Recovering failed hollandaise

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Experimental test of a culinary precision

Recovering failed hollandaise

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Abstract

A "hollandaise" sauce is a dispersion of microscopic solids (formed through the heating of compounds from egg yolks) and of oil droplets in an aqueous solution. When the sauce is heated too much, water evaporates, and phase separation can occur, perhaps because the quantity of dispersing water becomes insufficient. Adding water to a failed sauce ultimately brings the system back to a state of dispersion.

Keywords

sauce, hollandaise, suspension, volume fraction

Introduction

Molecular gastronomy seminars have taken place monthly in Paris since 2000 (This vo Kientza, 2021a). They include experimental tests of "culinary precisions", *i.e.*, tips, advices, proverbs, sayings, old wive tales (This vo Kientza, 2021b). Each monthly topic is decided by the participants, from one seminar to the next. In October 2012, it was decided to explore the sauce called "hollandaise", and more specifically how to make up again such a sauce when it "fails", *i.e.*, when a phase separation occurs.

Firstly an explanation of what a "sauce hollandaise" has to be given. Some chefs follow Gilbert (1898a):

- first wine vinegar ("one glass") is "reduced by boiling" (evaporation of liquid) of with salt and ground pepper,
- "cold" water ("some") and egg yolks (e.g. 3) are added,
- thermal treatment is performed until "thickening",
- butter (175 g, temperature not given) is added while whipping,
- lemon juice is added for seasoning.

It is sometimes written that the hollandaise is an "emulsion" (Maincent-Morel, 2015), but the thickening of the sauce before the addition of any butter and also microscopic observation (This, 2016) demonstrates that it is rather a "suspension", before becoming an emulsified suspension when butter is added (IUPAC, 2019). Indeed Carême (1847) is very clear about this question: in his recipe for a "Sauce au beurre à la hollandaise ordinaire" [Ordinary butter sauce in the Dutch way], he wrote "Il faut avoir soin de cuire les œufs avant d'y additionner le beurre par parties" [One has to cook the eggs before adding the butter parts by parts]. For such a system, the disperse systems formula (DSF) would be indeed $[D_0(O)+D_0(S)]/D_3(W)$, where $D_0(O)$, $D_0(S)$ and $D_3(W)$ represent respectively the oil (O) droplets (D_0), the coagulated solid (S) particles (D_0), the continuous (D_3) aqueous phase (W), and the "/" operator stands for random dispersion (for more explanation about DSF, see This vo Kientza, 2022).

This formula is useful because it allows comparison with various different states of the system considered. Indeed other recipes can lead to other physical systems: for example, Dubois and Bernard (1868) write that this particular sauce should be aerated ("bien mousseuse", *i.e.,* very foamy), corresponding to the formula $[D_0(G)+D_0(O)+D_0(S)]/D_3(W)$ (here $D_0(G)$ stands for the air bubbles) (Figure 3). Finally, it has to be observed that these sauces are quite different from what was named "sauce hollandaise" in the 18th century, which was formerly produced using butter, flour, garlic, clove, lemon slices, parsley, and meat stock (Marin, 1742). It is also different from other more recent recipes, for which the ingredients are water, salt, pepper, egg yolks and butter (Daguin, 1981).

Chefs know that the modern sauce, be it an emulsified suspension or an aerated emulsified suspension, can "fail", *i.e.*, that a phase separation can occur, and culinary precisions have been given to get the dispersed system renewed. In particular, it was proposed that "cold water" (the temperature is not given) can be added to the failed sauce to make it up again.

For example, Colombié (1893) wrote [personal translation]: "If the sauce was to fail, one can regenerate it again by adding a teaspoon of cold water". Gilbert (1898b) gave the same kind of culinary precision [personal translation]: "If, on the

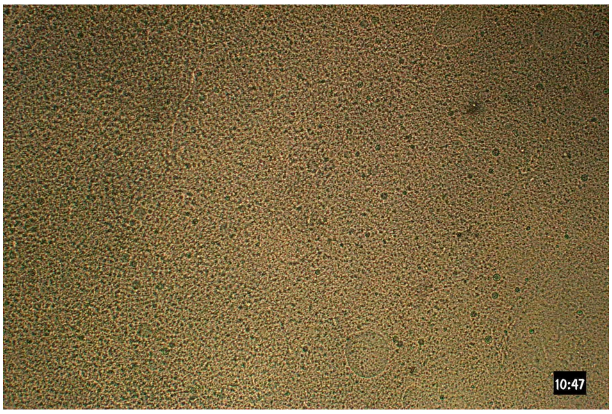

Figure 1. Egg yolk is made of granules (size ranging from 0.3 to 2 μm) dispersed in a plasma (H. This).

contrary, the sauce is heated too much and decomposes, one has to add immediately some drops of cold water and mix vigourously to make it up. If decomposition is too advanced, the sole way to make it up again is to take an egg yolk in a small pan and to add the failed sauce slowly".

The experiments

During a seminar on molecular gastronomy, the efficiency of these culinary precisions was tested experimentally. In a first experiment, two teaspoons of water (10 g) and two egg yolks (from 60 and 61 g eggs) were heated until thickening; then 100 g of non salted butter at room temperature was added while the sauce was heated and whipped manually, until the sauce which was obtained was considered as successful by the participants (including chefs). Then the sauce was heated much more, until phase separation occurred. At that point, heating was halted, and one tablespoon (15 g) of water at room temperature was added: contrary to what had been published, no change was observed, and manually whipping the sauce did not make any change. After another tablespoon of water was added, still no change was observed, but with two more tablespoons of water, the consistency of the successed sauce

was restored after some seconds of whisking with a hand whisk. These first experiments showed that indeed the quantity of added water is important, and it confirmed that words such as "some drops" are too imprecise, while "a spoon" is wrong.
We wanted to test the reversibility of the process: the same sauce missed and caught up was heated again, until phase separation occurred again; the same water addition made it well dispersed again. The process was repeated two times. Finally, we decided to heat the sauce very strongly, until it was transformed into something that looked like brown butter : phase separation was followed by boiling and browning of the content of the pan. Again, the right dispersion was obtained after the addition of 5 tablespoons of cold water and whisking. These tests were repeated publicly twice.

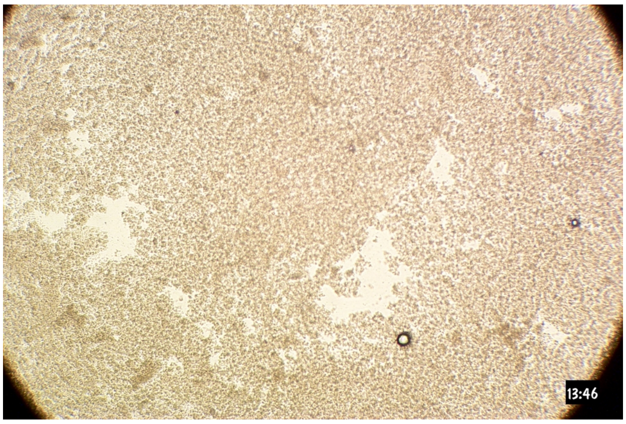

Figure 2. When an egg yolk is first cooked with an aqueous solution, in the first step of the making of hollandaise, small aggregates form (H. This).

Discussion

For the analysis done here, we don't consider the aerated version of the sauce, but only the more simple system described by the DSF formula $[D_0(O)+D_0(S)]/D_3(W)$. Egg yolks are made of granules (20 %, made of 70 % high-density lipoproteins, HDL, 16 % phosvitin and 12 % low-density lipoproteins, LDL) (Figure 1) dispersed in a plasma (the content of water is about 50 % of the mass of the yolk) (Anton and Gandemer, 1997). At the beginning of the making of the sauce, the egg yolk is diluted by the the initial aqueous solution, be it water or vinegar (maximum 96 % water (w/w) by law) (Codex Alimentarius, 1995).
Then, in the second step, solid particles form (perhaps through protein coagulation and/or association of various compounds for the egg yolk) that are dispersed in the liquid (This, 1996), which creates a suspension (Figure 2) (IUPAC, 2019).
Butter added later melts, and whipping of the sauce disperses the oil droplets in the water phase of the initial suspension. In order to get a successful sauce, one has to disperse the solid phases (egg aggregates) and melted butter in the aqueous medium.
Some chefs published physically unsound descriptions of the reasons why a colloidal dispersion is achieved. For example, Bocuse (1976) writes about another sauce (mayonnaise), which is an emulsion [personal translation]: "As in hollandaise, the oil-fluid and fatty substance- adheres to egg yolks that are binding and supporting materials, but only with this association is performed through a vigourous brewing that increases the temperature and the volume through foaming". This is nonsense, as when egg yolks are mixed with water (from vinegar), an emulsified suspension is obtained, with granules, proteins and phospholipids (among other compounds) in water. When oil is added while whisking, it is dispersed as droplets in the water phase, probably with proteins and phospholipids at the water-oil interface, and the increase in viscosity is due to the increased volume fraction of the dispersed medium (Farr and Groot, 2009; Rosti and Takagi, 2021). And as was shown in This vo Kientza (2021c), the system is not aerated (for mayonnaise).
Also Guérard wrote (1976) "It should be noted that the primary mechanical action of the hand whisk (empirical method) or its modern

transposition, the mixer, disarticulates the molecules of the egg yolks and fat in hot and cold emulsified sauces to homogenise them" [personal translation]; however if it is true that proteins can be denatured through shearing (Graham and Philips, 1979), the triglycerides do not denature, and the sauces are only visually homogenous (microscopically they are dispersed systems).

All this being said, the question here is to understand (1) why the phase separation occurs when the hollandaise is heated too much, and (2) why adding water even under very limited stirring results in a correct dispersion. About the first question, one can observe that an emulsion needs a minimum of 5 % (v/v) of dispersing medium (which is water in our present system) (Mabille *et al.*, 2000): during heating, the evaporation of water can reduce the water content under this minimum value, as can be shown by weight measurement of the sauce: whereas the initial volume fraction of water was calculated to be 41 % in a successful sauce (USDA, 2019a; 2019b), it was reduced to 4 % after phase separation in one reproduction of the experiment (3 egg yolks, 175 g butter, precision of the scale 1 g).

However this simple explanation is not enough, because it does not explain the mechanisms of the spontaneous re-formation of the dispersion after water addition. And as proteins can be pyrolized in the last step of the initial experiment (making of a system that looked like brown butter), one has to assume that the metastabilization of the dispersion is performed either through a Ramsden mechanism (1903) or because of phosophipids.

Here we report only an experimental test of a culinary precision, but scientific investigations are now needed to understand the established phenomenon at the molecular level. The following questions have now to be considered:

1. What is the composition of the suspended solids after heating the diluted egg yolk?
2. What is the fate of granules during this first step of the processing of the sauce?
3. Is the system after phase separation and addition of water the same as before phase separation?
4. If indeed proteins coagulate (through disulfide bridges) during the making of the sauce, how are the oil droplets stabilized: by non coagulated proteins, or through a Ramsden mechanism, or by phosophipids?
5. Assuming that all proteins are coagulated after the browing of the sauce (last experiments), how is the sauce stabilized (Ramsden mechanism or phospholipids)?

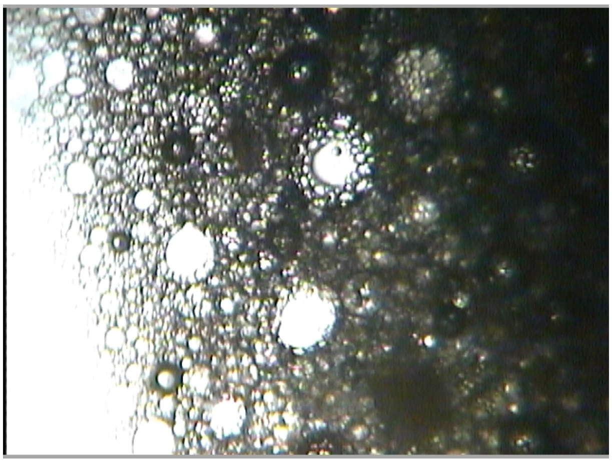

Figure 3. Microscopic appearance of a well prepared hollandaise: in this recipe, the initial mixture of egg yolk and water was whipped, creating the air bubbles (white shapes, size lower than 0.1 mm) that are finally surrounded by droplets of melted butter ; the two kinds of structures are dispersed in the aqueous continuous solution.

We conclude by observing that the renewing of the sauce needs remarkably very little energy, as if the high temperature was enough to compensate for surface tension. Calculations could be made to explain the phenomenon.

References

Anton M, Gandemer G. 1997. Composition, solubility and emulsifying properties of granules and plasma of egg yolk, *Journal of Food Science*, 62(3), 484–487. https://

doi.org/10.1111/j.1365-2621.1997.tb04411.x (last access 2023-07-10)

Bocuse P. 1976. *La cuisine du marché*, Flammarion, Paris, 104.
Carême MA. 1847. *L'Art de la cuisine française au XIXe siècle*, De Kérangué et Pollès (1981), I, 126.

Colombié A. 1893. *Traité pratique de cuisine bourgeoise*, Chez l'auteur, Paris, 152.

Daguin A. 1981. *Le nouveau cuisinier gascon*, Stock, Paris, 83.

Dubois U, Bernard E. 1868. *La cuisine classique*, Dentu, Paris.

Farr RS, Groot RD. 2009. *Close packing density of polydisperse hard spheres*, http://arxiv.org/abs/0912.0852v1, last access 2023-07-10.

Gilbert Ph. 1898a. *La cuisine de tous les mois*, Ollendorff, Paris, 172.

Gilbert Ph. 1898b. *La cuisine de tous les mois*, Ollendorff, Paris, 299.

Graham DE, Philips MC. 1979. Proteins at liquid interfaces, *Journal of Colloid and Interface Science*, 76 (1), 240-250.

Guérard M. 1976. *La grande cuisine minceur*, Robert Laffont, Paris, 84.

IUPAC. 2019. *Compendium of Chemical Terminology,* 2nd ed. (the "Gold Book", Chalk SJ ed.), https://doi.org/10.1351/goldbook last access 2023-07-10.

Larousse. 1999. *Larousse gastronomique*, Larousse, Paris.

Mabille C, Schmitt V, Gorria Ph, Leal Calderon F, Faye V, Deminière B, Bibette J. 2000. Rheological and Shearing Conditions for the Preparation of Monodisperse Emulsions, *Langmuir*, 16, 422-429.

Maincent-Morel M. 2015. *Cuisine de référence*, BPI, Paris.

Marin F. 1742. *La suite des dons de Comus,* Pissot, Didot, Brunet, Paris.

Pomiane E. 1957. *Code de la bonne chère*, Albin Michel, Paris, 107.

Ramsden W.1903. Separation of Solids in the Surface-layers of Solutions and 'Suspensions', Proceedings of the Royal Society of London, 72 (477–486), 156–164.

Rosti ME, Takagi S. 2021. Shear-thinning and shear-thickening emulsions in shear flows, *Phys. Fluids,* 33, 083319, https://doi.org/10.1063/5.0063180, last access 2023-07-10.

This H. 1996. Can a cooked egg white be uncooked ?, *The Chemical Intelligencer*, 10, 51.

This vo Kientza H. 2021a. The monthly INRAE-AgroParisTech Seminars on molecular gastronomy. In Burke R, Kelly A, Lavelle C, This vo Kientza H (eds) *Handbook of Molecular Gastronomy*, CRC Press, Boca Raton FL, 721-724.

This vo Kientza H. 2021b. Culinary precisions and robustness of recipes. In Burke R, Kelly A, Lavelle C, This vo Kientza H (eds) *Handbook of Molecular Gastronomy*, CRC Press, Boca Raton FL, 163-170.

This vo Kientza H. 2021c. Sauces, Handbook of Molecular Gastronomy. In Burke R, Kelly A, Lavelle C, This vo Kientza H (eds) *Handbook of Molecular Gastronomy*, CRC Press, Boca Raton FL, 495-498.

This vo Kientza H. 2022. Using the disperse system formalism DSF to determine the first two classes of complex suspensions, *International Journal of Molecular and Physical Gastronomy*, 2022, 2, 1-9.

https://icmpg.hub.inrae.fr/international-activities-of-the-international-centre-of-molecular-gastronomy/mol-phys-gast-journal/2-sc-foundations/research-notes/research-notes, last access 2023-07-21.

USDA. 2019a. Egg, whole, raw, fresch, *Food Central,* https://fdc.nal.usda.gov/fdc-app.html#/food-details/171287/nutrients, last access 2023-07-10.

USDA. 2019b. Butter, salted, *Food Central*, https://fdc.nal.usda.gov/fdc-app.html#/food-details/173410/nutrients, last access 2023-07-10.

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