Investigation of the effect of fat content on the yield stress of mayonnaise measured with Thermo Scientific HAAKE Viscotester iQ Rheometer and vane rotor

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Rheology, Mayonnaise, Yield Stress, Vane Rotor, Automated QC Evaluation and Documentation

Abstract

In the Quality Control (QC) of mayonnaise, one of the standard tasks is to determine the yield stress in the original container using a vane rotor, which needs to be moved into the intact product structure in a perfectly vertical movement. Efficient and high-throughput QC measurements require a viscometer with an easy-to-operate lift function as well as an easy-to-adapt universal container holder for different container designs as well as software routines for automated measurement, evaluation and QC documentation. An optionally available temperature sensor mounted parallel to the rotor allows for recording of the sample temperature.
The yield stress in food corresponds with important material characteristics as stability, mouth feeling and processability and is affected by the ingredients and their formulation – particularly the fat content [1 - 4].

Introduction

Mayonnaise is a semi-solid oil-in-water emulsion consisting basically of an oil and an acidic water phase plus emulsifier. Formulations differ widely in composition, texture and flavor. Conventional full-fat mayonnaise has an oil (i.e. fat) content of up to 80 %. Lowest-fat or no-fat mayonnaise, on the other end, is not even an emulsion in the classical sense. As soon as the fat content is reduced, it is necessary to adjust the formulation and to add further ingredients in order to obtain a texture, which will be well accepted by consumers [1 - 4].
Home-made mayonnaise usually consists of vegetable oil, egg yolk, vinegar and/or lemon juice and flavoring ingredients like pepper, salt, mustard and maybe sugar.
Industrial mayonnaise products may also contain modified starch and thickeners like carob bean gum or guar gum and colorants (e.g. beta-carotene) as well as additional flavors. Fat-reduced and light mayonnaise products may require a higher content of water and the addition of fat-reduced yoghurt or other milk products, other thickeners (e.g. xanthan gum) as well as artificial sweeteners. Moreover, fiber-rich ingredients like pectin can be used for fat replacement and for texturing [1].
Yield stress is by definition the minimum shear stress

Fig. 1: Thermo Scientific HAAKE Viscotester iQ rheometer with mounted universal container holder and vane rotor FL26-2 blades (left); universal container holder with three vane rotors: 4-blade rotors FL16 and FL22 as well as FL26-2 blades (right)

required to make a material flow. The yield stress is a measure for pourability, spreadability and spoonability and is used to predict the product stability [1 - 5, 8 - 10].
The calculated yield stress values τ_0 of mayonnaise can range from about 20 Pa (pourable) to about 300 Pa (spoonable), depending on the particular formulation as well as on the method used for yield stress determination and the pre-experimental sample handling [1 - 11].
As far as the composition is concerned, the yield stress strongly depends on the fat content.
Regarding rheological measuring methods, the most accurate and recommended method to determine absolute yield stress values is the Controlled Stress (CS) ramp with plate/plate measuring geometry, which requires careful sample preparation, handling and loading to maintain the intact structure [7].

Sample stirring or squeezing would lead from the static yield stress of the intact structure to the (lower) dynamic yield stress of a disturbed structure [9 - 10]. Loading a sample into a plate/plate, plate/cone or concentric cylinder measuring geometry with subsequent equilibration and CS ramp yield stress measurement takes about 10 to 20 minutes per sample.
For QC, this may be too time-consuming – therefore, relative vane rotor measurements with an intact sample structure in the original container are often preferred, since they can be conducted much faster and are related to the static yield stress [8 - 10]. The correct selection of the experimental parameters for vane rotor measurements is fundamental – this will be discussed in more detail below. In general, Controlled Rate (CR) mode with rotational speeds lower than 1 rpm is recommended [9].

Materials and methods

A Thermo Scientific™ HAAKE™ Viscotester™ iQ rheometer equipped with a 4-blade vane rotor FL22 (vane diameter 22 mm, height 16 mm) and an universal container holder (Fig. 1) was used for the yield stress determination in CR mode. Three industrial mayonnaise products from the same manufacturer with different fat content levels were investigated (Table 1). A sealed glass container was opened and fixed in the easy-to-adjust universal container holder. Using the manual lift function of the HAAKE Viscotester iQ rheometer and the features of the Thermo Scientific™ HAAKE™ RheoWin™ software (Fig. 2), the vane rotor was kept from rotating (element 1: CR mode $\dot{\gamma} = 0\ s^{-1}$) and lowered vertically into a well-reproducible position as well as penetration depth (according to the dimensions and shape of the container type).

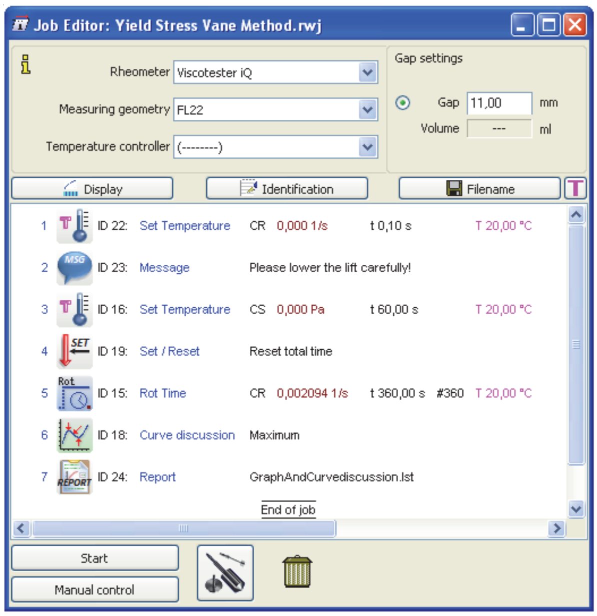

Fig. 2: HAAKE RheoWin measuring job for measurement and automated evaluation and documentation

Products, which are filling into a container with considerable speed in a filled plant, often show slightly different material properties when comparing sample-taking from the bottom center area, top center area or close to the container wall. In such a case it is mandatory to make the vane measurement always in the same position (in each particular container type) in order to obtain comparable and reproducible results.

After a short equilibration and recovery time (element 3), the total time t was set to zero (element 4) right before the measurement was started. A low rotational speed was applied and a set number of data points were recorded within the set time (element 5). With an automated evaluation and QC element (element 6: curve discussion), the maximum in the shear stress τ vs. time t plot was automatically evaluated and checked whether whether τ_0 is within the given range (pass) or outside (fail). Finally a report was generated (element 7), which can be either saved as a file (e.g. in pdf, jpeg, or tiff format) or can be directly printed out.
For each sample class, the most suitable rotor type and rotational speed need to be determined in a preliminary test. Smaller vane rotors are used for samples with stronger texture and higher yield stress, like peanut butter [5, 6], while larger vane rotors are more suitable for samples with lower viscosity and lower yield stress [8 - 10].
In order to determine one rotational speed, which fits all samples of a class, different rotational speeds need to be tested (Fig. 3). A too high rotational speed leads to a sharp peak which cannot be evaluated (red triangles). A rotational speed too low delivers an asymptotic curve with no maximum (green circles). The goal is to select a rotational speed, which generates a curve with evaluable maximum (blue rectangles). The speed corresponding to the highest evaluable maximum is the best choice for this particular sample.

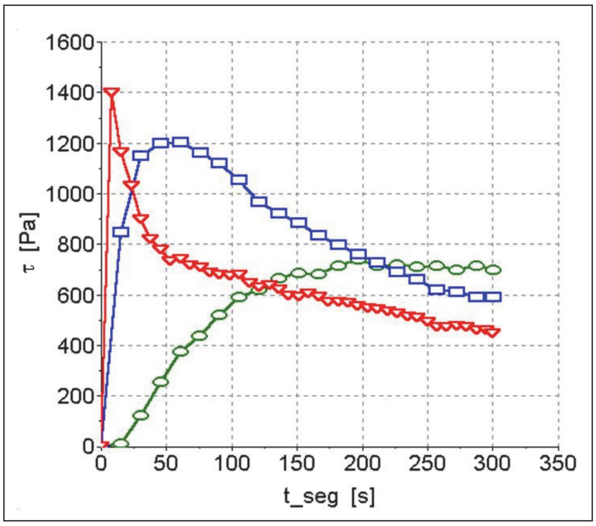

Fig. 3: Schematic comparison of vane rotor yield stress measurements with higher (red triangles), medium (blue rectangles) and lower rotational speed (green circles)

Results and discussion

The effect of the composition on the yield stress has been subject of different investigations in the past. Different behaviors have been observed according to the nature and number of ingredients of the formulation used for the studies [1 - 4].
Among the three tested mayonnaise samples, the highest fat content (22.5 %) product was most critical with regard to obtaining an evaluable maximum in the measuring curve. Therefore the preliminary test described above was run with different rotational speeds. Suitable settings were 0.02 rpm and 0.05 rpm, which delivered comparable yield stress results (95 Pa and 96 Pa) – see Fig. 4 and Table 1. With these both rotational speeds all sample were measured (Figs. 5, 6 and Table 1).

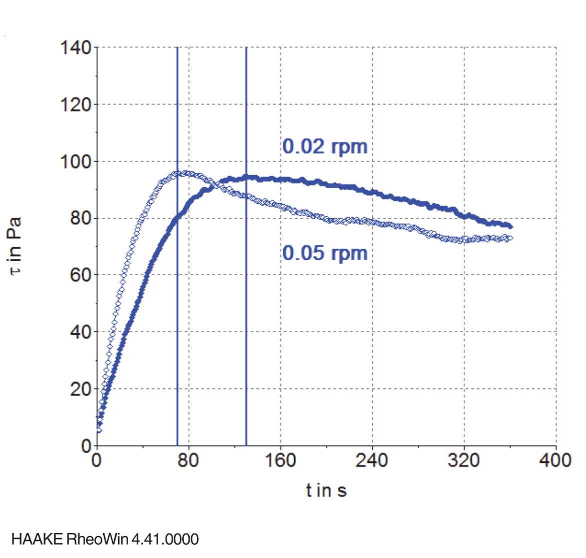

Fig. 4: Comparison of vane rotor yield stress measurements with 0.05 rpm (open circles) and 0.02 rpm (filled circles) with the mayonnaise with 22.5 % fat content

After a 4-blade rotor has turned by 85° to 90°, no intact sample can be sensed by the vane rotor anymore. Therefore, the measuring curves recorded with 0.05 rpm exhibited a little decrease at around 300 s (Figs. 4 - 6).

Fig. 5 and Table 1 show the results of the yield stress measurements for the tested three commercial mayonnaises at 0.05 rpm. All shear stress curves clearly exhibit a maximum. It can be seen that the product containing the lowest fat content (5.2 %) correlates with the highest yield stress (127 Pa). On the opposite, the sample containing the highest amount of fat (22.5 %) presents the lowest yield stress (96 Pa).

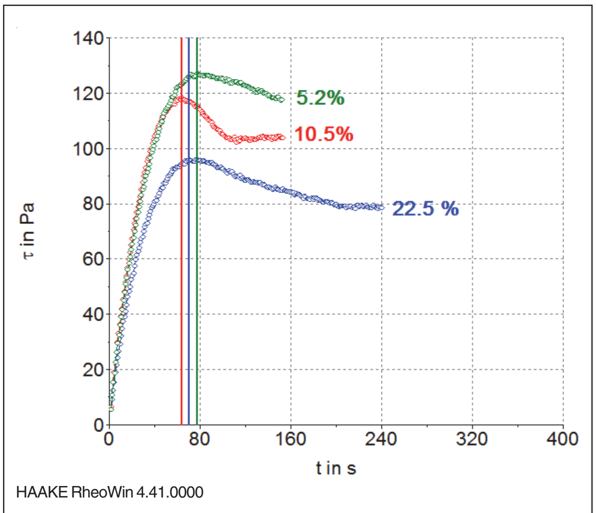

Fig. 5: Vane rotor yield stress measurements with 0.05 rpm for mayonnaises with three different fat contents

The rheological data collected at 0.02 rpm (Fig. 6) confirm the trend observed in the measurements carried out at 0.05 rpm. As expected, with the lower rotational speed each maximum in the stress curve appears at a later time and the measurement takes longer. The evaluated yield stress data for 10.5 % and 5.2 % fat content are higher at 0.02 rpm than at 0.05 rpm. Therefore, for the QC yield stress testing of these three samples, 0.02 rpm is the recommended rotational speed.

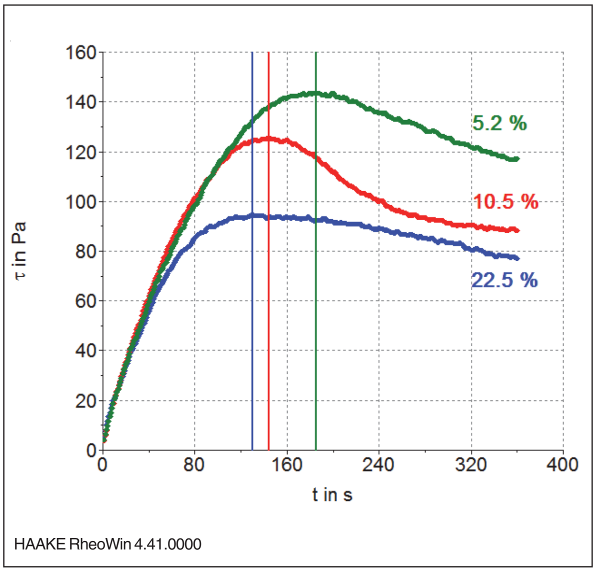

Fig. 6: Vane rotor yield stress measurements with 0.02 rpm for mayonnaises with three different fat contents

Table 1 lists the yield stress values which were calculated automatically by the HAAKE RheoWin software for both rotational speeds. For the formulation with the highest fat content the values are very close to each other, being 95 Pa and 96 Pa at 0.02 rpm and 0.05 rpm, respectively. As the fat content decreases, the difference between the two values becomes more significant. This clearly indicates how the set parameters can affect the results of the rheological measurements in a vane rotor measurement.

Fat content in %	τ_0 in Pa at 0.02 rpm	τ_0 in Pa at 0.05 rpm
22.5	95	96
10.5	126	118
5.2	144	127

Tab. 1: Yield stress results determined with two rotational speeds for mayonnaises with three different fat contents

Conclusion

The HAAKE Viscotester iQ rheometer equipped with the universal container holder and a vane rotor allows efficient, high-throughput measuring routines for mayonnaise QC testing, using samples in their original containers with intact sample structure.

The instrument's smart lift function ensures convenient and fast handling. In combination with the easy-to-adjust universal container holder, it allows for a very well-controlled and perfectly vertical placement of the vane rotor in a reproducible position in the particular container type – a key to reproducible results.

Operation of the HAAKE Viscotester iQ rheometer can be done either as a standalone unit with pre-defined or customized mea-surement and evaluation routines or, even more powerful, with the HAAKE RheoWin measurement and evaluation software, which even offers (as a standard feature) fully automated QC routines including pass/fail evaluation and documentation [11].

The maximum in the shear stress vs. time curve can be easily evaluated automatically and depends significantly on the fat content of the mayonnaise samples.

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