PRODIGY

White Paper on Acoustic Cavitation in Fermentation, Maturation, and Dry Hopping Processes

Multidisciplinary Technical-Scientific Studio — ALPEM Sagl

1. The Physical Mechanism of Action

The Prodigy system uses high-intensity longitudinal elastic waves to generate transient acoustic cavitation within the wort or beer. During alternating cycles of rarefaction and compression, the local pressure drops below the vapor pressure of the liquid medium, causing the formation and growth of gas microbubbles. The subsequent violent collapse of these bubbles releases high kinetic energy concentrated in microscopic volumes, generating points of extremely high local pressure and extremely high-speed liquid microjets.

At the cellular level, the shear stress induced by the microjets temporarily alters the permeability of the yeast plasma membrane. This phenomenon, known as sonoporation, increases the efficiency of transmembrane transport channels (nutrient exchange and byproduct expulsion) without lysing or damaging the cell.

2. Fluid Dynamics Engineering

In traditional cylindroconical tanks, mass transport between the solid phase (suspended yeast cells, hop particles) and the liquid phase is severely limited by the laminar boundary layer. Spontaneous molecular diffusion follows intrinsically slow dynamics.

Prodigy introduces the phenomenon of acoustic micro-streaming, a steady, vortical flow induced at the microscopic level that eliminates the laminar boundary layer, eliminating fluid dynamic resistance at the solid-liquid interface. The dynamic flow system ensures that the entire volume of beer undergoes perfectly homogeneous energy treatment, eliminating the dead zones typical of simple natural convection or mechanical agitation in large tanks.

3. Dynamic Gas Regulation and Controlled

Carbonation Module

The Prodigy system integrates a micro-management device for technical gases that works in perfect synergy with the sonomechanical action for the pre-bottling and conditioning phase, drastically optimizing the management of CO_2 and dissolved gases.

3.1 Forced Acoustic Nucleation

Ultrasonic waves create microscopic pressure gradients in the fluid. At rarefaction points, dissolved and supersaturated CO_2 is extracted from the solution, clustering into microbubbles. By introducing a calibrated flow of gas through the micro-oxygenation and gas management device, these microbubbles act as additional nucleation sites, exponentially amplifying the gas-liquid contact surface.

3.2 Maximum Stripping Efficiency (Zero Waste)

In traditional porous-plug systems, much of the injected technical gas escapes to the top of the tank without properly interacting with the liquid. With Prodigy, localized micro-turbulence (micro-streaming) breaks the gas flow into microscopic bubbles and maintains a dynamic emulsion. Mass transfer is so efficient that degassing or adjustment to the desired CO_2 target is achieved using a fraction of the technical gas (up to 60-70%) in a single inline pass.

3.3 Oxidation Protection and Precision in Packaging

The use of ultrasonic-assisted counter-pressure nitrogen allows for the surgical removal of residual dissolved oxygen (DO), extending the shelf life of products that are often susceptible to premature aging. Stabilizing CO_2 levels before packaging eliminates uncontrolled foaming (gushing) in the filler, optimizing the efficiency of the bottling or canning line.

4. Applications and Advantages in Bioprocessing

4.1 Fermentation Optimization (High and Low)

- **Cut time by 30-50%:**Sonoporation accelerates the absorption of fermentable sugars (maltose, maltotriose) and essential nutrients, shortening the lag phase.
- **Controlled CO_2 degassing:**The constant removal of supersaturated CO_2 eliminates the inhibitory effect this gas has on yeast during peak metabolic activity.

4.2 Maturation and Removal of Defects

- **Rapid Diacetyl Removal and Lagering:**Prodigy maximizes fluid-cell contact, reducing traditional lager conditioning and thermal dwell times to an optimized range of 2-7 days (compared to weeks with traditional processes).
- **Acoustic Coalescence and Clarification:**The acoustic field promotes the mechanical aggregation (coalescence) of exhausted cells and colloidal complexes. The process ensures complete stabilization and visual clarification (removal of chill haze) within a controlled period of 2-5 days.

4.3 Dry Hopping and Hop Yield

- **Instant Extraction of Essential Oils:**The micro-jets mechanically destroy the cell walls of lupulin, completing the release of the main aromatic compounds (Myrcene, Linalool) in a dynamic flow cycle lasting between 2 and 6 hours overall.
- **Yield Increase (+20-30%):**It allows you to reduce the quantity of pellets used while maintaining the same organoleptic profile, minimizing beer loss.
- **Preventing Hop Creep:**The extremely short contact times (2-6 hours) prevent the massive extraction of plant dextrinolytic enzymes responsible for unwanted secondary fermentations.

5. General Comparison Matrix: Traditional Technology vs. PRODIGY System

Process / Quality Parameter	Traditional Cellar (Static Process)	PRODIGY System (Acoustic Cavitation)	Industrial Impact & ROI
Maturation & Lagering	7 – 21 days Linked to passive diffusive dynamics and slow convective motions for the reabsorption of diketo-vicinals.	2 – 7 days The elimination of the fluid dynamic boundary layer dramatically accelerates the metabolism of diacetyl by the	Accelerated tank turnover; drastically reduced energy costs for extended refrigeration.

Process / Quality Parameter	Traditional Cellar (Static Process)	PRODIGY System (Acoustic Cavitation)	Industrial Impact & ROI
		yeast.	
Clarification & Chill Haze	5 – 14 days Natural decantation by gravity.	2 – 5 days Forced acoustic coalescence aggregates protein-tannin complexes and exhausted cells, accelerating sedimentation.	Naturally clear and stable beer over time; reduction or elimination of the use of chemical fining agents.
Dry Hopping Extraction	3 – 5 days Prolonged static contact with the pellets, with slow and partial extraction of the essential oils.	2 – 6 ore The micro-jets mechanically pulverize the lupulin, instantly emulsifying the aromatic compounds in-line.	20-30% hop savings; complete prevention of hop creep and green/astringent notes.
Technical Gas Management	Inefficient process Insufflation through a porous candle disperses most of the technical gas into the tank ceiling.	Dynamic in-line injection Acoustic nucleation fragments the gas into stable microbubbles, optimizing stripping and solubilization.	Savings of up to 60-70% on technical gases (N_2/CO_2); instant stripping of dissolved oxygen (DO).
Foam Stability	Standard	Enhanced	More persistent,

Process / Quality Parameter	Traditional Cellar (Static Process)	PRODIGY System (Acoustic Cavitation)	Industrial Impact & ROI
	Linked exclusively to the native composition of the must and thermal stability.	Micro-turbulence induces partial unfolding of hydrophobic proteins (LTP1), cementing the bond with iso-alpha-acids.	compact, fine-grained foam with a markedly superior "Brussels lace" effect.
Sanitization (CIP)	Standard wash Removal of biofilm and beer stone is entrusted exclusively to the thermal and chemical action of detergents.	CIP Assisted The sonomechanical effect exerts a continuous microscopic scrubbing that physically disintegrates the encrustations.	Savings on water, energy, and chemicals (soda/acid); reduction of washing downtime.
Product Losses (Beer Loss)	Standard (3% – 5%) High volumes of beer remain trapped in macro-throws of spent hops and yeast lees.	Minimized Reducing the required hop mass proportionally reduces the liquid retention in the waste sludge.	Direct increase in saleable litres per single commercial batch, optimising the yield of the brewhouse.

6. Timeline and Total Production Times: Style Profiles

In order to quantify the economic impact and optimize cellar capacity, the following is a comparative analysis of total production times for the two reference macro-styles of the global market: a bottom-fermented beer (Lager) and a highly hopped top-fermented beer (IPA).

6.1 Total Production Time Comparison Table (Traditional vs. PRODIGY)

Process Phase	LAGER STYLE: Traditional	STILE LAGER: Con PRODIGY	IPA STYLE: Traditional	STILE IPA: Con PRODIGY
Main Fermentation	8 – 12 days	**5 – 7 days**	4 – 6 days	**2 – 4 days**
Diacetyl Maturation & Pause	14 – 28 days	**2 – 7 days**	3 – 5 days	**1 – 2 days**
Clarification (Cold Crash / Haze)	7 – 14 days	**2 – 5 days**	3 – 5 days	**1 – 2 days**
Dry Hopping (Flavour Extraction)	N/A	**N/A**	3 – 5 days	**2 – 6 hours (0.2 days)**
Gas Stabilization & Pre-Pack	1 – 2 days	**Online (Instant)**	1 – 2 days	**Online (Instant)**
TOTAL CELLAR TIME	**30 – 56 days**	**9 – 19 days**	**14 – 23 days**	**4.2 – 8.2 days**

7. New Frontiers of Stability and Plant Engineering (CIP)

- **Foam Engineering (Protein Unfolding):**Improves binding with hop iso-alpha acids for a finer, more compact and persistent head.
- **Chill Haze Precipitation Prevention:**It accelerates the interaction and cold precipitation of protein-tannin complexes, ensuring visual stability without the addition of PVPP.
- **Mechanical Action in CIP (Clean-In-Place):**The sonomechanical effect exerts a continuous microscopic scrubbing that breaks down the bacterial biofilm and counteracts the deposition of calcium oxalate.

ALPEM Sagl— Lugano, Switzerland