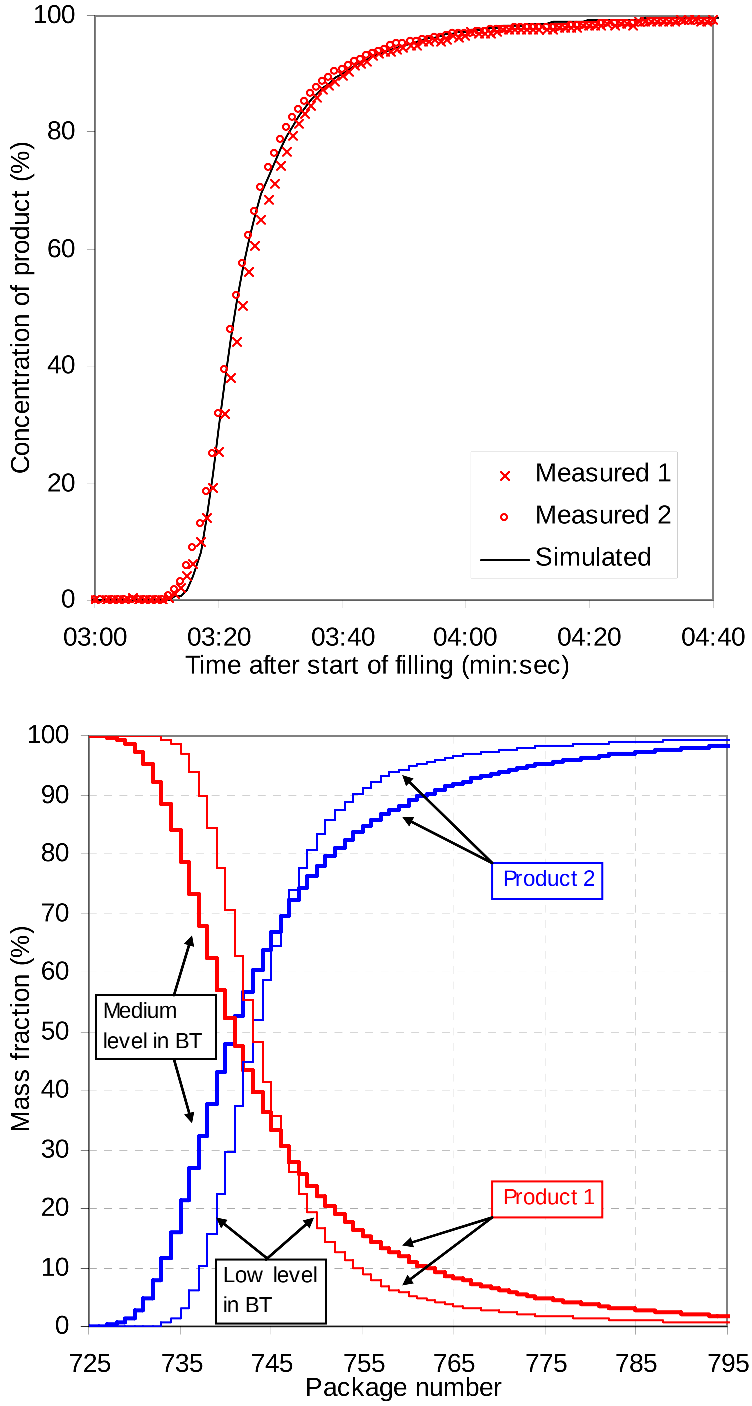

Fig. 3. Tank changeover in the process illustrated in Figs. 2a and 2b.

a) (top figure) Measured and simulated product composition in the pipe at the filling machine (near valve V3). The diagram shows the concentration of the succeeding product ("product 2") after changeover of the valve V1. Data from measurements at two experiments and one simulation are shown. The changeover level in the balance tank (BT) was medium.

b) (bottom figure) Simulated product composition in individual packages. The diagram shows the result of two simulations, one with medium level in the balance tank during changeover (the same simulation as in Fig. 3a) and one with a low level in the balance tank during changeover.

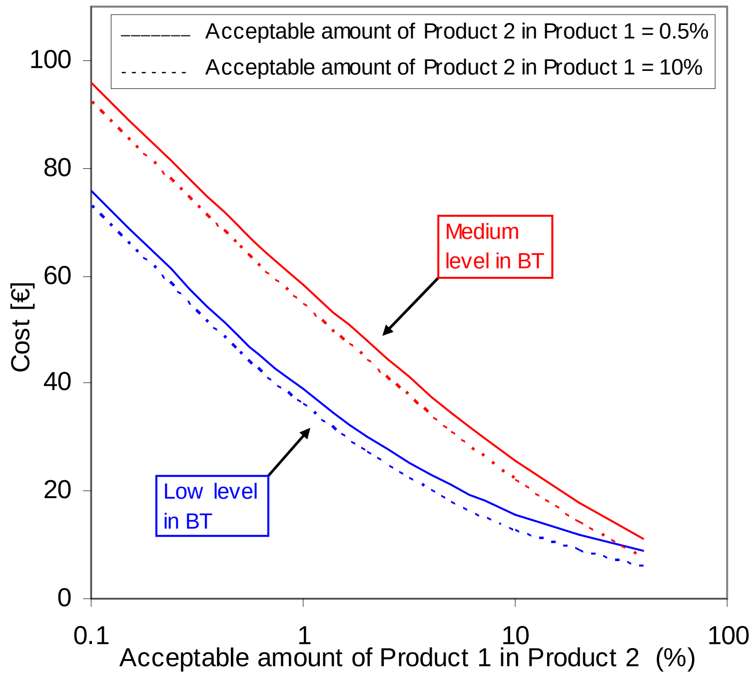

Fig. 4. Cost of withdrawal depending on the acceptable contamination levels for a system tuned differently for changeover level in the balance tank (BT in Fig. 2a). The production cost is assumed to be 0.5 € per litre.

4. Discussion & Conclusions

Traceability systems for efficient and knowledge based handling of unintentional mixing zones in continuous production of liquid food need further improvement. The development of IT, in terms of computational power and efficient software, has enabled the dynamic simulation of fluid composition along complex production systems. Dynamic simulations as a complementary source of information to traceability systems, to enhance internal traceability, offers the potential for improvements in production management in terms of better process information. The information concerns batch composition in consumer packages and costs related to batch composition criteria, which enables improved handling of rejects or withdrawals and market communication. In the future, dynamic simulation may thus become common in traceability systems to provide a means of making decisions based on explicitly formulated criteria though “fuzzy reality”.

References

Cocucci, M. Ferrari, E. and Martello, S., 2002, Milk traceability: from farm to distribution. *Italian Food & Beverage Technology*, 29: 15-20.

Deasy, D. J., 2002, Food safety and assurance: the role of information technology. *International Journal of Dairy Technology*, 50: 1-4.

Depuy, C., Botta-Genoulaz, V. and Guinet, A., 2005, Batch dispersion model to optimise traceability in food industry. *Journal of Food Engineering*, 70: 333–339.

EU Regulation (EC) 178/2002 of the European Parliament and of the Council (28 January 2002), articles 14-20.

Loader, R. and Hobbs, J.E., 1996, The hidden costs and benefits of BSE. *Brittish Food Journal*, 98: 26-35.

Palmer, C.M., 1996, A week that shook the meat industry: the effects on the UK beef industry of the BSE crisis. *British Food Journal*, 98: 17-25.

Kim, H.M., Fox, M.S. and Gruninger, M., 1999,. An ontology of quality management – enabling quality problem identification and tracing. *BT Technology Journal*, 17: 131-140.

Levenspiel, O. and Smith W., 1957, Notes on the Diffusion-Type Model for the Longitudinal Mixing of Fluids in Flow. *Chemical Engineering Science*, 6: 227-233.

Moe, T., 1998, Perspectives on traceability in food manufacture. *Trends in Food Science and Technology*, 9: 211-214.

Peyret, F. and Tasky, R., 2004, A Traceability System between Plant and Work Site for Asphalt Pavement. *Computer-Aided Civil and Infrastructure Engineering*, 19: 54-63.

Serpemen, Y. and Deckwer, W-D., 1974, Instationary Dispersed Plug Flow Model with Linear Rate Processes. *Ind. Eng. Chem. Fundam.*, 13: 399–400.

Skoglund, T. and Dejmek, P., 2006, A model library for dynamic simulation of liquid food process lines. In *Proceedings of FOODSIM 2006*: 5-12, Naples, Italy, June 15-17, Organized by EUROSIS.

Skoglund, T. and Dejmek, P., 2007, A dynamic object-oriented model for efficient simulation of fluid dispersion in turbulent flow with varying fluid properties. *Chemical Engineering Science,* 62: 2168-2178.

Acknowledgements

We would like to express our gratitude to Tetra Pak Processing Systems for the funding of the work that has led to this article. The article was written within the framework of the project, "*Modelling of Traceability and Risk Analysis for Safe and Sustainable Food Production*", funded by VINNOVA (The Swedish Governmental Agency for Innovation Systems).