# Rheology of Swiss Cheese Fondue

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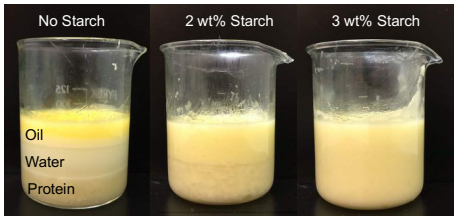
## Introduction

Cheese fondue is a traditional Swiss dish prepared by melting cheese while adding wine, starch, and seasoning. Fondue is a multi-phase system with fat droplets and charged casein dispersed in continuous water. These complex colloidal interactions determine the rheology of fondue[1].
Fondue rheology is of importance for mouthfeel, flavor perception, and letting the cheese cling to the bread for consumption. This study aims at providing a scientific framework for the influence of fondue ingredients and their interactions on the rheology of cheese fondue.

## Methods

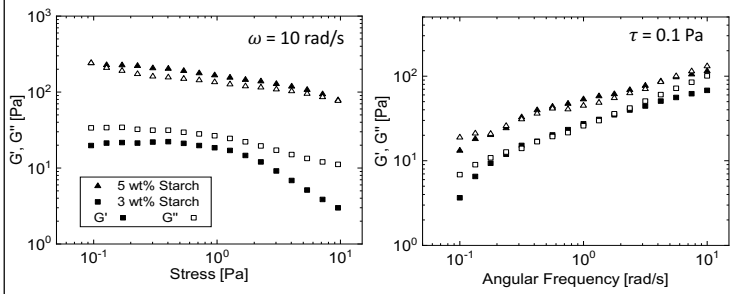
Model moitié-moitié fondues (Gruyère & Vacherin 1:1) were prepared with 40 wt% distilled water.
Fondue stability was evaluated and rheology assessed in steady shear (MCR 302, BMS2) and oscillatory mode (DSR, C32-29-44) at 70°C.
The effect of starch concentration, ethanol, and pH was investigated. (model fondue pH = 5.5, pI casein = 4.7)

## Starch prevents Fondue Phase Separation




Without starch addition, fondue phase separates into a rubbery protein, an aqueous, and a creamed oil phase.
A critical starch concentration of 3 wt% (rel. to water content) is required to obtain a stable fondue

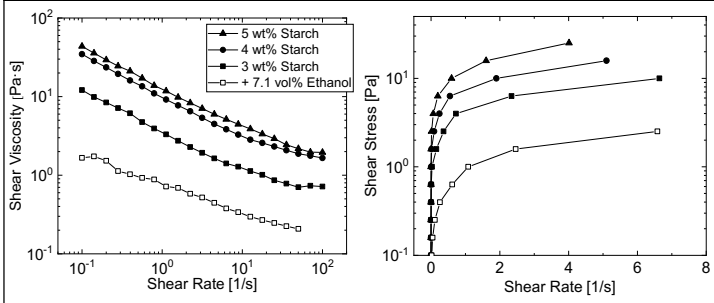
## Fondue Viscoelasticity




- Fondue is a viscoelastic fluid around the gel point (G'≈ G'')
- Starch increases elastic properties and stress resistance

Viscoelasticity may be crucial for oral texture perception: too gummy (G' >> G'') vs. too liquid (G' << G'')

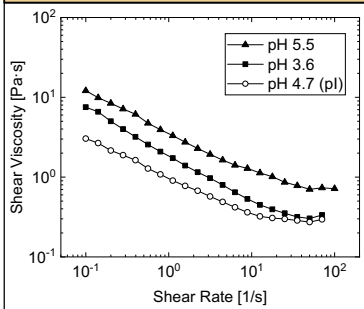
## Starch & Ethanol



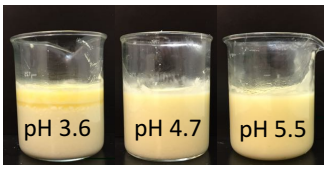

- Fondue is a shear-thinning Bingham fluid
- Starch increases viscosity and apparent yield stress
- Ethanol decreases casein micelle size[2] and is a good solvent for many colloidal ingredients → decrease in viscosity

A yield stress is desired to let the fondue cling to the bread. Shear thinning is associated with pleasant mouthfeel and enhanced flavor release[3]

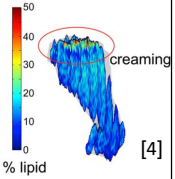
## Influence of pH




- Viscosity depends on pH due to charged casein (pI=4.7)
- Casein micelle size is lowest at pI → lowest viscosity
- This is only partially reversible at pH < pI, potentially due to ceased interactions with $Ca^{2+}$




Fondue is unstable below pH = 4.7
This could delay satiation due to fat layering, as often observed for acid unstable emulsions




[4]

## Conclusions

- Fondue is a viscoelastic, shear-thinning yield stress fluid
- Fondue rheology and stability has implications on oral structure perception, flavor release, and fat digestion
- Fondue rheology is governed by the colloidal interactions of charged casein, starch granules, and fat globules
- Controlling these interactions allows to achieve desired fondue structure

[1] Fischer & Windhab 2011, *Curr. Opin. Colloid Interface Sci.*, *16* (1), 36–40.
[2] Ye & Harte 2013. *J. Dairy Sci.*, *96*(2), 799–805.
[3] Stokes et al. 2013. *Curr. Opin. Colloid Interface Sci.* , *18*(4), 349–359.
[4] Scheuble et al. 2018. *ACS Appl. Mater. and Interfaces*, *10*(21), 17571–17581.
For more fun with fondue: „Rheology of Swiss Cheese Fondue" *ACS Omega* 2019, *4* (1), 1103–1109.

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