Effect of Chaotic Mixing on the Rheological Characterization of Mayonnaise

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Abstract

In this study, a new mixing method for mayonnaise was developed. A chaotic hand mixer was designed. The speed of the mixer rotor was chaotically changed with the proposed method. Performance of the mixed mayonnaise was evaluated by a rheological characterization method. The results showed that the proposed chaotic mixing for mayonnaise has a better performance in terms of energy efficiency than conventional mixed ones indicating potential use in industry or as home appliance.

1. Introduction

Mixing process is one of the most used basic operation in the food industry as it applies on many different food products. Despite its inefficiency, the most widely used mixing process technique used in the industry is conventional mixing that is the type of mixing with constant speed. In a conventional mixing process, high energy consumption and therefore high operating costs may be required depending on the process capacity [1]. Thus, cost saving opportunities via providing efficient mixing without changing the quality of the product is of great importance.

Chaotic mixing is known to be one way of mixing that provides efficient mixing. When compared with the conventional techniques, chaotic mixing provides more significant lower electrical energy consumption, less mixing time and more homogenous mixing [2-9]. Thus, in this study we consider the effects of chaotic mixing on one of the oldest and most used sauces known in the world, i.e. mayonnaise, and its possible extension to industry.

Mayonnaise is produced in stirring tanks. It is conventionally prepared by gentle mixing of egg yolk, oil, vinegar, water, salt and sugar. There are also optional ingredients such as spices, sweeteners. In a standard mayonnaise production, all the ingredients except oil are mixed gently in order to ensure that the materials are thoroughly dispersed within each other. Mayonnaise is a shear-sensitive food that can be damaged in high shear stress in fast stirring modes for mixing process. Thus, its production time cannot be reduced by faster mixing. However, new mixing modes can be used for more efficient production. One candidate for such a mixing mode is chaotic mixing. Recently, chaotic mixing has been shown to be a good alternative to establish energy efficient fluid mixing in high level of homogeneity [2-9]. In chaotic mixing, instead of using complicated impeller vanes, a practical chaotic motion is considered as a targeting mixing parameter. This chaotic motion can be created electrically by modifying the standard mixer rotor. At this point, it is not only the crucial point to change the device by changing the mixing mode, the importance lies on the usage of chaotic mixing mode with a newly designed equipment in some niche applications. Relevant study also creates a potential for adaption of the newly developed mixing model to the other emulsified food products. The proposed chaotic mixing system is an extension of the chaotified DC motor mixing liquid systems available in the literature [4, 7-9].

The purpose of this study is to design a motor driver which is capable of changing mixing mode from standard, alternatively said conventional, mode into chaotic mode and to measure the effect of chaotic mixing on the rheological properties of mayonnaise while comparing the mixing mode with the classical mixing in terms of energy efficiency. In the end, chaotic mixing appears to be advantageous in energy saving while keeping the same rheological properties of the produced mayonnaise. Since rheological properties have a considerable role in the product quality, we conclude that chaotic mixing provides a cost saving opportunity without changing the quality of the product.

The paper is organized as follows. In Section 2, the developed mixer is briefly described. In Section 3, the chaotified mixing system algorithm and implementation are presented. Section 4 provides applications and the rheological properties of mayonnaise. The results and conclusions are given in Section 5 and Section 6, respectively.

2. Chaotic Mixer

Chaotic mixer consists of three parts such as mechanical part, dc motor part and electronic card. The typical specification of the mixer is that hand mixer can move in the bowl. This specification guarantees that the hand mixer rotates the impeller controlled by users. In this mixer, there is a DC motor with redactor that has the maximum speed of 1900 rpm. There is also an encoder that is attached to the DC motor shaft. Chaotic system was calculated in the microcontroller card to chaotify DC motor speed. The DC motor was mounted at the fixed holder of the plant. The number of rotation of the shaft is obtained via encoder unit on the same card. Technical parameters are given in Table 1 and the modified chaotic hand mixer which is used for the experiments in this study can be seen at Fig.1.

Fig. 1. Experimental setup with chaotic hand mixer

3. Chaotification of Mixer

In this section, the mathematical model for chaotification is given. The mathematical model for chaotification is based on Logistic Map. The speed of DC motor in hand mixer is controlled by Logistic Map recursion so that a chaotic mixing is obtained. Logistic Map iterations are carried out in the microcontroller and the speed signal information obtained by these iterations is transmitted to the encoder of the motor in a feed-forward way. The Logistic Map recursion is defined as:

$$x^{k+1} = \alpha\, x^k\, (1 - x^k) \tag{1}$$

where, $\alpha \in (0,4)$, $k = 0,1,2,\ldots$ and x^k is the value of the state variable at the discrete time k. The considered basic approximation model for real DC motor is $\frac{dx(t)}{dt} = -a_m x(t) + b_m u(t)$ where $x(t)$ is the speed of DC motor shaft (rpm), a_m and b_m are constants of model and $u(t)$ is the input obtained from the Logistic Map iterations. A simulation of a chaotic system output (speed) for arbitrary model parameters ($a_m = 100, b_m = 200000$ and $\alpha = 4$) and Logistic Map iteration in every 0.25 second was plotted in Fig. 2.

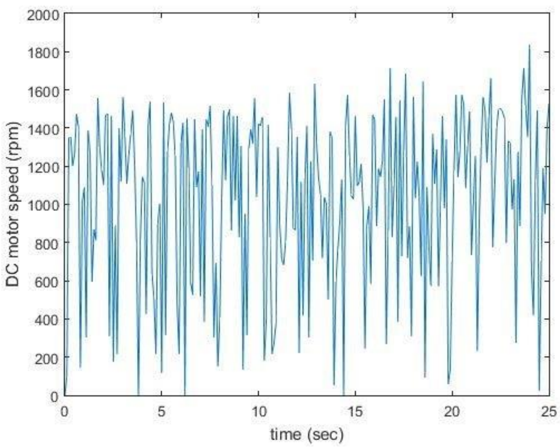

Fig. 2. An example of a chaotified DC motor speed

4. Applications and Analysis

4.1. Materials and Methods for Application

Mayonnaise samples were prepared for rheological characterization with the formula including 6% (w/w) egg yolk, 10% (w/w) water, 1.2% (w/w) vinegar, 1.55% (w/w) sugar, 1.25% (w/w) salt, and 80% (w/w) vegetable (sunflower) oil. 250 gram mayonnaise sample was prepared and stored in the refrigerator until measurement.

A commercial hand mixer whose motor is derived by the developed electronic card was used for preparation of mayonnaise samples. First of all, egg yolks, vinegar and water were mixed in the bowl for 1 minute. Then, salt and sugar were introduced to the mixture and mixed again for 1 minute. After that, vegetable oil was slowly added and the mixer was operated for 45 minutes for standard mixing. 45 minutes of standard mixing is the minimum time needed for the desired levels of rheological properties. Before that time, the mayonnaise characteristics, such as emulsion, do not reach to a required quality. Therefore, firstly the standard flow curve of mayonnaise produced by standard mixing for 45 minutes was plotted and accepted as the control curve. After that, the time necessary to produce mayonnaise with same rheological properties by using chaotic mixing is determined as 23 minutes and the motor runs for 23 minutes in the chaotic mixing mode. The average mixing speed was arranged as approximately 930 rpm for both mixing mode. In order to study the effect of mixing mode on the rheological properties of mayonnaise, two series of samples were prepared containing the same ingredients. One series of mayonnaise samples was prepared by the standard mixing mode, the other series was prepared by the chaotic mode while other conditions were kept constant.

4.2. Rheological analysis

All rheological properties (shear rate, stress stress, storage modulus G', loss modulus G'') were determined using the Rheometer MCT 302 (Anton Paar, Austria) in the system of concentric cylinder (diameter 27mm). The measurements were performed at a temperature of 25 °C. The visco-elasticity moduli were determined by means of dynamic tests with forced oscillation by frequency 50 rad/s and 900 rad/s. Flow curves were determined over the shear rate range of 0–150s^{-1} and the apparent viscosity was calculated at the same shear rate applied (0-150s^{-1}). All measurements were done in triplicate and average values were calculated.

5. Results

Fig. 3 depicts rheograms of mayonnaise samples produced by standard and chaotic mixing type, respectively. Shear stress grows with increasing shear rate and all mayonnaise samples showed hysteresis between forward and backward curves. This flow behavior is defined as pseudoplastic. Moreover, rheological properties of samples depend on time. In other words, mayonnaise samples exhibit thixotropic behavior. The change in mixing mode did not lead to a significant change in flow nature. In the literature, it was reported that mayonnaise shows pseudoplastic behavior and tixotropic characteristics [10].

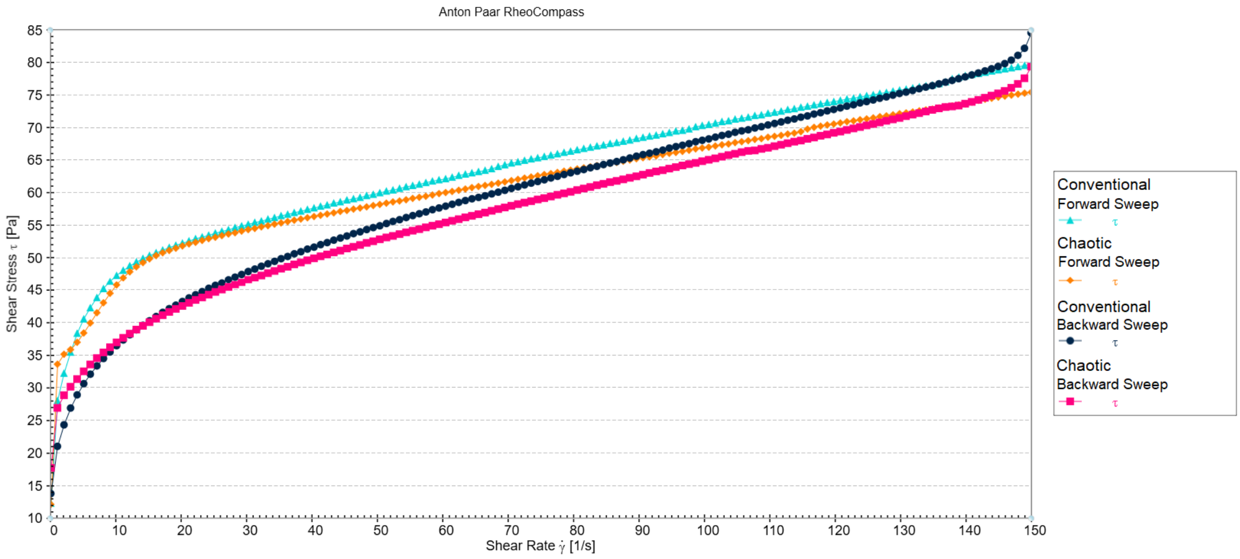

Fig. 3. Rheogram of mayonnaise samples (both standard and chaotic mixing)

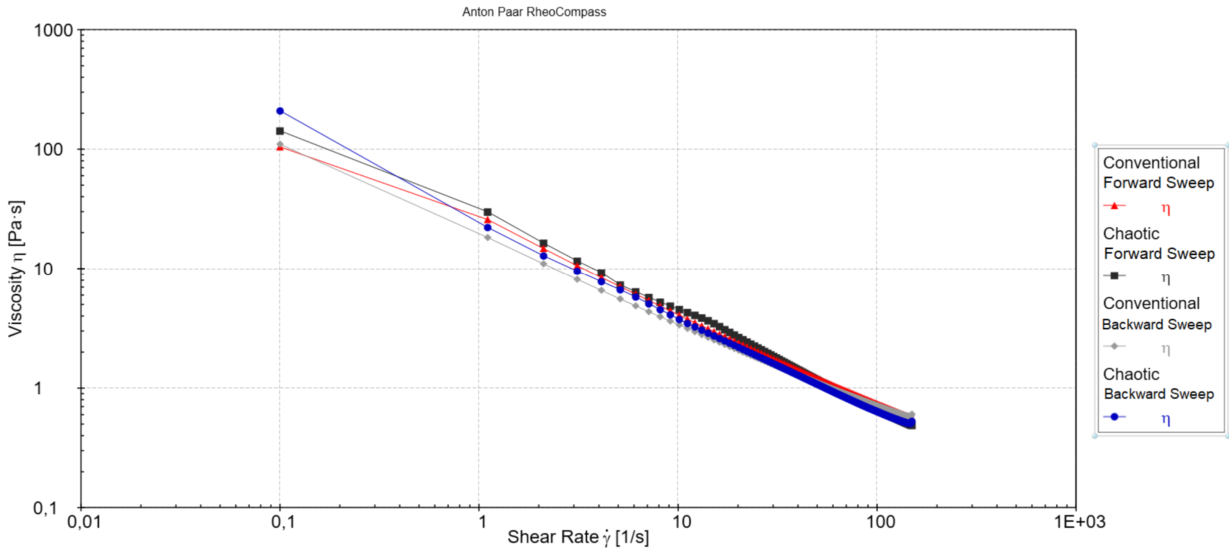

Fig. 4. Effect of shear rate on viscosity of mayonnaise samples (both conventional and chaotic)

In the study of Singla et.al., two different commercial mayonnaise samples were analyzed by using rheometer. The results showed that mayonnaise samples displayed a time-dependent non-Newtonian behavior [11]. Stern et al. investigated the effect of oil content on the rheological and textural properties of mayonnaise and they showed that pseudoplastic behaviour of mayonnaise was confirmed [12].

The viscosity curve of the samples versus shear stress plotted for all mayonnaise samples for shear rate applied between 0-150 s^{-1} (Fig.4). As seen in Fig. 2, a rapid fall in viscosity at the initial shear rate values up to 10 s^{-1} points out that there is rapid disruption in emulsion structure. After that, decrease in viscosity continues and slows down at higher shear rates. Furthermore, there is no substantial difference in viscosity between samples produced by two mixing mode (standard and chaotic mixing).

From the rheological properties of mayonnaise samples, the storage modulus (G') and loss modulus (G'') values were investigated as a function of angular velocity. G' represents solid-like character of emulsion structure. If emulsion structure is destroyed, mayonnaise becomes more fluid and it loses its solid-like character. For both cases (conventional and chaotic mixing mode), storage modulus values are higher than loss modulus values which is the characteristics of mayonnaise sample. Especially G' of mayonnaise produced by chaotic mixing has the highest solid-like character indicating rich storage stability as shown in Fig.5.

6. Conclusion

In this study, a chaotic mixing system for mayonnaise production was proposed. The mixer rotor speed was chaotically controlled with the proposed system. The results showed that the proposed chaotic mixing for mayonnaise has a better performance than conventional ones. It can be concluded from the results that, the use of chaotic mixing mode did not show any substantial change in flow nature, consistency, physical stability and viscosity of mayonnaise samples. Moreover, it leads to time and energy saving about half compared to standard mixing mode. As

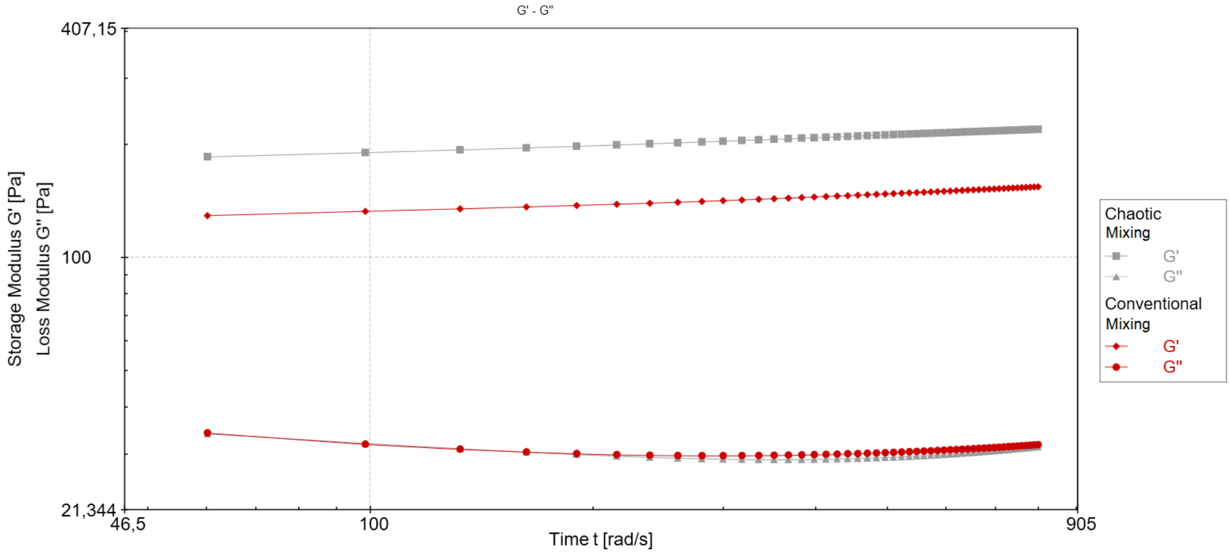

Fig. 5. Storage modulus and loss modulus values as a function of angular velocity.

a result, chaotic mixing mode would be considered as an option for mayonnaise production in the industry or as home appliances.

7. Acknowledgements

This study is supported by Scientific Research Fund of Yaşar University with Grant Number BAP052.

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