NAVIGATING THE MAYONNAISE MAZE

Taking the guesswork out of production

PROTECTS WHAT'S GOOD
Tetra Pak®

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CONTENTS

7 Introduction
7 Who is this booklet for?
Why is mayonnaise so important to the food industry?

8 What is mayonnaise?
8 Mayonnaise in the world
Mayonnaise from the inside
9 Reduced-fat mayonnaise
10 Mayonnaise by law

11 Mayonnaise quality
11 How consumers perceive quality
12 How industry defines quality
Texture
13 Yield stress
Apparent viscosity
14 Droplet size

15 Processing
15 Emulsification
16 Mayonnaise production methods
Controlling challenges and predicting quality
The mayonnaise challenge
18 The challenge of reduced-fat formulations
19 Process control for consistent product quality

20 Simulations and prediction models
20 Prediction of flow field

22 Cold emulsion mixers
22 Ingredients inlets
Mixer unit for emulsification
23 Tank agitation
Vacuum system

24 Conclusions and implication for the food processing industry
24 What does this combination mean for mayonnaise producers?
Cost savings
Predictable product quality
Faster development of mayonnaise, dressings and other emulsified sauces

25 Tetra Pak – your partner in processing

INTRODUCTION

Who is this booklet for?

This booklet on state-of-the-art mayonnaise production is primarily intended **for food technologists and R&D personnel** in food processing plants who are looking for best practices for producing emulsified sauces, such as mayonnaise.

It is also relevant to **general plant managers** who are on the lookout for best practices at a plant and organizational level.

Finally, it may also be of interest to **procurement managers** who are considering new or additional mixing equipment.

Why is mayonnaise so important to the food industry?

The world's chefs have been practising on mayonnaise, and it shows. Wherever it travels in the world, it is adapted for different consumer preferences for taste, texture and appearance – and some of those adaptations are regulated by local laws or industrial standards.

As a result, there are many different varieties of mayonnaise, but the challenge to producers is constant: being able to accurately predict and control the quality of the mayonnaise to be manufactured.

In these few pages, we at Tetra Pak would like to share with you how we view the mayonnaise production process, how we measure quality, and how you can adapt and optimize your processes using state-of-the-art equipment. This will in turn lead to optimization of your production costs, trouble-free production scale-ups, and faster development of new products for mayonnaise and other emulsified sauces.

WHAT IS MAYONNAISE?

Mayonnaise in the world

Mayonnaise is a cold condiment sauce with a thick texture and a rich flavour. It is used as spreads on sandwiches and burgers, the creamy base in cold salads, dip for French fries and much more. For each application, consumer preferences for taste, texture and appearance vary considerably and are highly dependent on country and region, with traditions in some cases extending back for 250 years.

As a result, the mayonnaise variants in production are numerous. Add the web of local codes for naming, labelling and formulation and throw in ever-changing consumer trends, and the challenges of mayonnaise producers become obvious. Being able to accurately predict and control the required quality parameters is of utmost importance, as this allows optimization of production costs, trouble free production scale-up and, not least, rapid development and shorter time-to-market for new products.

It is certainly not a trivial task to predict mayonnaise texture and appearance, as these parameters are influenced not only by ingredient types and composition, but also heavily by the processing method, equipment type and scale of production. However, Tetra Pak has developed a prediction tool to optimize mayonnaise production methods, and offers specialized equipment that can be tuned to different modes of production. We can help convert your emulsified sauce processes from trial-and-error activities that require a lot of resources into a systematic, efficient and measurable portfolio of processes.

Mayonnaise from the inside

From a technical point of view, traditional mayonnaise is an oil-in-water emulsion containing 65-80% vegetable oil, 5-8% egg yolk and a spiced water phase. The latter typically includes vinegar, mustard, salt and sugar. The oil is present as dispersed droplets with an average size ranging from 2 – 10 microns. The closely packed droplets are responsible for most of the viscosity and texture. For fat content above 75%, the oil droplets are typically so closely packed that they are non-spherical in shape.

The interfacial membrane surrounding the emulsified droplets is comprised of surface-active egg yolk proteins that reduce the surface tension and stabilize the drops. The continuous water phase located between the oil droplets contain the spices but also a network of aggregated egg yolk granules that contribute to both stability and texture. The microstructure of an 80% mayonnaise sample, produced on a Tetra Pak® High Shear Mixer, is shown in figure 1.

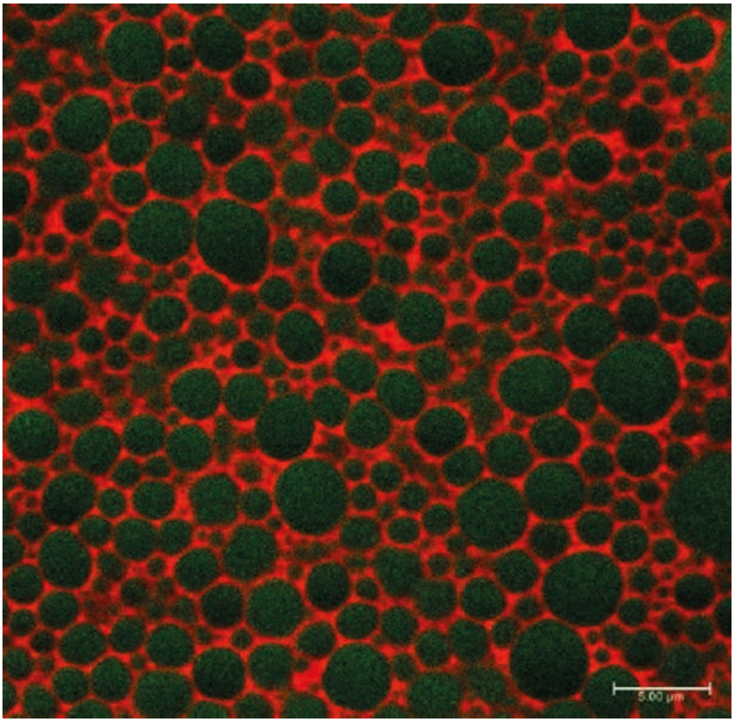

Figure 1. The microstructure of an 80% mayonnaise evaluated by Confocal Scanning Laser Microscopy (CSLM).

Reduced-fat mayonnaise

Consumer demands for low-calorie products with the same taste and feel as traditional versions are well known. But lowering the amount of oil in an otherwise standard mayonnaise will lead to a less dense packing of the dispersed oil droplets and thereby to reduced viscosity and texture. Various thickening and gelling compounds can therefore be added to the water phase to match the viscosity and texture of traditional mayonnaise. Starch is frequently used but other hydrocolloids are also common.

Dressings and other emulsified sauces are *less regulated* compared to mayonnaise and naming varies from country to country.

Mayonnaise by law

The definition of mayonnaise varies from country to country. In some areas content and labelling are defined by law, in others by industry standards. The differences are well illustrated in table 1, showing regulations for traditional mayonnaise and a group of reduced-fat formulations in selected countries.

	MAYONNAISE	REDUCED-FAT FORMULATIONS
USA	≥ 65% fat No stabilisers	Spoonable salad dressing ≥ 30% fat ≥ 4% egg yolks
GERMANY	≥ 70% fat ≥ 5% egg yolk No stabilisers --------- ≥ 80% fat No stabilisers	Salad mayonnaise ≥ 50 % fat
RUSSIA	≥ 50% fat Containing egg ingredients ≥ 1% egg yolk powder	Mayonnaise sauces Not regulated
UK	≥ 70% fat ≥ 5% egg yolk No stabilizers	Salad cream Not regulated
BELGIUM	≥ 80% fat ≥ 7,5% egg yolk No stabilizers	Salad dressing Not regulated
POLAND	≥ 78,5% fat	Dressing / Table mayonnaise 50,5-78,5% fat

Table 1
Regulations for mayonnaise and some reduced fat formulations in selected countries.

MAYONNAISE QUALITY

How consumers perceive quality

It is not trivial to define what consumers perceive as "good" mayonnaise quality, and it is even harder to link these preferences to measurable quality parameters. Mayonnaise quality is therefore often characterized by a combination of sensory evaluations and various laboratory analyses.

Mayonnaise commercials and labels often highlight texture attributes using descriptors such as "creamy", "smooth" and "thick". This is certainly not without merit as the texture highly influences the eating experience through visual appearance, handling feel and in-mouth feel. Figure 2 shows a sensory evaluation regarding texture and appearance of 3 different mayonnaise samples, one full-fat and two reduced fat mayonnaise types, all produced on a Tetra Pak® High Shear Mixer.

This specific texture evaluation was carried out by the Descriptive Sensory Texture Expert Panel run by INGREDION Germany GmbH.

The spider plot confirms more colour intensity (yellowish colour), a shorter spoon texture (less cohesiveness from spoon), firmer product and thicker mouthfeel when full-fat mayonnaise is compared to the chosen formulations. But overall, a good resemblance between full-fat mayonnaise and salad mayonnaise products is evident.

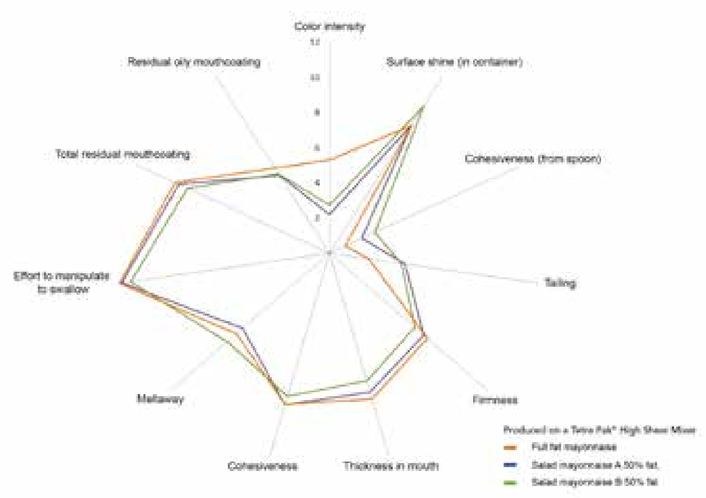

Figure 2: Sensory evaluation of 3 different mayonnaise samples utilizing Ingredion's proprietary texture attribute definitions TEXICON™. In this case 11 out of 18 TEXICON™ attributes were rated on a 15-point universal scale, denoting significant differences and similarities between the samples.

How industry defines quality

Mayonnaise producers need to be able to control the quality of every batch of mayonnaise that is produced in their production lines. Apart from having a sensory panel, which evaluates parameters such as appearance, texture and mouthfeel, laboratory analyses are also performed based on *rheology*.

Rheology is the study of how materials that have both solid and fluid characteristics flow and deform when subjected to a force. These materials are routinely measured using a rheometer. Understanding the rheological properties of mayonnaise is extremely important, as it allows mayonnaise producers to link consumers' perception of quality to measurable properties. We can illustrate this by examining some measurement methods, without getting into too much detail or formulas.

Texture

One way that consumers perceive texture is the way the food is broken down in the mouth before it is swallowed. Texture is measured by using a texture analyser, where a compression technique similar to the compression performed by the mouth is applied to the mayonnaise. Texture measurements are not as standardized as viscosity measurements, but are easier and faster to perform.

A probe penetrates the mayonnaise surface, travels to a given depth and returns to its initial position. A typical penetration probe and a typical obtained force-time history curve are shown in figure 3. The average force obtained during a defined timespan is often used as a measure of texture.

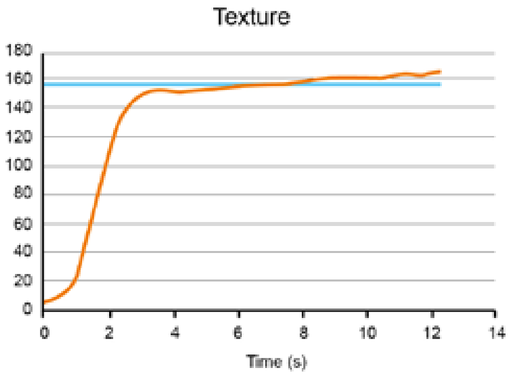

Figure 3
Left: Grid type penetration probe often used for texture measurements.
Right: Obtained force – time history curve

Yield stress

If you place a sample of mayonnaise on a plate, its shape will not change for several minutes if not disturbed by any force. The mayonnaise behaves more like a solid than a fluid. If you then insert a spoon into the mayonnaise and start to stir, the mayonnaise resembles a thick, viscous liquid. *Yield stress* is the minimum force that must be applied to the mayonnaise for it to start behaving as a liquid instead of a solid, and then start to flow. This solid-like behaviour is created by the network of closely packed droplets. Yield stress can be measured using a rotational rheometer with a vane rotor as shown in figure 4 (left). At first, a very low constant force is applied to the vane immersed in the sample and the resulting viscosity is measured. The force is increased in steps and at a critical yield stress, the applied force overcomes the inherent resistance within the sample and the material flows. Figure 4 (right) shows a typical yield stress curve. The yield stress is the maximum stress in the stress-time profile.

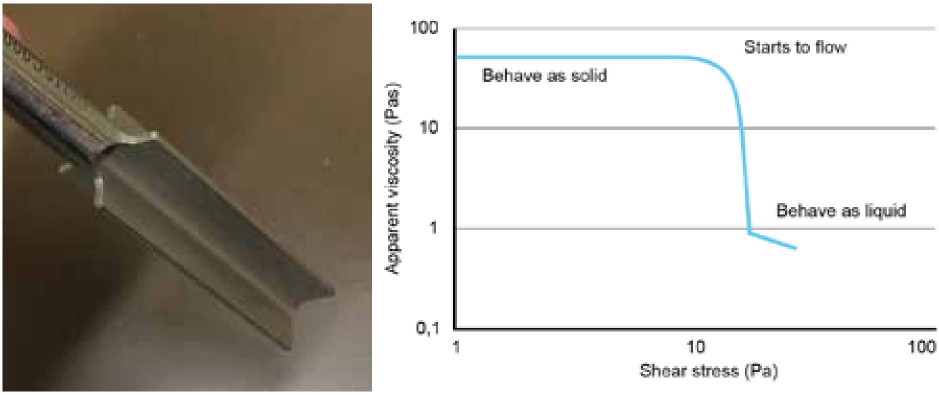

Figure 4
Left: Rheometer vane for measuring yield stress.
Right: Viscosity-stress profile.

Apparent viscosity

The apparent viscosity correlates to the product behaviour during pumping, mixing, chewing and pouring. It also describes some of the perceived "mouth feel" during chewing and swallowing. This parameter is measured using rheometers, where the viscosity is measured for a given shear rate.

Droplet size

The droplet size distribution of the dispersed oil droplets in mayonnaise is of no interest to consumers, but for mayonnaise producers it is extremely important. This is because the size of the dispersed oil droplets influences taste, texture, viscosity, appearance and emulsion stability. Smaller droplets have larger interfacial and higher internal pressure than larger droplets, resulting in higher viscosity, yield stress and texture. Smaller oil droplets release flavours differently than larger oil droplets, reducing the intensity and delaying the flavour experience as the product is tasted. Smaller oil droplets refract light differently than larger droplets, producing a whiter mayonnaise.

Droplet size measurements are therefore often part of quality control, or might even be specified in performance guarantees offered by some equipment manufacturers. A convenient method is to use laser diffraction to evaluate the droplet size distribution, but microscopy is sometimes used for that purpose as well. A typical droplet size distribution from a mayonnaise sample is shown in figure 5.

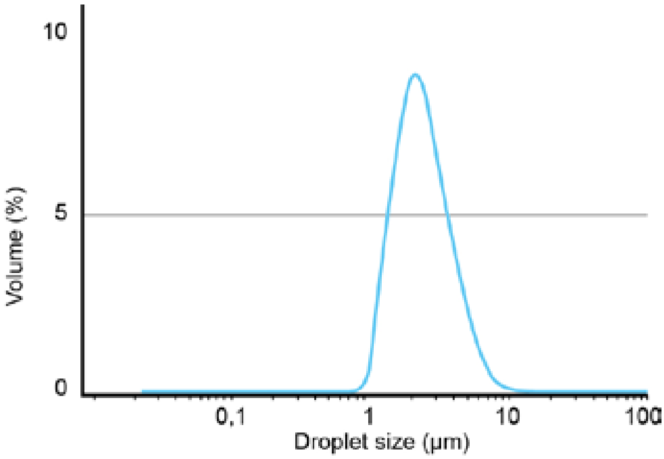

Figure 5: Typical droplet size distribution for a mayonnaise sample.
Average droplet size is approximately 2,5 microns

PROCESSING

Emulsification

A key element in mayonnaise processing is emulsification, which includes breaking up the oil droplets. An oil droplet is broken up when the fragmenting stresses acting on the droplet exceed the stabilizing stresses opposing droplet deformation, and do that for a period of time surpassing a critical minimum. Without going into details of the underlying physics and mathematics, the parameters that contribute by resisting or promoting drop break-up are given in table 2:

FACTORS THAT **RESIST** DROPLET BREAK-UP		FACTORS THAT **PROMOTE** DROPLET BREAK-UP	
Primary factor	Influenced by	Primary factor	Influenced by
γ Surface tension	Egg yolk type Egg yolk amount Temperature Oil type	ε Local energy dissipation rate	Machine type Impeller tip speed Rotor-stator gap size Stator opening size Homogenization pressure
μ_D Oil viscosity	Temperature Oil type	μ_C Viscosity of emulsion phase	Egg yolk type Egg yolk amount

Table 2: Parameters that contribute to resisting or promoting drop break-up.

Only the local energy dissipation rate ε is a non-material parameter. Its values are determined by the machine type and how it supplies energy to the product flow. Being able to calculate the local energy dissipation rate will enable an accurate prediction of the droplet size distribution. This is, however, far from trivial and require highly advanced simulation methods typically involving use of computational fluid dynamics (CFD). Therefore, other equipment-related parameters that correlate somewhat with local maximum values of ε are often used instead to predict droplet size. Commonly used parameters include impeller tip speed and the shear rate in rotor-stator gaps.

Mayonnaise production methods

In industrial mayonnaise production, it is common to use high-intensity mixers such as high-speed rotor-stator mixers or colloid mills. The energy from these devices is dissipated in a relatively small product volume, which creates high levels of local energy dissipation rates and thereby small oil droplets. These mixers can be combined with, or in, mixing tanks in various ways and the complete mixing system can be set up to operate in both batch and continuous production.

Controlling challenges and predicting quality

The mayonnaise challenge

It is evident that mayonnaise is a complex product with many different quality attributes. As these quality attributes are influenced not only by ingredient types and composition – but also greatly by equipment type, processing parameters and scale of production – the challenges for mayonnaise producers become obvious.

Focusing on two quality parameters, texture and droplet size, when changing different process and recipe parameters in a batch manufacturing process, clearly shows how final product quality is developed. Figure 6 shows how mayonnaise texture builds up in parallel to reduction of droplet size during emulsification. Note that all the oil has been introduced in a previous step and turned into a coarse emulsion.

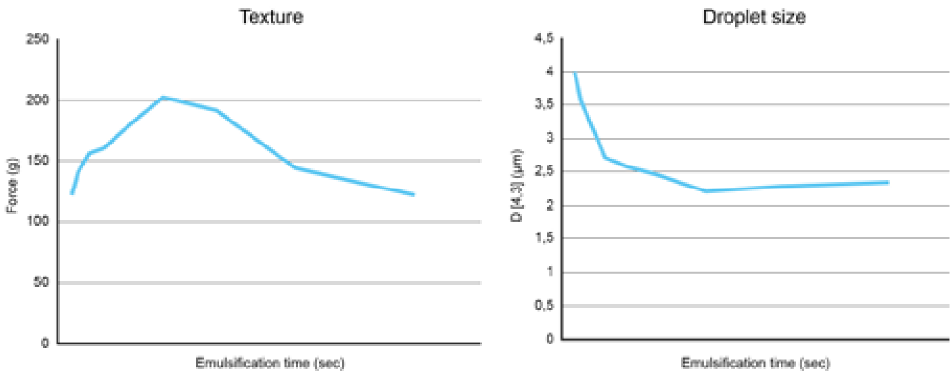

Figure 6: Texture and droplet size during emulsification.

The texture of mayonnaise increases almost linearly as the size of the oil droplets are reduced by a high-shear mixer. After a given time, the texture curve reaches a peak and then texture starts to decline slightly. With prolonged emulsification time, the mean drop size continues to reduce but egg yolk granules around droplets also start to disintegrate. Continued mixing will accelerate destabilizing of the egg yolk and initiate coalescence of oil droplets, which causes considerable texture loss.

The microstructure of a mayonnaise produced in a batch high-shear mixer is seen in figure 7. Photos below represent mayonnaise with different droplet sizes, the first from peak of texture and the second from over-sheared mayonnaise.

Peak | Over-shear

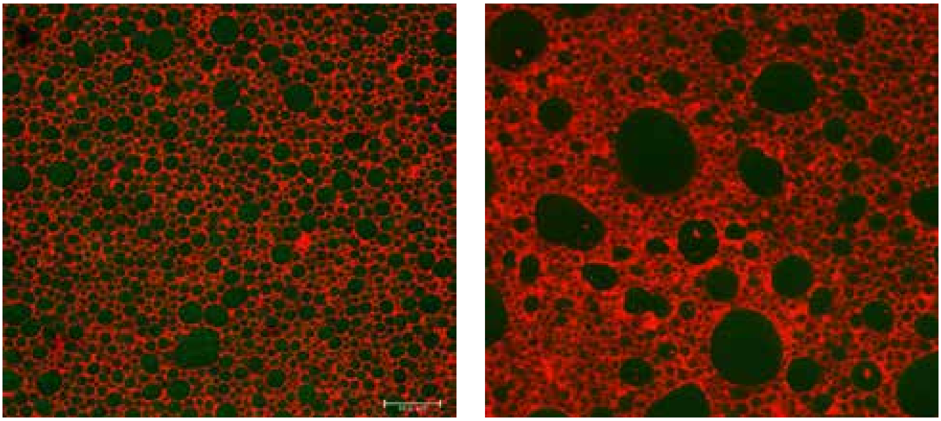

Figure 7: The microstructure of two 80% mayonnaise samples evaluated by Confocal Scanning Laser Microscopy (CSLM).

A number of parameters influence the exact shapes of curves, which mirror how final product quality can be altered.

Naturally, the ratio of dispersed oil phase has a considerable impact on mayonnaise texture and droplet size. This is very highly related to droplet distribution and how densely the oil droplets are packed in the mayonnaise microstructure. Increased oil content increases texture and decreases droplet size, as shown in figure 8.

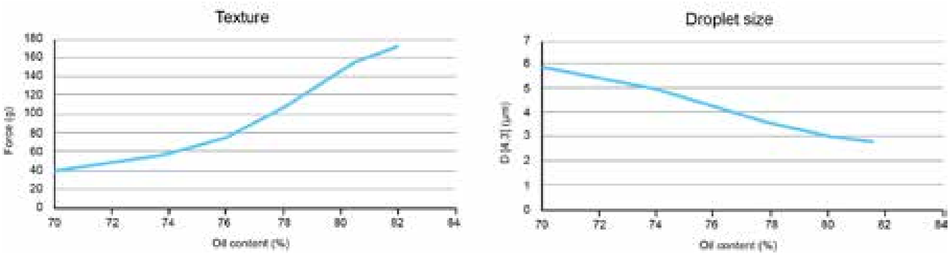

Figure 8: Influence of oil content onto texture and droplet size at fixed processing conditions

The role and function of egg yolk in mayonnaise is complicated and contributes not solely as an emulsifier of mayonnaise, but also as a texturizer. Increasing amounts of egg yolk increases texture and decreases droplet size, as in figure 9.

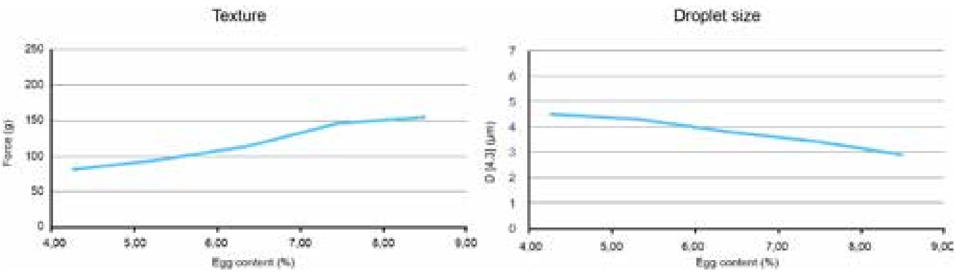

Figure 9: Influence of egg content onto texture and droplet size at fixed processing conditions

The effect on texture depends on the type of egg yolk.

When ingredient functionality can be maximized, it offers potential savings of ingredient costs. To fulfil that ambition, producers must control the factors influencing these final product quality curves.

This can be solved by knowing equipment performance, how changed parameters will influence the process, and not least, how key ingredients in each specific formulation will influence the result. By applying specific mixing procedures, combining insights from both key ingredient and process parameters, we can predict targets of preferred texture and/or droplet size.

The challenge of reduced-fat formulations

Sauce producers handling a versatile product portfolio face different challenges, depending on formulation types. Traditional mayonnaise requires optimal emulsification conditions, while reduced-fat mayonnaise products change the focus to efficient powder dispersion of thickeners and stabilizers, e.g. starches and gums.

Powders with cold swell properties, suited for a cold manufacturing batch process, react rapidly with water. If dispersion of powder granules (separation) is poor there is a risk of lump formation right from the start of the batch processing.

To maximize ingredient utilization and guarantee the shortest possible mixing time, an efficient dispersion process must be carried out from the very beginning, when powders are added to the product mixture. Mixing proceeds until a smooth and shiny mayonnaise-like product results.

By knowing the equipment performance and how process parameters and ingredients interact, it is possible to save ingredient costs. Figure 10 (right) shows how similar droplet size around 3 microns is achieved by same mixing procedure applied to various reduced fat formulations, including different powder blends and amounts.

The texture curve of reduced-fat mayonnaise, e.g. salad mayonnaises or salad dressing, looks different than texture curves characteristic of traditional mayonnaise. Variations in formulations are countless, but still exhibit the patterns shown in figure 10 (left). The texture curve shifts up with increased amounts of thickeners and stabilizers. The shape of the texture curve depends on how well each specific starch type can resist shear during mixing.

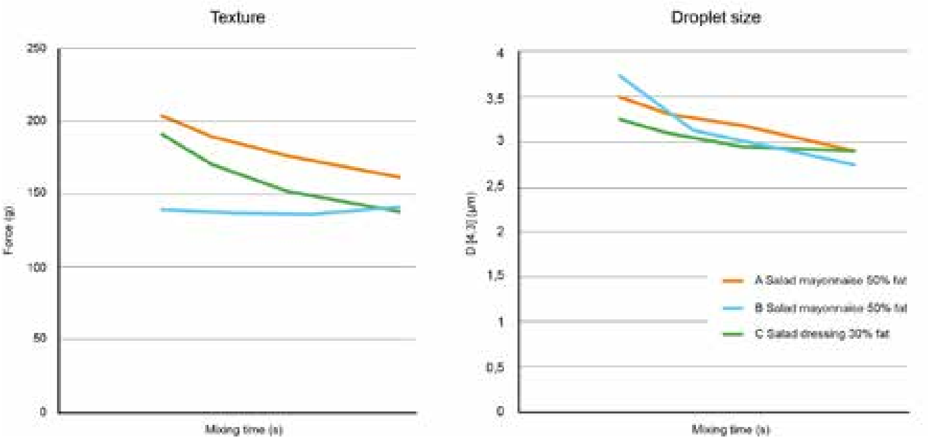

Figure 10: Left: Texture reductions as a function of mixing time
Right: Droplet size reduction as a function of emulsification time

Process control for consistent product quality

In addition there are more relevant parameters to control when producing mayonnaise such as:

- Temperature, for example higher mayonnaise textures are developed when starting the batch manufacture with cooled oil
- Good flow in the mixer vessel, allowing a high oil injection rate without compromising final product quality. The good flow in the mixer vessel also shortens overall batch mixing time and ensures trouble-free scale-up.

All of these described challenges have been captured in our prediction tool.

SIMULATIONS AND PREDICTION MODELS

The examples above illustrate some qualitative effects from selected influencing factors. Accurately predicting the quantitative effects is much harder.

But Tetra Pak has developed such a prediction tool and uses it to optimize both mayonnaise processing equipment and specific mayonnaise processes. It also allows optimizations of production costs, trouble-free production scale-up, and not least, faster development and shorter time-to-market for new emulsified products.

The tool is able to predict the both the droplet size and Stevens texture value for mayonnaise and other emulsified sauces. However, in order to assure these parameters, predicting the flow field inside the processing equipment is essential.

Prediction of flow field

Detailed information about the flow field inside the processing equipment is a necessity when trying to predict quality parameters of the produced mayonnaise. Both the large-scale flow structures occurring in a mixing vessel and the small-scale details occurring in the emulsification device are needed. Tetra Pak has developed simulation models based on computational fluid dynamics (CFD) to deliver both flow structures. In combination with experimentally determined drop break-up models, these models allow accurate prediction of texture, droplet size and many other variables important to optimizing mayonnaise production.

Figure 11 shows the mayonnaise flow field in a batch mixing vessel with a double counter-rotating helix agitator securing proper tank circulation. The flow is ejected from the rotor-stator and then recirculated back again using agitators: scrape, paddle and helix. Figure 12 shows the energy dissipation rates ε, responsible for the oil droplet break-up in the bottom mounted rotor-stator mixer. The orange dots correspond to the position of droplet breakup in the jet emanating from a stator slot.

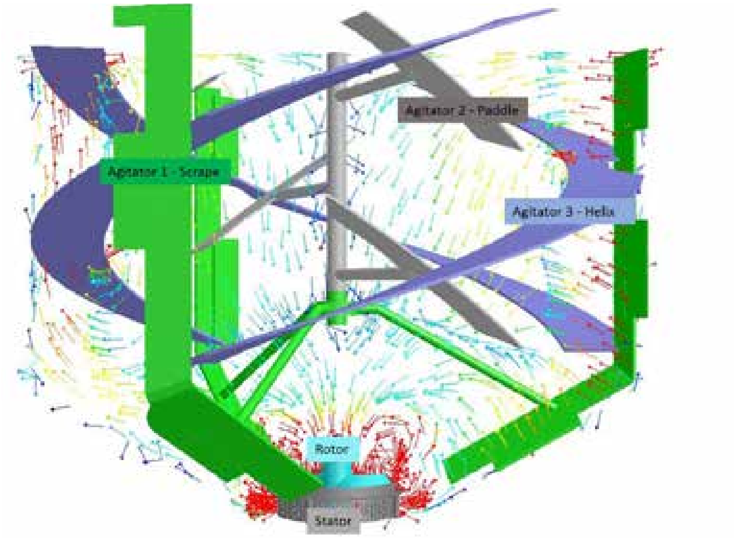

Figure 11: The mayonnaise flow field inside a Tetra Pak® High Shear Mixer. The high-shear rotor is in the bottom, emulsifying the droplets while the agitators (scrape, paddle and helix) transport the mayonnaise globally in the tank.

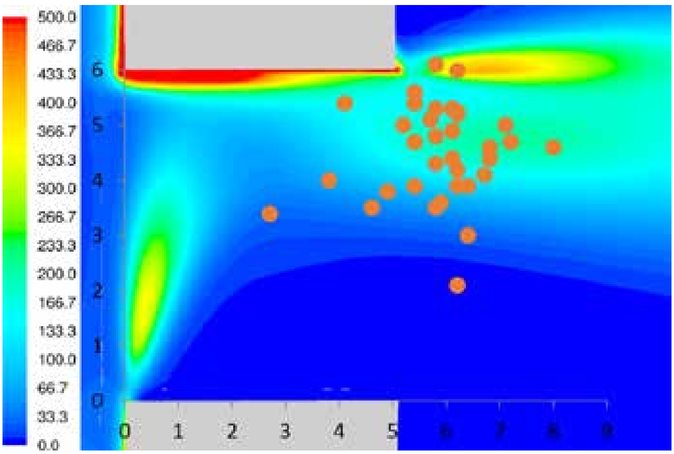

Figure 12: Showing energy dissipation rate in the stator hole (opening 6mm) together with position of droplet break up (orange dots). The droplet break up was measured; notice that it mainly occurs outside the stator hole.

For further information about CFD and simulation possibilities please see http://www.tetrapak.com/about/cases-articles/optimize-mixing-process-food-quality-cfd

COLD EMULSION MIXERS

Several vendors offer mixer solutions for industrial production of mayonnaise and dressings, but most of these solutions lack the flexibility to operate in both batch and continuous setups, and the possibility of producing both reduced and full-fat products, including variants with added particles. In addition, many mixers are restricted to intake of liquid ingredients only and do not allow direct intake of powders (e.g. stabilizers and sugar) or larger particles (e.g. peas or carrot bits). The following section describes preferred features of industrial mixer solutions designed for cost-efficient and flexible production of mayonnaise and dressings.

Ingredients inlets
Ingredients such as oil, egg yolk, spiced water phase and powders should be added to the mixing vessel, and not the mixing head. Adding ingredients directly to the mixing vessel will reduce variations in the ingredient dosing rates, while adding to the mixing head will create oscillating product composition.

For emulsified products with high fat content the most time-consuming step is often oil intake. In traditional mayonnaise processers, the intake rate is severely limited because the oil is dosed directly into the mixer head and immediately emulsified to final drop size. Preferably oil should be dosed into the vessel in a "coarse emulsification step" as this allows much higher intake rates.

The vessel should also include a dosing opening for adding ingredients, such as herbs and vegetables, via bin-lifts.

Mixer unit for emulsification
A batch solution should include a mixer unit with the possibility of varying the shear rate independently of the generated flow. High shear is needed for rapid emulsification, while lower shear is needed to form a coarse emulsion during oil intake. Initial formation of a coarse emulsion allows much higher oil intake rates than systems where the oil is added directly into the mixing head. Low shear is also needed for efficient dispersion and dissolving many types of thickeners and stabilizers. The mixer unit should be located inside the vessel, as this provides much higher flow rates and thus shorter process times, compared to solutions where the generated flow is directed through an external recirculating pipe, and then leading the out-stream back to the top of the vessel.

For continuous production solutions, a high-shear mixer-pump should be located in the outlet stream of a mixing vessel designed for continuous formation of a coarse emulsion.

Tank agitation

The mixer tank should be equipped with an agitator system that secures efficient product turnover without local recirculation zones. The agitator must take the product flowing out of the emulsification unit and gently lead it around in the tank. A double-shaft counter-rotating device with a helix ribbon blade on the outside is preferred as this provides optimal control of the tank flow. It also enables gentle in-blending of shear-sensitive particles.

Vacuum system

The mixer tank should be equipped with a vacuum system that allows full control of the vacuum level inside the vessel. Mixing under vacuum prevents incorporation of air and thus allows intake of powders and liquids.

CONCLUSIONS AND IMPLICATIONS FOR THE FOOD PROCESSING INDUSTRY

Given our successful experiments and technology development around mixing and emulsified sauces, we can now remove the guesswork from your mayonnaise production, by delivering a combination of:

- Application knowledge on mayonnaise, dressings and other emulsified sauces
- Mixing procedures that take into account your ingredient characteristics
- High-shear mixer design that enables flexible and efficient production

What does this combination mean for mayonnaise producers?

This combination of expertise, tools and equipment provides you with values in three major areas: (1) consistent product quality in every scale, (2) cost savings and (3) faster product development with shorter time to market.

Cost savings

Our improved mixer design for viscous products consists of a double-agitator system and a dynamic stator. This design allows much higher flow rates for ingredients and thus significantly shorter batch times. Furthermore, the combination of know-how, mixing procedures and new mixer design enable potential cost savings on ingredients such as thickeners and stabilizers.

Predictable product quality

Our prediction tools and application knowhow, based on the new mixer design, enable customized solutions. Combining your specific recipes into our mixing procedures will give predictable and consistent product quality. Furthermore, by controlling the flow in the tank we can offer a trouble-free production scale-up.

Faster development of mayonnaise, dressings and other emulsified sauces

Combining our prediction tool with your own quality targets offers a shorter time to market for new emulsified sauce products. By knowing the effects of oil amount, egg amount, egg type and thickeners, and their interactions during the mixing process, you can meet your targets at every scale.

TETRA PAK – YOUR PARTNER IN PROCESSING

Tetra Pak is an innovative partner and is able to offer unique competence in the processing of mayonnaise and many other emulsified products.

We have the know-how, advanced methods, CFD simulations and tools to predict product results, in any scale based on multiple variables. We also offer highly sophisticated high-shear mixers that can be tuned to a variety of sauce processes, ingredients and production modes.

For additional information about mixing see:
http://processinginsights.tetrapak.com/category/mixing-blending
http://www.tetrapak.com/processing/mixing
or contact your Tetra Pak representative at http://www.tetrapak.com/contact

Mayonnaise research performed by Tetra Pak:

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- Håkansson, A., Mortensen, H.-H., Andersson, R., Innings, F. (2017). Experimental investigations of turbulent fragmenting stresses in a Rotor-Stator Mixer. Part 2. Probability distributions of instantaneous stresses. Accepted by Chemical Engineering Science.
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