Bubbles, Foam and Gushing
...the ‘shameful disease’

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Champagne!
A few words on the Champagne area
after Comité Champagne
HARVEST (2013)

349 000 000
349 millions de bouteilles
Rendement = 12 008 kg/ha

4 630 vigneron expéditeurs
43 coopératives qui commercialisent
360 maisons

Turnover (2013):
- 4.4B€
- 2.3B€ exportation

after Comité Champagne
How can we explain the Champagne success?

Why bubbles and foam must be important for us?
**Little academic exercise:**

- same engine,
- same security level,
- same options...

*Appearance is of first importance!*

What car do you prefer?...
Why bubbles & foam are important for the enologist...

« ...l'information traitée la plus rapidement par le cerveau et qui parvient en premier à la conscience est l'information visuelle. ... Lorsque les autres représentations sensorielles, fournies par la langue, le toucher ou l'ouïe parviennent à la conscience, elles confirment ou contredisent les attentes induites par l'information visuelle. » after Mc Léod.

_Arômes, Additifs & Ingrédients, 29, sept 2000, p13-14_
Bubbles & foam … high marketing values

Price dive in bubbly war

FIZZICAL THERAPY

With the battle of the discounts on sparkling wines continuing in stores, only “aspirational” Champagne and value-for-money cava are holding on to their market share. As Giles Fallowfield reports, in the middle ground it is mainly the brands which are likely to survive.
How to protect bubbles and foam quality?

Temperature of the wine?

Glass shape?

Glass quality?
- chemistry
- surface properties

Glass aging?

Washing, rinsing, storage, ...?

The way to poor the wine?
### Parameters vs. Impacts

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass shape</td>
<td>+/-</td>
</tr>
<tr>
<td>Glass chemistry</td>
<td>0</td>
</tr>
<tr>
<td>Liquid pouring</td>
<td>&gt; ou &lt;</td>
</tr>
<tr>
<td>Temperature (wine/glass)</td>
<td>≤ 0</td>
</tr>
<tr>
<td>Glass story</td>
<td></td>
</tr>
<tr>
<td>whashing</td>
<td></td>
</tr>
<tr>
<td>(liquid of…) Rinsing</td>
<td></td>
</tr>
<tr>
<td>drying</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td></td>
</tr>
</tbody>
</table>

‘Bubbles & foam … fragile objects.’ P-G de Gennes
Bubbles & foam … not so simple to understand…

By principle: to have foam you need bubbles…

A lot of bubbles … and no foam…

A lot of foam… and no bubbles…
# Bubbles & foam … not so simple to understand…

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Beer (g/L)</th>
<th>Sparkling wine (g/L)</th>
<th>Impact on foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol (% Vol)</td>
<td><em>5</em></td>
<td><em>13</em></td>
<td>5 % is a good content for foam stabilisation</td>
</tr>
<tr>
<td>CO₂ amount (g/L)</td>
<td><em>3</em></td>
<td><em>10</em></td>
<td>The quantity of gas governs the foam formation</td>
</tr>
<tr>
<td>Protein conc. (eq. mg/L BSA)</td>
<td><em>0.5</em></td>
<td><em>0.05</em></td>
<td>The quantity of protein governs the foam stability</td>
</tr>
<tr>
<td>Polysac. (g/L)</td>
<td>&gt; <em>5</em></td>
<td><em>0.1</em></td>
<td>The quantity of polysac. helps to stabilise the foam</td>
</tr>
</tbody>
</table>

*Figures are indicating values*
Why the sparkling wine collar is so unstable?

3 mechanisms explain the rapid bubble collapse at the wine surface:

1 - disproportionation (Ostwald ripening)

\[ P_1 > P_2 >> P_3 \]
Why the sparkling wine collar is so unstable?

3 mechanisms explain the rapid bubble collapse at the wine surface:

2 - drainage

CO₂ → drainage → air

CO₂

IOC
Why the sparkling wine collar is so unstable?

3 mechanisms explain the rapid bubble collapse at the wine surface:

3. collapse (film rupture)


Bubbles & foam: we begin to understand the foam stability of sparkling wines…

… more or less …

But things are not all rosy with bubbles …
**Definition:**

Gushing can be considered as a disequilibrium between foam formation and foam collapse.

2 extreme cases:

1/ Foam formation is relatively low but if this foam is very stable, this last one will be pushed out of the bottle due to the bubble formation (in this present case, gushing intensity is relatively low).

2/ At the opposite, foam stability is low, but bubbles formation is intense: in this case, the liquid can be directly ejected out of the bottle. (gushing intensity is high)

*Photo: G. Liger-Belair*
Case 1/ : high foam stability

after G. Liger-Belair et al., 2013
Minimum radius for an existing bubble:

\[ \Delta P \sim 5 \text{atm.} \]

\[ \gamma \sim 50 \text{mN/m} \]

\[ R_c \sim 0.1 \text{ à } 0.2 \mu \text{m} \]

In a sparkling wine bottle more than thousand particles able to create bubble exist... nevertheless, gushing is a problem concerning 10 ... 20 nucleation sites.
Bubbles are detached when gravity forces > capillary forces

\[ \text{buoyancy (Archimedes)} \sim \frac{4}{3} \pi R_b^3 \delta \rho g \]

\[ R_b^3 > R_c \gamma / 2 \delta \rho g \]

\[ \text{capillary forces} \sim 2 \pi R_c \gamma \]
Bubble size able to grow up after bottle opening is highly dependent of the wine temperature.

Increase of the probability to create bubbles
Bubble growth kinetics are governed by the CO\textsubscript{2} content

\[ \frac{dR_b}{dt} = k \Delta P \]

with \( \Delta P = P_{i\text{CO}_2 l} - P_{i\text{CO}_2 g} \)

- During disgorging step, CO\textsubscript{2} is released from 0,5 to 1,5g/L de (initially close to 11,5g/L if ‘tirage’ at 24g/L). This explains why the risk of gushing is less at the ‘consumer step’ compare disgorging step.
- One solution adopted by some clients is to add ~ 20g/L of sugar for tirage
Particles (mineral or organic) are always described to generate the gushing phenomena ... However ...
Hydrophobins … (?)

- Hydrophobic proteins,
- ~ 300 AA residues,
- agglomeration => superstructure,
- very active to stabilize foam and create gushing (10 ppb scale!),
- origin: asco- (Fusarium, Trichoderma / beer) and basidiomycetes,

- in some cases, has been demonstrated to be at the gushing genesis of beer. (after S. Deckers et al., JASBC, 2011, T. Sarlin, Ph D. thesis, 2012).

- particles (100nm) attached to the bubbles can be detected on gushing beers when contaminated with HB,

Can we suspect hydrophobins in sparkling wine ?.... (ascomycetes are described in wine)
Surface active material (from wine) is deposited on the lig/gas interface and can stabilize the bubbles.
<table>
<thead>
<tr>
<th>Where</th>
<th>Fq</th>
<th>Reason</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>rare</td>
<td>Essentially particles (do not forget the cork) + mishandling: shocks, temperature to high,…</td>
<td>0 (except: sugar content at bottling stage is a good way)</td>
</tr>
</tbody>
</table>

**In the cellars**

<table>
<thead>
<tr>
<th>Disgorging step</th>
<th>high</th>
<th>Particles: tartaric stability, riddling problem, MLF in bottle (in fact biological contaminations in correlation with turbidity impact) Contaminants adsorbed on glass wall (?), Too high temperature before disgorging,…</th>
<th>Diminish the temperature and line speed cronwcap-top-hammer Upstream process to manage: tartaric stabil., filtration, Riddling program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquor addition (dosage)</td>
<td>medium</td>
<td>Particles from the liquor, (filtration but take care to stable bubbles…), temperature, high sanitary levels required for tubing, nozzle, …</td>
<td>Efforts on microbiological / biological decontamination</td>
</tr>
<tr>
<td>Remploi</td>
<td>rare</td>
<td>Particles and temperature management</td>
<td>Filtration and cleaning</td>
</tr>
</tbody>
</table>
CO$_2$ bubbles inside yeast during AF.

after Swart et al., 2012.
Gushing consequences:

On production sites:
- Decrease of the productivity ............. Impossibility to disgorge!,
  ⇒ First solution: decrease the temperature (glycol pumps, mobile fridge, ...),

Quality impact (depending on the gushing moment):
- Sugar heterogeneity (if gushing during/after dosage),
- CO₂ decrease (up to 10% less),
- O₂ heterogeneity (see scheme hereafter / foam in the bottle neck is the main factor impacting the O₂ intake).

\[ [O_2] : 1-2.5 \text{ ppm} \rightarrow \leq 0.5 \text{ ppm} \rightarrow \text{de 1 à + de 3 ppm} \]
after G. Liger-Belair et al., 2011
Figure 5: Fibre creuse enfermant une poche de gaz à l'origine d'un train de bulles dans une flûte à champagne (image caméra).
Semi-hypothetical gushing genesis with the help of crystals...
No clear demonstration at the moment ...

(surface hydrophobicity of CaT
(experiments conducted after M.C. Fuerstenau method, 1994)
In this example, the wine is tartarically unstable because of Ca salt addition. CMC shows an activity on the inhibition on gushing (positive action on crystallisation on CaT / the wine is stable in regards to KTH).

Using CaT as model, we have never demonstrated a relationship between crystal quantities and gushing. The correlation should be more: surface area / gushing.
Finally ...

1/ Carbone dioxide level:
- sugar content, temperatures, shocks, ... **Solutions which permit to decrease the CO₂ amount is a good way of management.** (CO₂ is the driving force of the gushing).

2/ Particles :
- tartaric stabilaization (KTH and CaT), filtration before tirage (présence de fibres de cellulose) ou dosage liquor, sanitary management (biological material becomes very hydrophobic after they deposit on tubing and drying), corking quality (consumer).

4/ Bottles…:
- Some contaminations inside the wall …

5/ The wine :
- At the moment: no relationship between grape, wine composition and gushing has been established.

**Finally: gushing remains a mysterious phenomena not well-understood for sparkling wine and without simple solutions.**
… but it can’t all be bad in gushing
Jetting principle:

Jet diameter < 200 µm
Air

Height: from 3 to 5 cm

after M. Brévot, P-Y Bournérias, L. Viaux, B. Robillard, 13ème AWITC, 2008
Thanks for your attention!

... and to:

J-E BARBIER – IOC / Epernay,
D. CHAUDRUC – Champagne Moët & Chandon / Epernay,
Pr G LIGER-BELAIR – Univ. Reims,
Pr G. POLIDORI – Univ. Reims,

Pr Richard ZARE / Stanford University