Mathematical and Statistical Applications in Food Engineering

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CHAPTER 1

Role of Mathematical and Statistical Modelling in Food Engineering

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1. Importance of Mathematical Modelling in Food Engineering

The food engineering domain is considered to be a complex process due to the presence of various scalable throughputs, rheological properties of food molecules, different processes and environmental parameters, quality and stability concerns. Moreover, the influencing parameters impact the other parameters through the mutual dependencies. The complexity also lies in the raw and processed food commodities in the form of variability, which impacts the composition and their processability in further operations. Various food engineering problems, such as heat and mass transfer operations, are heterogeneous and variable. Therefore, it is not possible to handle them with only basic disciplines, such as mathematics, physics and science (Barnabé et al., 2018).

The heterogeneity and variability encountered in the food engineering domain can be made manageable by utilizing the modelling approaches which put forth the non-linear relationship of the different process parameters on the performance of the process or on the final yield of the food product (Shenoy et al., 2015). Mathematical modelling plays a vital role in understanding the food process related to thermal (heat and mass transfer) and non-thermal processes (high-pressure processing, pulsed electric field) and in assessing the possible microbial and biochemical changes during the shelf-life of the food products (Farid, 2010). The modelling approaches also tackle the scale-up associated problem and are useful in simulations, since they take care of impossible process parameters, such as high temperatures (Dutta, 2016).

The machine-learning/simulation-based optimization approaches help in attaining/predicting the optimum output by considering the individual, square and interaction parameters of the process. The machine-learning based optimization approaches produce a huge set of data for processing with the intuitive knowledge of the nature-based phenomenon. Moreover, the modelling and optimization approach also helps in attaining a deductive conclusion with a smaller set of experiments with the positive expert-knowledge based methodologies (Perrot et al., 2016). Computational Fluid Mechanics (CFM) also play an essential role in the food engineering domain, with various applications in process operations, such as drying, freezing, cooking, sterilization and baking, by providing food engineers with new insights into the probable performance of the equipment during the time-course of quality or safety (Dutta, 2016). Artificial Neural Networks (ANN) are also one of the machine learning tools with the potential for use in the food industry to tackle the food characteristics and understand the structure-process interaction during the production step of food products (Huang et al., 2007).

2. Experiment Design and Data Analysis

The most important step in food engineering is the experiment design. In all the related work, such as enzyme production and other food related products, there is a need to design the experiment before beginning in the laboratory or at pilot scale. All of the dependent and independent variables need to be defined before the experiment, and based on the optimization methods, an accurate mathematical method should be chosen. Figure 1 explains the various basic terminologies used in experiment design.

Figure 2 shows the three basic principles used for the design of experiment (DOE). The three basic principles for DOE are 'replication', 'randomization' and 'control of experimental error'.

Using randomization eliminates the systematic bias and aids in the distribution of all the designed experiments. In order to make a completely randomized design (CRD), the entire experiment must be divided into a number of experimental units, say x. In this design, the total number of replications for different treatments are fixed in advance. The replication procedure helps in repeating the experiment at the centre stage and it also estimates the experimental error. The experiments are repeated twice or thrice and mean values are also estimated. The control of experimental error will in turn increase the efficiency. If the sample size is large, the CRD experiments are not homogenous and there are n treatments to be compared, then it may be possible to: # Blocks are build and this procedure is called as randomized block design (RBD). The experimental material is divided into rows and columns in the Latin square method (LSD). In the LSD, each experiment occurred only once in the each row and column.

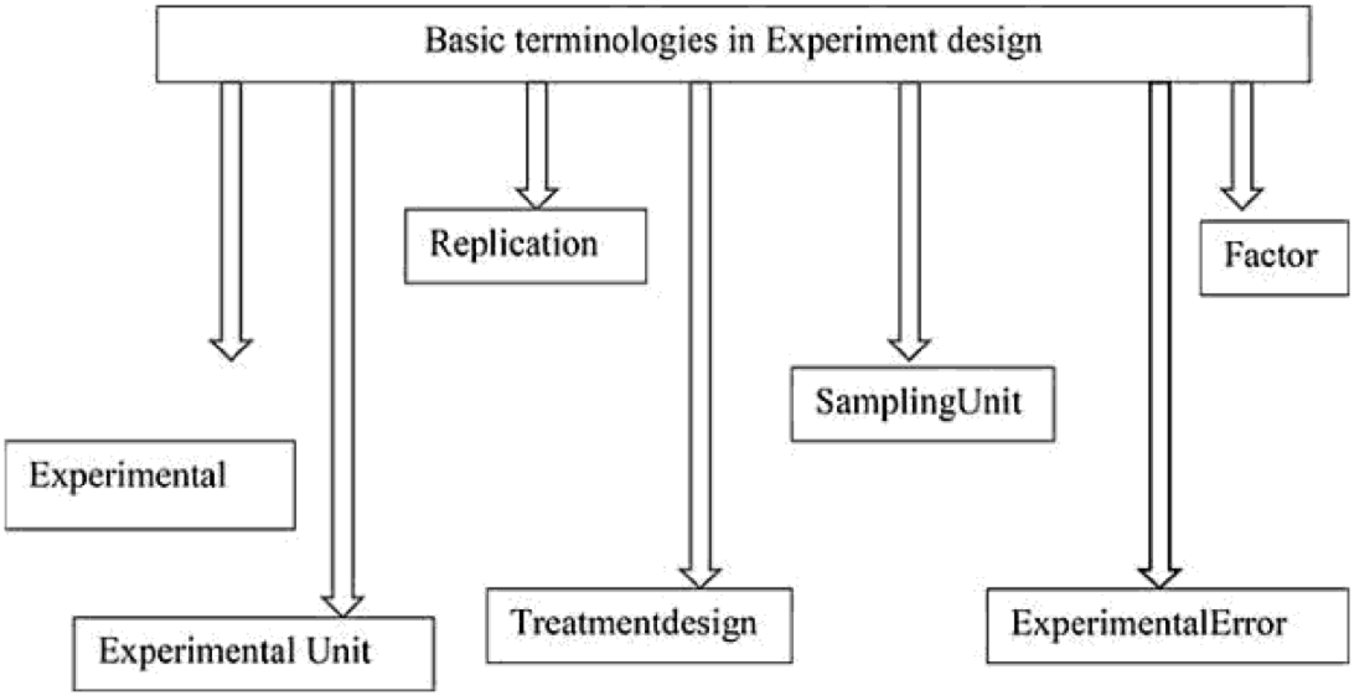

Figure 1: Shows all the basic terminologies in the experiment design.

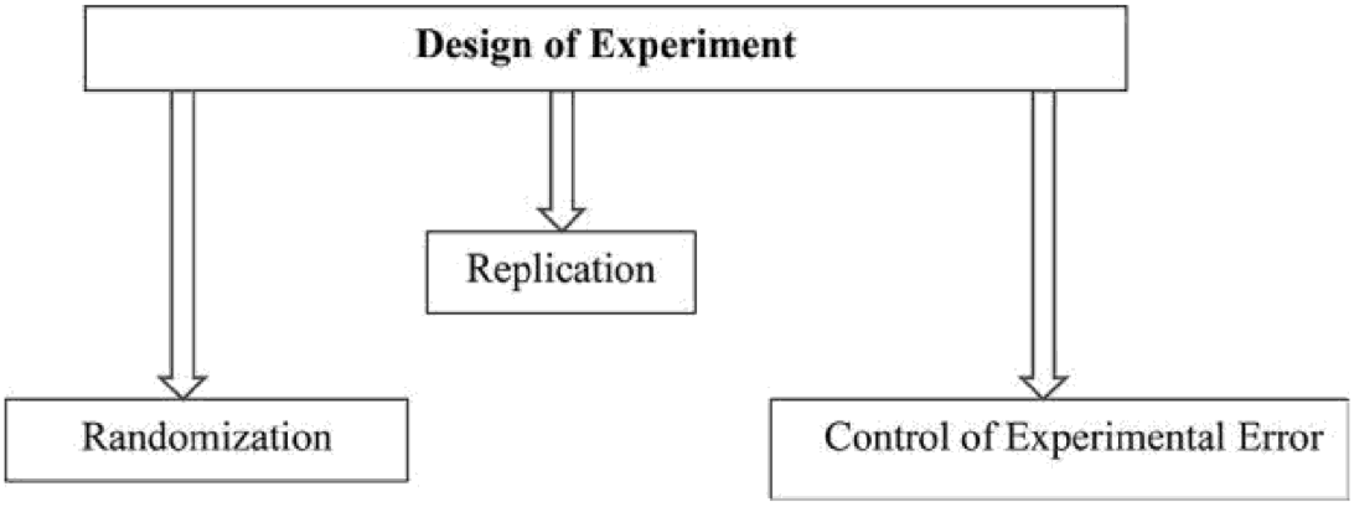

Figure 2: Shows the basic principles used for the design of experiment.

3. Typical Problems in Application of Mathematical Modelling in Food Engineering

The typical problems encountered while using the modelling and optimization approaches in a food engineering discipline are mainly due to the usage of low-level manual-coded languages, such as FORTRAN or C, for implementation. This is highly resource-consuming and error-prone. Furthermore, it is impossible to utilize the approaches to plant-wide simulation by taking care of multiple interacting units. The FORTRAN or C-based modelling approaches also lack robustness and efficiency in dealing with the multitask problems associated with the food engineering domain (Banga et al., 2003).

Despite the well-proven modelling and optimization approaches in the food industry for the typical processes, the utilization of the adopted approaches for other food engineering operations is limited due to the following factors:

- The developed food process model's applicability is not straightforward (Bimbenet et al., 2007).
- Uncertainties encountered due to the raw material properties, process parameters and unreliability associated with the process conditions (Ioannou et al., 2006).
- The developed process models are applicable to tiny sectors of the food engineering domain (Perrot et al., 2006).
- The proposed process models are not able to integrate with the other developed models (Bimbenet et al., 2007).

Moreover, due to the dynamic nature of food processes, the developed food process models are very complicated in terms of the structural understanding, nature of simulation and optimized control. The complexity will be greater while developing a process model and taking care of relationships between composition, structure, properties, quality and shelf-life of the food, resulting in a very challenging task (Fito et al., 2007).

4. Conclusion

Mathematical/statistical modelling facilitates a real understanding of the non-linear problems associated with food engineering operations with the aid of statistical heuristics and helps in the development of validated non-linear regression models. This approach helps in attaining the process optimization with well-planned and less experimental DOE. The developed mathematical models help in straightforward extrapolation towards the scale-up studies. In conclusion, there is a need for the industry and academia to work together in order to further the progression in modelling approaches by handling the typical problems encountered in the execution of modelling approaches in food engineering.

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