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FOOD PRODUCTION QUALITY AND RISK ASSESSMENT ON MACHINERY DESIGN

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Abstract

Today global market requires: new products, each developed to ever-increasing levels of sophistication. A fundamental requirement is that the products must be safe to consumer. The food engineering processes and products recipe interact in a very complex way. This also raises a demand for the data on food safety, origin and traceability, on environmental impact, on hygiene, pathways of food contamination and risk evaluation.

For the equipment in food production, researches and engineers will mainly focus their attention on: product design for tomorrow regarding different group needs, on technological line with higher degree of flexibility, cost effectiveness, and increasing automation and product variation with short set-up between products.

The hygienic and environmental demands will characterize the development of new production system by: a) hygienic design of buildings, b) new processing equipment together with cleaning and disinfection system, c) methods evaluation and validation of risk levels, d) inactivation and killing processes of microorganisms, e) risk related to packaging and food transportation vehicles, f) food quality assurance systems.

Special attention should be paid to the diagnosis and monitoring food production processes regarding mainly the model of microbial grows in the specific process engineering conditions. These could result in flexible configurations of periodic sampling and updating of control signal with a significant effect on the food quality control.

Key words: *Quality, food production, risk assessment, machinery design*.

1. Introduction

Nowadays, the food industry is: changing, and developing more quickly, and more radically then ever before. Today global market requires: new products, each developed to ever - increasing levels of sophistication, and above all, a fundamental requirement is that the products must be safe to consume. In food production it means that the food engineering process and recipe interact in a very complex way. There is not easy to find the right combination of that interaction without having to perform hundreds of experiments. Product quality is described by numerous measurements, i.e., sensory, microbiological, instrumental, etc. These problems also raises a demand for data on food safety, origin and traceability as well as on environmental and ethical impact, It also means that more knowledge will be needed in the areas of hygiene, pathways of food contamination and risk evaluation, requiring new strategies and refined analytical methods. The product developers have to solve day-to-day problems related to customer complaints without losing the focus on long term objectives. With respect to the equipment and production lines, researches and engineers in food industry will mainly focus their attention on the following: product design for tomorrow regarding different group needs, food production line with higher degree of flexibility, cost effectiveness, and increasing automation with up-to-date process control, and product variation with short set-up between products, and at the same time to increase production and reduce operational costs. Today effectiveness in equipment design in food production it means of updating process plant, providing better accuracy and reliability and the possibility of integration into higher level control and monitoring systems (Matuszek [2] and [5]). All that changes in machinery design should also include: hygienic and environmental demands that will characterize the development of new production system by two factors: LCA and EIA. That factors have to be assessed by the following: a) hygienic design of buildings, b) new processing equipment together with cleaning and disinfection system, equipped with control system of the lowest pollutant level after cleaning before leaving the production plant, c) methods of risk evaluation and validation of risk levels, d) processes for inactivation and killing of microorganisms, e) risk related to packaging and food transportation vehicles, f) quality assurance systems of both final food product and the FMEA for processing equipment (Matuszek [1]).

2. Food quality

It is known that the terms "food quality" is one of the most difficult to define, because of the unknown multi responses of the consumers. Food quality strongly depends on food production system arrangement from "farm to fork", i.e., from the place where the raw materials were taken to the area of plant and food engineering processes, through the storage and distribution system to the consumer. The food production quality in general is related to the recognition of specific equipment function possibilities for the precise defined task, and also to the different preventing ways of any risk case that could be against the above mentioned function. Once the appropriate variable of that functions are identified the relevant instrumentation and procedures must be selected (Otto and Wood [4]).

2.1 Food production

It means that: the food engineering process and recipe interact in a very complex way, there is not easy to find the right combination of that interaction without having to perform hundreds of experiments, product quality is described by numerous measurements, i.e., sensory, microbiological, instrumental, etc. These problems also raises a demand for data on food safety, origin and traceability as well as on environmental and ethical impact, It also means that more knowledge will be needed in the areas of hygiene, pathways of food contamination and risk evaluation, requiring new strategies and refined analytical methods, the product developers have to solve day-to-day problems related to customer complaints without losing the focus on long term objectives (Duke - Rohner [9] and Gengenbach [10]).

2.2 Machinery design

Machinery design is an interdisciplinary process always influenced by basic knowledge of mathematics, physics, mechanics and thermodynamics. Furthermore, in the same process, the rules of manufacturing methods, material engineering, economy and cost ratio together with marketing and distribution strategies also should be taken into account. Every technical system can be described by the following features: stream of energy, materials and information bus as well as by the structural and functional relationship between parts of the machinery design is build up (equations number 1 and 2) (Matuszek [8], [11]). All the above mentioned technical system features have to be considered accordingly to the surroundings of the system too.

$$S : \overset{\text{def.}}{=} \{e_r \in R_s : \bigwedge_{e_r} \bigvee_{S_r} S_r(R_s) \Rightarrow F_c\ (S_r)\} \quad (1)$$

$$O : \overset{\text{def.}}{=} \{e_0 \notin R_s : \bigvee_{e_0} e_0\ R\ S\} \quad (2)$$

where:

S - technical system,

R - relation in general,

Rs - relation between the set of elements chosen to the system regarding expected design structure,

Sr - structure with order according to the properties of chosen elements,

Fc - function describing changes between properties of input and output inside the system,

O - surroundings with other set of elements, paying special rules in food equipment,

e_r - structure elements,

e_0 - surrounding elements.

When looking at existing in technical system any of the stream elements distribution it can be observed that within the parts of such a system, the following relationship exist: e→ R→ S→F→ T.

All components belong to the design system only when there are proved by the above sequence. That is the elements (e) are in relation (R) between them for creating logical constraints that ensure well-defined structures (S) for the best operability function (F), and that will match adequate target assignments (T). Usually, designer is facing the task in which any system- object, not only the technical one, should be verified under the criteria of learning to know how to prove either the validity of that system or to recognize its practical use. In both cases the following steps ought to be considered:

a) By assumption there are some set of elements that can make entirety {e},

b) With respect to the target and by chosen criteria it is possible to describe relationship (Rs),

c) Based on the relationship (Rs) it is possible to set up the set of elements {er} which belong to the {e},

d) Set of elements {er} is making the structure (Sr) of design system,

e) Designed structure of the system (Sr) is being considered as a basement and facilities for all requirements as far as function (Fc) of that system is concern, and

f) Function (Fc) achieved within the designed structure can guarantee that all expected target (T) of the system can be reached.

The above way for all steps considered when verifying the system can be described by the following equation (3):

$$(\{e\} \wedge Rs) \rightarrow \{er\} \rightarrow \sum Rsr \rightarrow Sr \rightarrow Fc \rightarrow T \qquad (3)$$

It is obvious that one target can be characterized by many functions and realized through many design systems. For instance, in case of pipes line installation system variety of valves can play the same role on media transportation way, i.e., reducing the pressure, velocity or even closed that flow in this installation. The differences of these valves will appear due to amount of elements to build up and design types of them. It also will be connected with relation to the kind of materials chosen as well as to the shape and geometry, and to the way of finishing surfaces of their elements and how they were manufactured and assembled. In accordance with that considerations it becomes clear that all target learned out from the theory have to fulfill practical expectation target for any variety aspects and its combination. Assessment of such amount varieties can provide to the following sequence of combinations. For example, suppose that there are different functions (NF) which can be used to achieve expected target. And also there are many structures (NS) to comply with those functions together with existing different structural relationship (NR) regarding adequate amount of elements (Ne) to all of them. Then the maximum of design system combination (MDSC) can be calculated from the equation (4):

$$MDSC = NF \times NS \times NR \times Ne \qquad (4)$$

In general there are two approaches to the technical build up systems: science - driven approach, and design - driven approach. In the first one is the starting point is from the recognition of the atomic level structure, followed by crystallography, defect structure, thermodynamic and kinetics, micro - structure, material properties, mechanical (for example: modulus, strength, hardness, toughness, damping), thermal, electrical and optical properties to engineering design. The second one is containing the same elements but is following in the opposite way. At the food industry manufacturing area, there are six major factors that strongly influence on the food equipment design from its safety, hygienic, and food quality point of view. Namely there are: raw materials, human being, air, water, facilities, and packing. All of them can be immediately extended to the level of processes either single one or to the multi stages. When taking into consideration the process design equipment, it is necessary and becomes obligatory, that with respect to that above mentioned six factors, there is the necessity for variety of broad approaches to all of them. It comprise their structure governing rules, the theory and place left for them regarding logical inspiration and creativity at the professional engineering activity areas. It also contains the relation to other subjects from different area of education as well as tradition, culture, and religion influences. Besides of that there are as well the market, marketing strategy, trade in general, and the utmost important consumer needs and expectation (Matuszek [13]).

2.3 Designer and his framework

With respect to the above mentioned six factors influencing the food equipment design procedures, designer that creating new idea for the engineering foodstuff materials ought to include the following elements that covers indicated below the area from which many of valuable data should be taken into consideration. *Raw material*: freshness, structure, microbial content, pesticide, manure or fertilizer used, micro - structure components concentration, density, color, shape, natural, consistency, temperature/ pressure resistance, place to growth, the way of delivery to the processing plant, the way of storage, GMO. *Human being:* behavior and human needs, quality and level of education for more or less complicated service for the design equipment, psychological, physiological, and sociological factors, culture, tradition, religion. *Air:* temperature, pressure, velocity, transparency, moisture content, dust content, cleanliness. *Water:* temperature, pressure, sources, velocity, volume, cleanliness, recovery possibilities, Fe, Mg and other components limit content. *Facilities*: materials, corrosion and micro - corrosion resistance, way of the parts connection, mechanical and strength of material factors, surface cleanliness, disinfection, sterilization and aseptic achievement possibilities, surface roughness, durability, maintenance, exploitation, adhesive adherence and cohesive disposed, surface reaction resistance to the raw material components, *Packing:* freshness content, color stability, and microorganisms stable level keeping, durability, easy opening, light and radiation resistance, none interaction between the product and packing materials, suitable for pasteurization, sterilization and aseptic filling processes, stable shape, forming feature, transparency, hermetic closed. Among that action needed the following can play the crucial role: food structure and microbial growth, microbial adaptation and survival to define safety margin for more natural foods, detection of hygiene on surfaces in food processing equipment through the microbial assessment methods used in cleaning efficiency evaluation, sampling methods especially the basement for the number of samples and the frequency of sampling for detection of attached microbes and biofilms on that surfaces, development of optimizing the cleaning and disinfection systems like the CIP, COP, CIS, and general cleanliness at the food factory area, method for detection and evaluation of air and water contamination content, risk assessment and risk communication, safety of gene technology, material engineering research for required solution and manufacturing of water and air material filters to reduce particle and contamination level to the lowest possible level, methods for equipment better exploitation due to the elongation of its durability through the adequate food grade lubricants for every its joint parts at the horizontal, vertical or revolution movement, better methods for visualization and monitoring every operational parameters changes each stage of food manufacturing processes (Matuszek [11], [13] and Sperber [12]).

2.4 FMEA

A failure modes and effects analysis (FMEA) (Figure 1) is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. Failure modes are any errors or defects in a process, design, or item, especially those that affect the customer, and can be potential or actual. Effects analysis refers to studying the consequences of those failures (Hata *et al*. [3]).

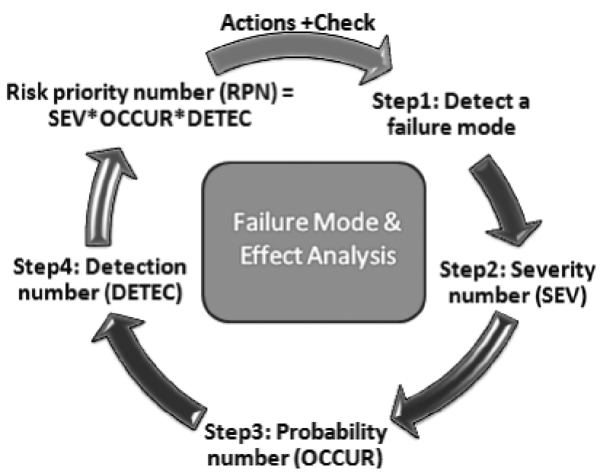

Figure 1. FMEA cycle (Hata *et al*. [3]).

Using FMEA in designing it can provide an analytical approach, when dealing with potential failure modes and their associated causes. When considering possible failures in a design – like safety, cost, performance, quality and reliability – an engineer can get a lot of information about how to alter the development/ manufacturing process, in order to avoid these failures. FMEA provides an easy tool to determine which risk has the greatest concern, and therefore an action is needed to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements and customer needs. Depending on the result of the FMEA, it may be necessary to: change design, introduce redundancy, reconfiguration, recovery etc., introduce tests, diagnoses, preventive maintenance, focus quality assurance, inspections etc., on key areas select alternative materials, components, change operating conditions (e.g. duty cycles to anticipate/avoid wear-out failures), adapt operating procedures (allowed temperature range etc.), perform design reviews, monitor problem areas during testing, check- out and use exclude liability for identified problem areas. To start it is necessary to describe the system and its function. A good understanding simplifies further analysis. This way an engineer can see which uses of the system are desirable and which are not. It is important to consider both intentional and unintentional uses. Then, a block diagram of the system needs to be created. This diagram gives an overview of the major components or process steps and how they are related. These are called logical relations around which the FMEA can be developed. It is useful to create a coding system to identify the different system elements. The block diagram should always be included with the FMEA. There are three main steps have to be taken to assess the value of each of them based on the described name of the failure and relevant to that rating. These steps are as follows: step 1: Occurrence / Severity, step 2: Sensitivity, and step 3: Detection. In case of the step 1, for example, the description of failure and adequate value rates are given: meaning (1), no effect (2/3), low (relatively few failures) (4/5/6), moderate (occasional failures) (7/8), high (repeated failures) (9/10), very high (failure is almost inevitable). After all steps value data the risk (R) probability (P) numbers (N) has to be calculated. RPN play an important part in the choice of an action against failure modes. They are threshold values in the evaluation of these actions. After ranking the severity, occurrence and detectability the RPN can be easily calculated by multiplying these three numbers: RPN = S × O × D. This has to be done for the entire process and/or design. Once this is done it is easy to determine the areas of greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, but which occur more often and are less detectable. All of the failure from 5M (Man, Machine, Material, Method, Management) + E (Environment) categories can be detected and presented graphically by the Ishikawa drawing (Matuszek [6], [8]).

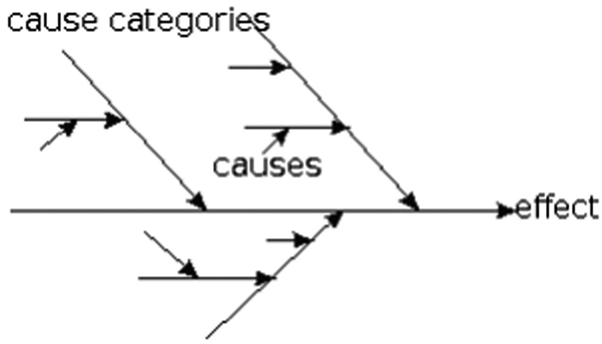

Figure 2. Ishikawa drawing with 5M categories + E.

After all of these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted. These actions can include specific inspection, testing or quality procedures, redesign (such as selection of new components), adding more redundancy and limiting environmental stresses or operating range. Once the actions have been implemented in the design/process, the new RPN should be checked, to confirm the improvements. These tests are often put in graphs, for easy visualization. Whenever a design or a process changes, an FMEA should be updated (Kmenta and Koshuke [7], Sperber [12] and Matuszek [3]). It is pertinent to stress that hygienic design refers to design features that may be unique at the processing plant and are intended to reduce the risk of contamination by biological, physical and chemical hazards from any unit processing operations. It also necessary to point out that there is a lot of examples that processing equipment is doing traditionally design, and built to be suitable for more or less defined purpose, when the expectation of hygienic level a rather rarely included. It is not the common knowledge but it has been recognized that almost 90 % of quiet new equipment is not properly designed in terms of hygienic requirements. There are also opposite examples, for instance aseptic fillers are usually designed with much higher hygiene standard than any other filling machines. It is because of the risk of a hazard could be transferred from the equipment to the product and thus to the consumer.

3. Conclusions

- Consumer perspective will be a key factor in food product development, both in general and for products with specific "added value" properties (sensory, nutritional, environmental and ethical or directed towards chosen consumer needs).
- Special attention should be paid to the theoretical and practical issues of diagnosis and monitoring food production processes regarding mainly the model of microbial grows in the specific process engineering conditions.
- Respective food quality assurance program ought to be set up for diagnosis and monitoring of all food engineering operations, and in the light of that food quality should be continuously interpreted and monitored.
- Based on computers and microprocessors in control system applications, these could result in flexible configurations of periodic sampling and updating of control signal with a significant effect on the food quality control.
- Effective implementation of any food quality control diagnosis and monitoring program goes directly to the company bottom line, increasing product quality, yield, consistency and profitability.
- The task of hygienic design is to minimize risks of contamination and to make easier the challenges of cleaning and maintaining the plant and equipment that should cover the following: factory site and construction, design of the building structure, selection of surface finishes, segregation of work areas to control hazards flow of raw materials and product, movement and control of people, design and installation of the process equipment, design and installation of services (air, water, steam, electrics, drainage, etc.).

4. References

[1] Matuszek T. (1999). *Environmental impacts regarding cleaning of fouled surfaces in food industry.* Int. Conference on Environmental Degradation of Engineering Materials, Vol. II, Gdansk-Jurata, Poland, pp. 223-228.

[2] Matuszek T. (2000). *Modular design process applied to the food industry.* Scientific Papers, Białystok University of Technology, 7, pp. 185-193 (in Polish language).

[3] Hata T., Kobayashi N., Kimura F. and Suzuki H. (2000). *Representation of Functional Relations among Parts and Its Application to Product Failure Reasoning.* Proc., CIRP International Seminar on Design, Haifa, Israel.

[4] Otto K., and Wood K. (2001). *Product Design - Techniques in Reverse Engineering and New Product Development.* Prentice Hall.

[5] Matuszek T. (2002). *Chosen aspects of equipment exploitation diagnosis in food production.* Scientific Papers, Białystok University of Technology, 9, pp. 285-288 (in Polish language).

[6] Matuszek T. (2003). *Selected aspects of system design theory.* J. of Transdisciplinary Systems Science, Vol. 8, No. 2, pp.132-140.

[7] Kmenta S., and Koshuke I. (2004). *Scenario - Based Failure Modes and Effects Analysis Using Expected Cost*. Journal of Mechanical Design, 126, (6), pp.1027-1042.

[8] Matuszek T. (2004). *Chosen aspects from theory and technical systems design applied to the equipment in food industry.* XI Conference on Design and Exploitation Food Industry Equipment, Koszalin, Poland, p. 98 (in Polish language).

[9] Duke- Rohner M. (2007). *Evolution of the food industry-people, tools and machines.* Trends in Food Science & Technology, 18, pp. S9-S12.

[10] Gengenbach R.J. (2008). *GMP qualification and validation of facilities manufacturing active pharmaceutical ingredients, a practical guide.* WILEY-VCH, Verlag GmbH & Co. KGaA, Weinheim, pp. 68-86.

[11] Matuszek T. (2008). *Hygienic pump design.* New Food, issue 2, pp. 31-34.

[12] Sperber W.H. and Richard F.S. (2009/2010). *Happy 50th Birthday to HACCP: Retrospective and Prospective*. Food Safety Magazine, pp. 42, 44-46.

[13] Matuszek T. (2011). *Food equipment hygienic design philosophy.* EHEDG Yearbook 2011/2012, pp. 63-65.