ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ENG-606 DESIGN OF EXPERIMENTS

DOE PROPOSAL - FALL 2022

Investigating experimental process conditions in automated robotic food manufacturing

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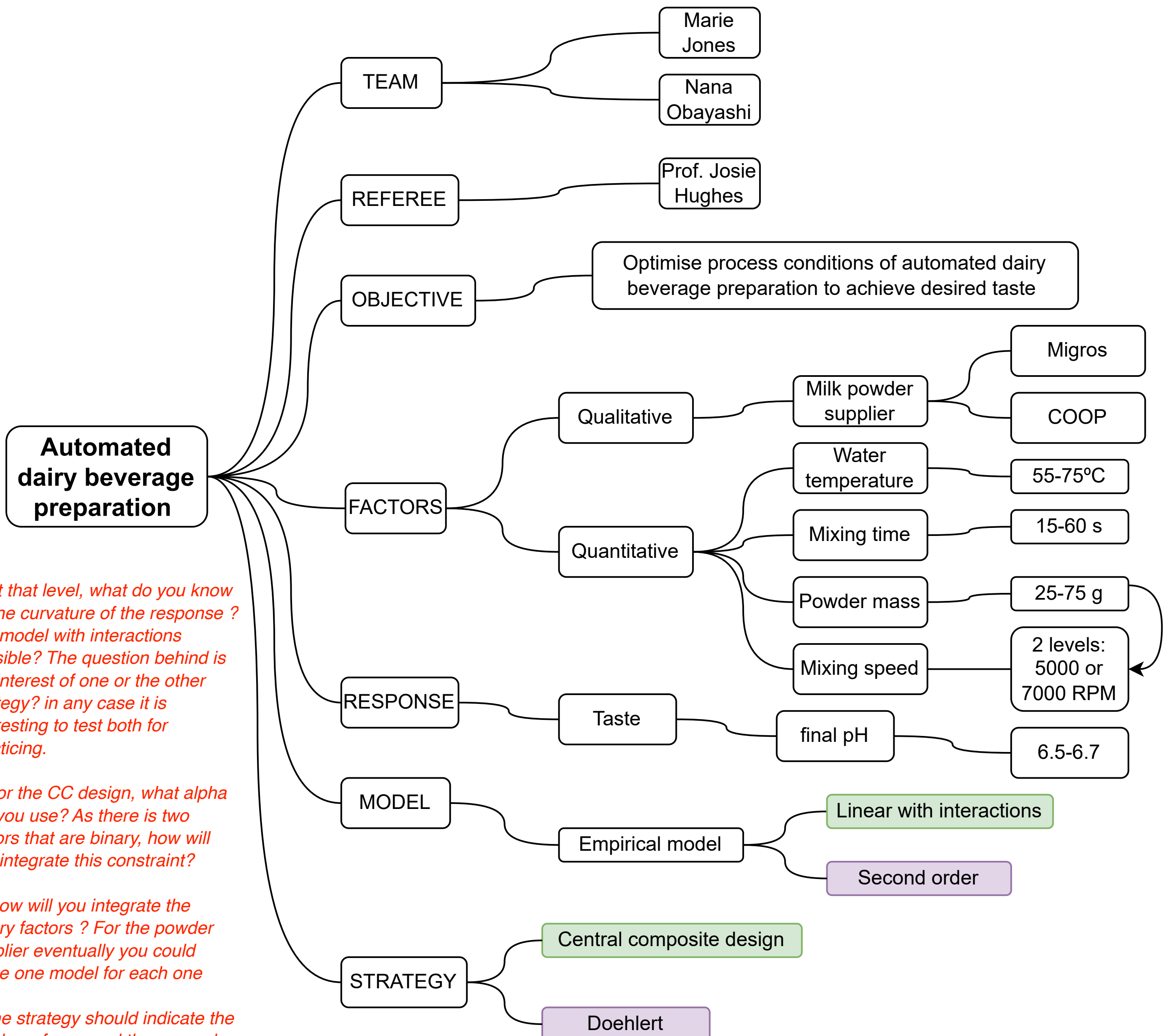
1 Group

Nana is a second year PhD student from the CREATE Lab working on soft robotics that exploit the fluidic environment. Marie is also a second year PhD student working on process development for novel biorefinery. We know each other as part of the EPFLglobaLeaders program. Our referee is Professor Josie Hughes, PI of the CREATE Lab. The set-up on which the experiments will be performed was designed by our colleague Stefan Ilic, who is also an EPFLglobaLeaders fellow.

2 Project Mindmap



1) At that level, what do you know on the curvature of the response ? Is a model with interactions possible? The question behind is the interest of one or the other strategy? in any case it is interesting to test both for practicing.

2) for the CC design, what alpha will you use? As there is two factors that are binary, how will you integrate this constraint?

3) How will you integrate the binary factors ? For the powder supplier eventually you could make one model for each one

4) the strategy should indicate the number of runs and the pro and cons. ;-)

Figure 1: Project mindmap

I see that most of the questions are answered in the dedicated paragraphs, nevertheless it is a good practice to have a comprehensive map. From my point of view, minimum would be to have the number of runs and address the question of the binary factors.

3 Objectives

The main objective of the project is to investigate the impact of experimental process conditions for food science applications, specifically on the preparation of a dairy beverage from powdered milk. Currently, much of recipe optimisation is performed manually and also relies on subjective assessment methods, limiting the accuracy and repeatability of the results [4, 9]. By using robotic automation, the impact of variance in process parameters in terms of precision, accuracy, and reliability of sensory measurements can be explored [6].

The customised robotic setup is shown in Figure 2 and the experimental process consists of four main stages: water filling, pouring of dairy powder, mixing of the ingredients with an over-head mixer, and finally measurement with a pH probe. The sample is automatically transferred from one process step to the other with a UR5 robotic arm. This experimental set-up enables a high through-put generation of results, which is well suited for our project. Screening of the various process variables has previously been done and we will focus here on understanding the relative significance and impact of those selected factors on taste to optimise the process.

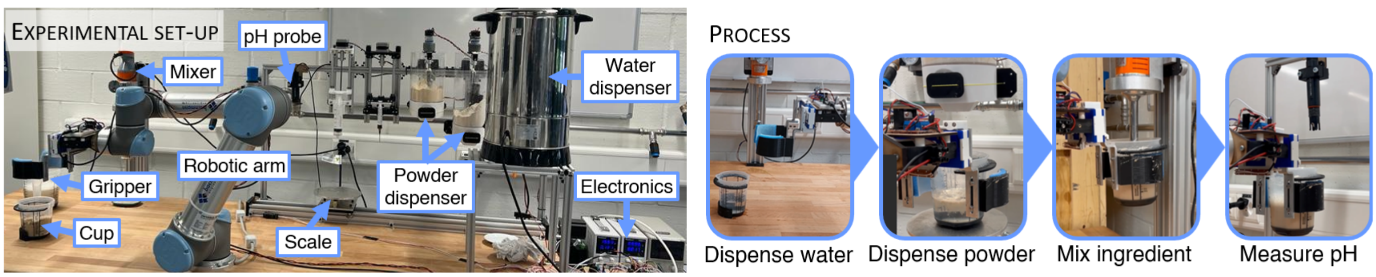


Figure 2: Left: Customised automated robotic setup for food science processes. **Right:** Experimental process for dairy beverage making and pH measurement.

4 Factors

We have identified five main factors affecting the dairy beverage preparation, summarised in Table 1. The type of milk powder is the only discrete variable in our analysis. We will try two different powders from two different suppliers (Migros and Coop). The temperature of the water is controlled with a heating mat and measured with a temperature probe within a range recommended by the external collaborator and from literature [2]. The cooling rate will depend on the outside temperature and the time of the whole process (from the dispenser to the final temperature probe). Mixing is accomplished by a kitchen mixer [3] and programmatically controlled. No factors have been recognised to be difficult to vary. Previous experiments have shown the close link between mixing speed and powder concentration. From those experiments, we concluded that we should consider two mixing speeds depending on the concentration range.

5 Response

Our objective is to improve the taste of the dairy beverage, which is not easily measurable and subjective to external factors. The final pH of the drink will be used as a proxy measure of taste [7]. Our industrial partner has conducted large scale tasting panels and concluded that the final pH of the dairy beverage should be between 6.5 to 6.7. pH will be experimentally measured with a probe with a tolerance of +/- 0.05 [8].

Table 1: Factors

Item	**Nature**	**Range**	**Unit**	**Measurement**	**Dependence**	**Uncertainty**	**Relation to process**
Milk powder type	Qualitative	Two different suppliers	NA	NA	Batch to batch differences	Unknown composition	Affects all other factors
Water temperature	Quantitative	65-75	°C	Temperature probe	NA	0.5°C	NA
Mixing speed	Quantitative	5000 or 7000	RPM	Over-head mixer	Two levels based on powder concentration	NA	May impact temperature
Powder mass	Quantitative	25-75	g	100 kg load cell	Influences mixing speed set-point	2 g	NA
Mixing time	Quantitative	15-60	s	Python program	NA	1 s	May impact temperature

6 Model

For the design of experiment, due to the relative quickness in the ability to gather data, two models will be considered—linear with interaction and quadratic. These models are expected to be able to capture the behaviour of the complex response given a total of five (four, with one coupled pair) factors where there are possible interactions as well as quadratic effects. The predicted causal model and its interactions are shown as Fig. 3. Our design will be made of 10 and 14 coefficients for the linear with first order interactions and quadratic models respectively. Constructing a quadratic model is of great value here since we aim at optimising the process to improve taste [5].

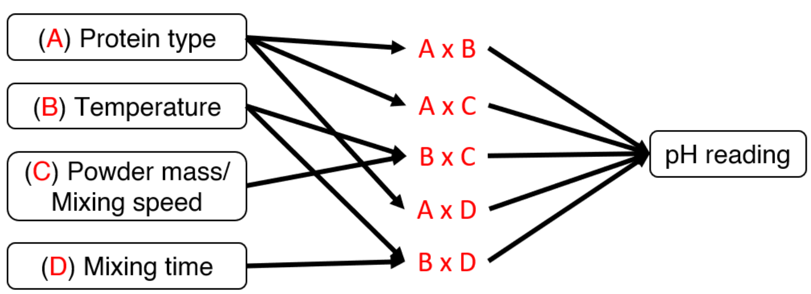


Figure 3: Predicted causal model for three factors and one response.

7 Strategy

Our strategy is two-fold: we first aim at designing an essay matrix to maximise the amount of information collected with the minimal number of experiments; and then analyse the results to identify the main effects on the response (here pH of the beverage as a proxi of taste) and understand the main interactions between the factors.

First we will use the Central Composite Design (CCD) step-by-step to fit a linear model with interactions and then a quadratic model. With the first model, we aim at validating our assumptions presented in Figure 3. The CC design consists of three portions [5]:

1. A fractional 2^k factorial design where we test two levels (min and max), which are coded as -1,1.
2. 2^k points arranged on a radius α from the origin of the coordinates system, at the intersection with the axis of each control variable.
3. Centre points, on which several replicates should be performed.

We will also resort to the Doehlert design which is less precise but has been proven suitable for food chemistry applications [1]. For k factors, the designs are obtained from a regular k-dimensional simplex. Each variable is assigned a code with different levels, therefore enabling not only to test the bounds. Moreover, the Doehlert design is convenient to move through the experimental domain. It indeed takes advantage of the previously explored points to search for the optimal conditions of the system. The minimum number of experimental points is defined by: N = k^2 + k + pc, where pc is the number of replicates of the central point. With 4 factors and at least 3 replicates, we would have to do 23 experiments.

8 Program

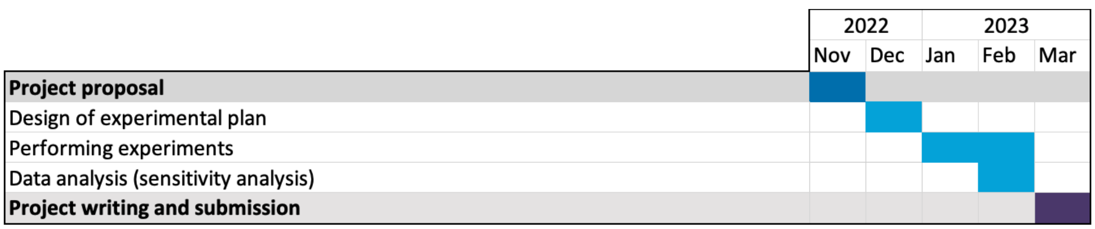


Figure 4: Gantt chart

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