EBC-Symposium 2012 „From Chiller to Filler“

Process and plant for the CONTINUOUS FERMENTATION of fluids

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Continuous Fermentation

+ Advantages of continuous (fermentation) processes +

- Improved plant performance, due to the reduction of processing times
- Increased space-time yield
- A resulting reduction of the cost of capital
- Less space consumption due to smaller plants
- Reduced energy consumption, especially by avoiding costly energy peaks
- Reduced costs for cleaning, detergents, disinfection and amount of wastewater
- An increase in labor productivity
- Reduced personal costs
- Less losses
- Improved fermentation gas (e.g. CO_2) recovery
- Less cleaning intervals
- Lower equipment costs
- Achievement of high standards of hygiene in closed systems
- Qualitative benefits
- Achievement of a constant quality of the final product

Continuous Fermentation

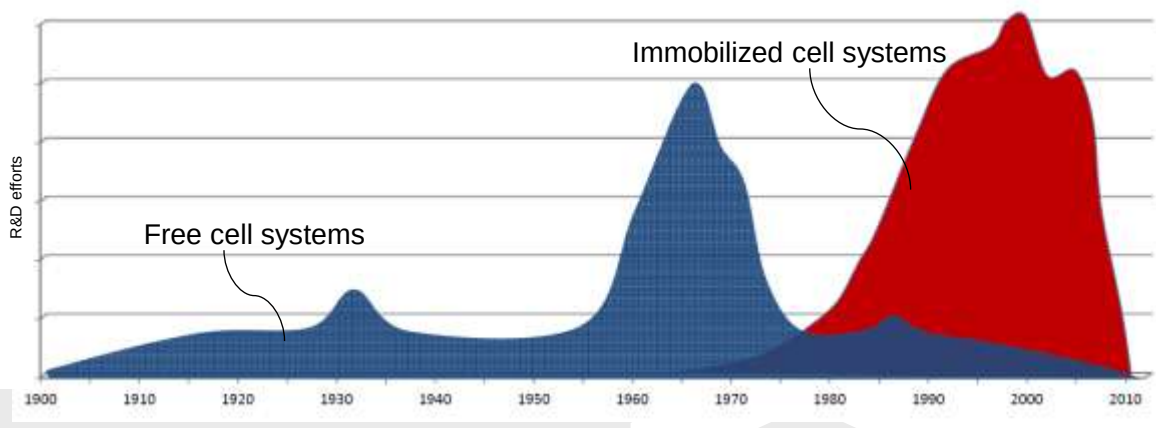
http://www.n-tv.de/img/70/705696/O_1000_680_680_krones.jpg

- Disadvantages of continuous (fermentation) processes -

- Lack of flexibility with respect to sales fluctuations
- Each production line can only produce one type of product
- Increased costs for proper organization of work (24-hour operation)
- Better qualified personnel is needed
- Higher expenses for the preservation of infections
- For process stability, a consistent quality of the raw materials is necessary
- Increased risk of mutations of organisms due to aging and long-term stress

Significant changes of the product character

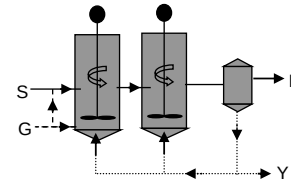
R&D effort in continuous fermentation processes



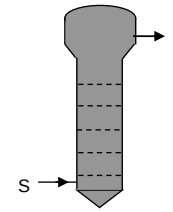
More than 150 different relevant systems where found & studied…

Continuous fermentation processes in praxis

Coutts (1959): Dominon Breweries (New Zealand), New Zealand Breweries Ltd. (New Zealand), Canadian Breweries Ltd. (Canada), San Miguel Brewery Co. (Manila)

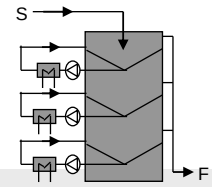


Fort Woth Fermenter (1965): Carling Brewing Company (USA)



Bishop Process (1970): Watney Mann (England)

APV Tower Fermenter (1960): Cape Hill Brewery (England), Brewery in Burton upon Trent (England) , Brewery in Runcorn (England), Brewery in Warrington (England), Oranjeboom Brewery (Netherlands), Cerevecera del Norte (Spain)



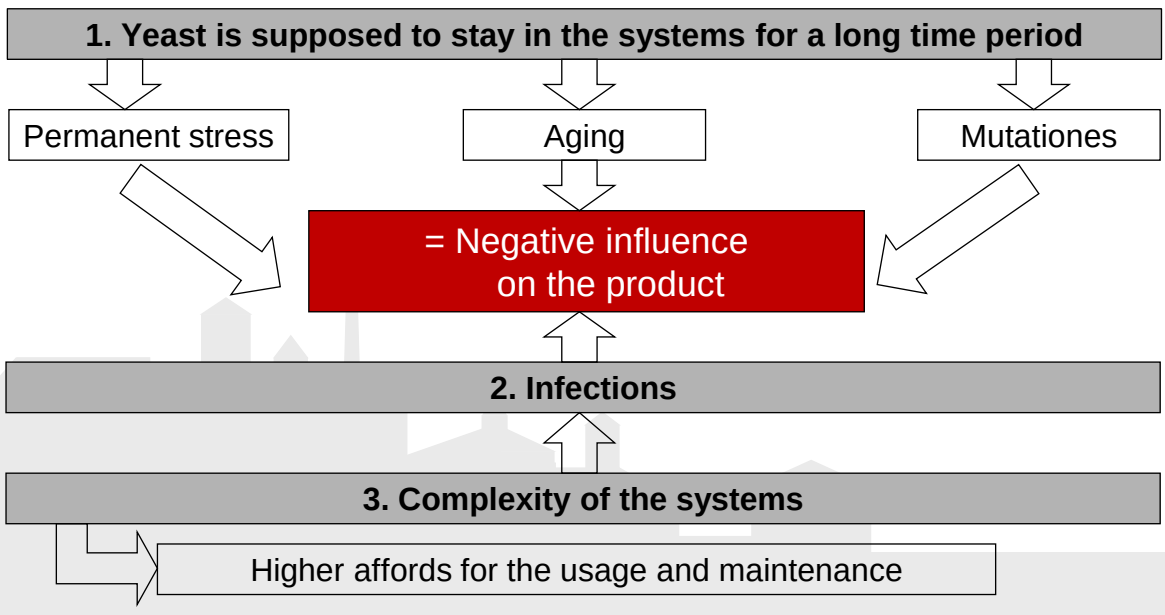
Gotha Fermentation System (1973): Brewery Gotha (East Germany)

Conclusion

- **Technology offers significant advantages, which will gain importance in the near future.**
- **In praxis only very view systems with free cells were tested (40-50 years ago!)**
- **Nearly all of them failed.**
- **Due to those failures and the potential higher efficiency the research and development has focused on systems with immobilized cell reactors.**

•Does further research in this field make sense?
•Why did systems fail in the past?
•Which systems should be preferred; Immobilized or Free-Cell Systems?

Main resons for the failure of existing systems



Demands

1. Yeast should be treated nearly identically to classical batch process

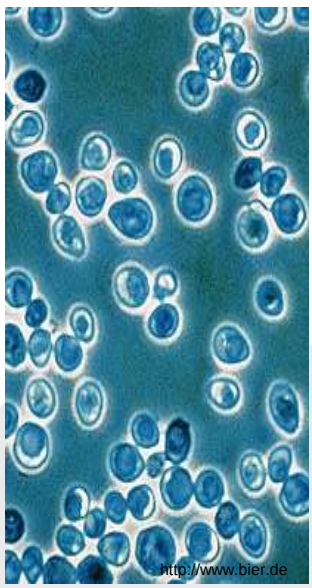
2. System has to be safe against infections

3. Simple construction and usage

4. Integable into existing plant
5. Multifunctionality
6. Usage of existing equipment if possible

Economic and ecological advantages
High constant product quality

Key to sucess: Properties of the yeasts



Yeasts determine the product character!

Intentionally adapted to batch process since centuries

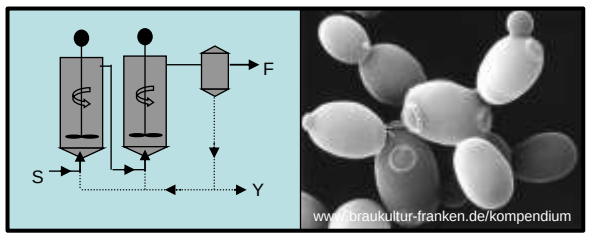
Significant gain of knowledge within the past 40-50 years!

Influence:

- Temperature
- Pressure
- Substrate properties
- Aeration
- Cell amount
- Age

Concept — Continuous Fermentation

Free cell systems

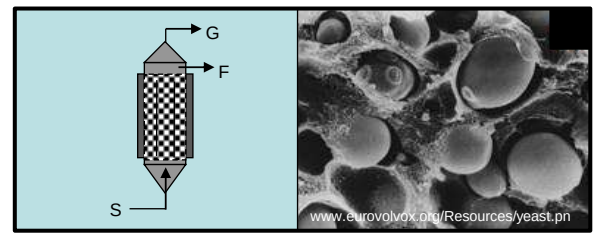


+ Yeast cycles can be reproduced
+ Aged yeast can be discharged
+ Lower risk of permanent infections

- Larger reactors
- More produced biomass
- Rather complicated systems

= Lower Efficiency?!?

Immobilized cell systems

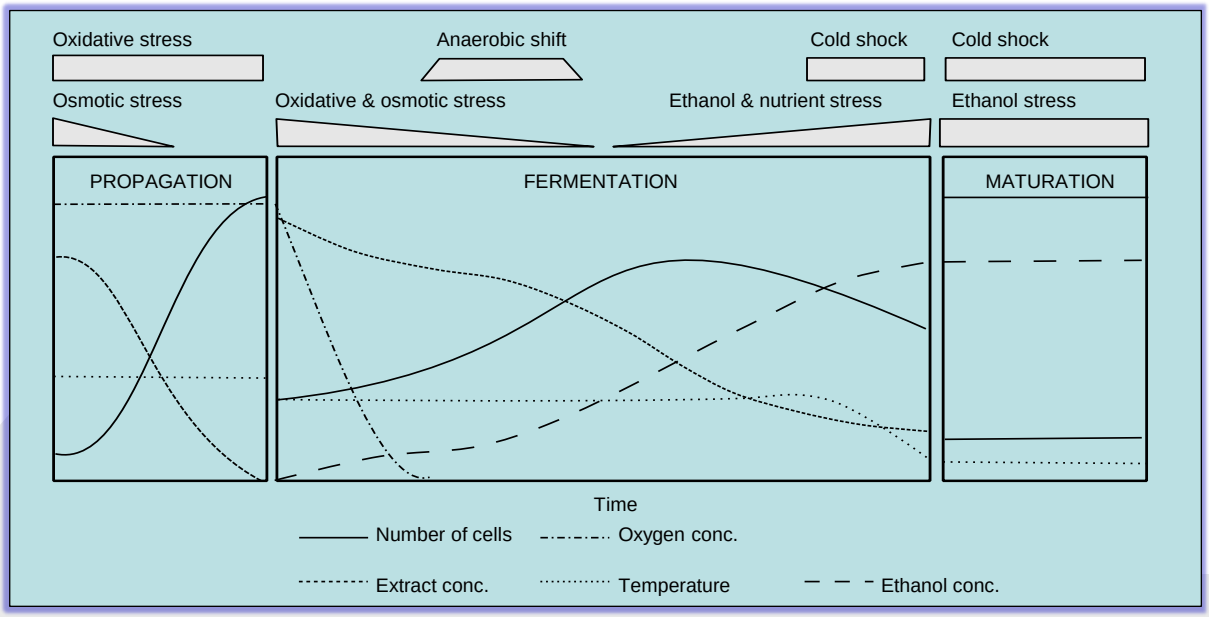


+ Small reactors
+ Less produced biomass
+ Uncomplicated systems

= Higher Efficiency?!?

- Long term stress for yeasts
- Yeast ages in system
- Higher risk of yeast mutations
- Higher risk of permanent infection

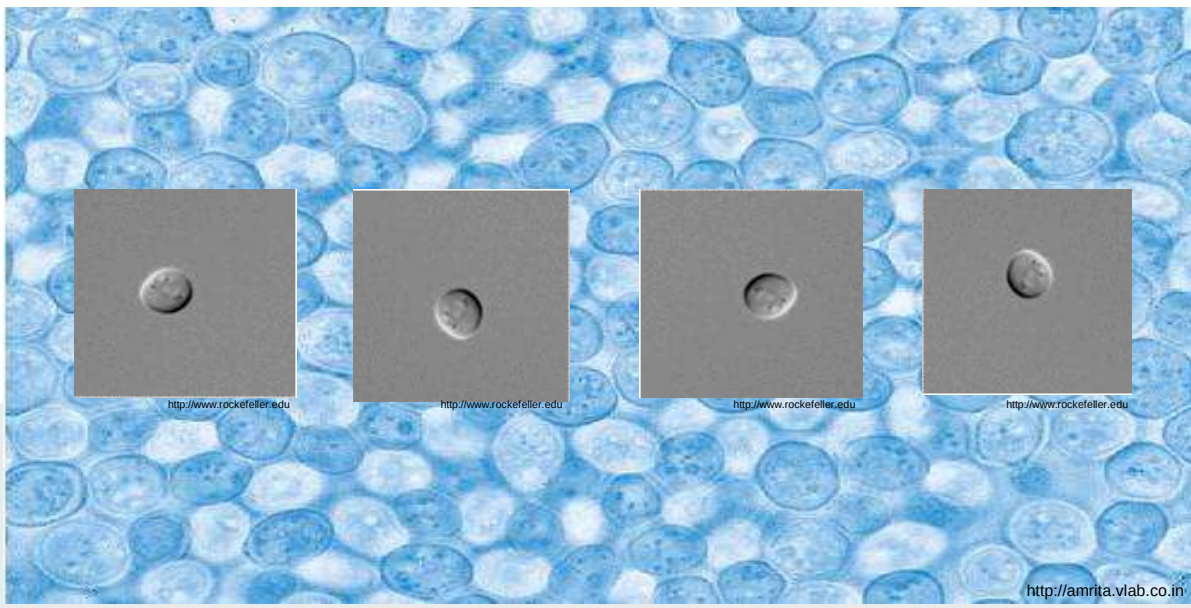
Stress situations for yeasts in the brewery



Brewers: Traditional & hard to convince…

www.langersamstag.ch/media/bierbrauer-susch.jpg

Systemes with free cells!!!



Patent- & literature research: Free cell systems

Conclusion

Many systems are very complex

Often many mechanical parts are being used

Difficult clean ability ➔ higher risk of infections

Commissioning times are often long

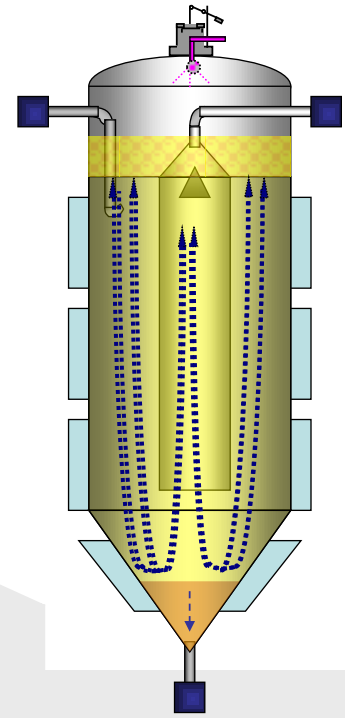
Nearly no system focuses on yeasts demands

Yeasts are supposed to stay in systems for long time periods

Often no possibility to remove yeasts and particles regularly

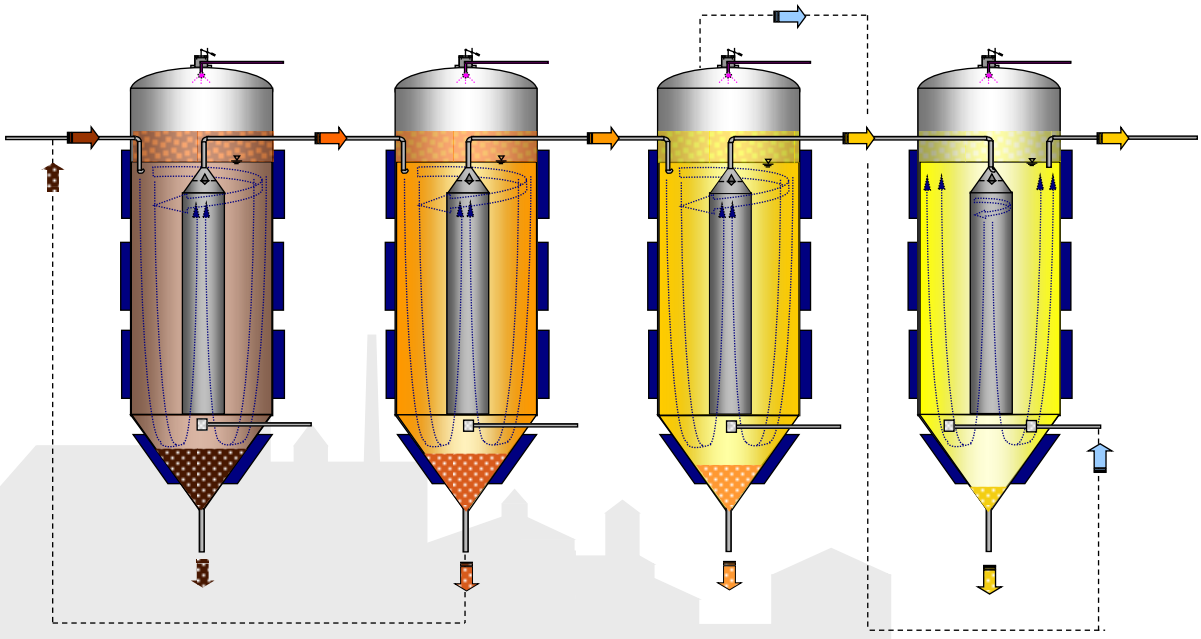
Conception: Free cell system

- Usage of state of art equipment!
- Simple installation of a central conduction pipe through which the fermentate can be charged or discharged
- Other installations for intake/outtake in the top part of the tank are foreseen
- Further equipment like a cooling system for the conduction pipe may be integrated
- Particles and yeasts can be discharged at the tank bottom
- The system is operated continuously or at least semi-continuously

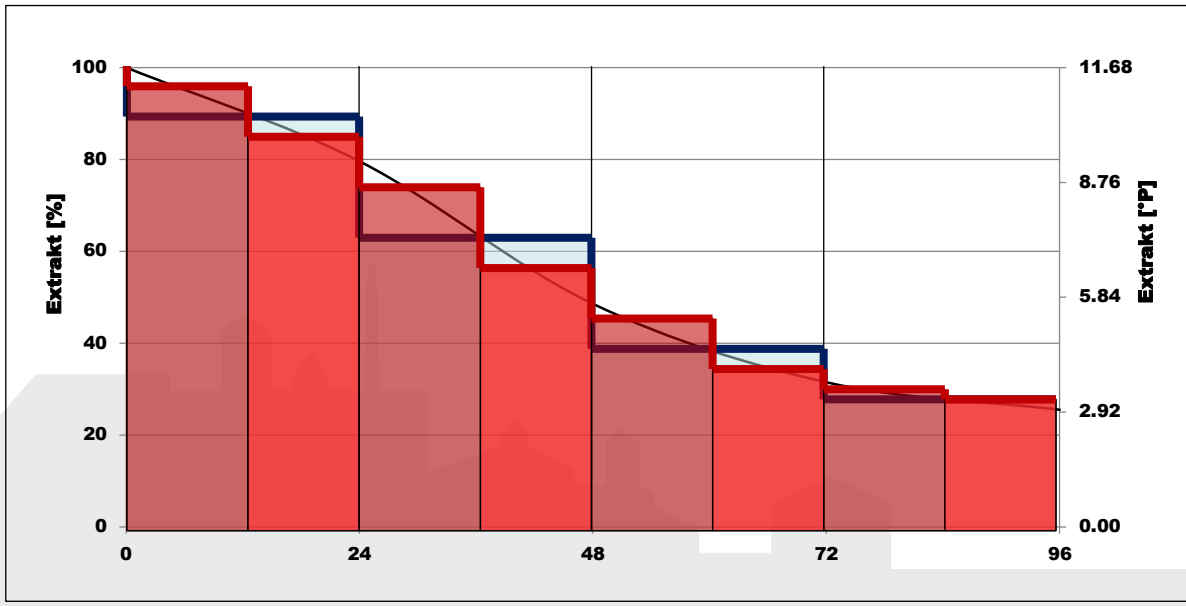


Concept

Continuous Fermentation



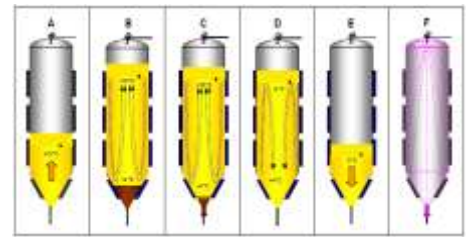
Fermentation progress & resulting yeast stress

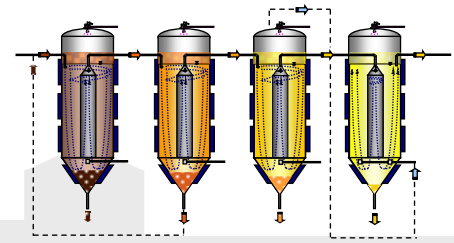


Advantages of this concept

- The yeast cycles, as they exist in classical batch fermentations can be simulated
- Particles (e.g. trub, yeasts) as well as gases can be discharged and added to the process variable
- Pressure and temperature gradients can be adjusted precisely.
- Existing plants may partly be used by modification
- The function, commissioning, as well as the cleaning and maintenance are fairly easy

--? Economic advantages ?--





Simplified calculation

In a classical batch fermentation the filling time and the discharge times should each not be longer than 10% (referring to the fermentation)

(Example:5 days main fermentation =120h: Filling/discharge time $_{max}$ =12h each)

Longer filling and discharge cycles would lead to the following disadvantages

(Independent of batch size!)

- Due to the longer supply of amino acids more Diacetyl will be produced
- The oxygen supply might lead to oxidations
- The yeast cycles may be disrupted
- The content can not be cooled fast enough

Simplified calculation

Classical Batch Fermentation

Filling	Fermentation	Discharge	CIP	Occupation time	Necessary tanks	Tanks/day	Tank size
12 h	5 days	12 h	4 h	148,0 h	14 tanks	2	50% daily production
9,6 h	4 days	9,6 h	3,2 h	118,4 h	14 tanks	2,5	40% daily production
7,2 h	**3 days**	**7,2 h**	**2,4 h**	**88,8 h**	**14 tanks**	**3,3**	**30% daily production**
4,8 h	2 days	4,8 h	1,6 h	59,2 h	14 tanks	5	20% daily production
2,4 h	1 day	2,4 h	0,8 h	29,6 h	14 tanks	10	10% daily production

Continuous Fermentation

Filling	Fermentation	Discharge	CIP	Occupation time	Necessary tanks	Tanks/day	Tank size
	5 days			120 h	5+1 Tanks		100% daily production
	4 days			96 h	4+1 Tanks		100% daily production
	3 days			**72 h**	**3 +1 Tanks**		100% daily production
	2 days			48 h	3+1 Tanks		66% daily production
	1 day			24 h	3+1 Tanks		33% daily production

Costs of a modern tank cleaning with fresh substances

Detergent	Consumption	Price/Unit [Euro]	Costs[Euro]
Water[m³]	5,6	3,83	21,47
Caustic [l]	37	0,07	3,07
Acid [l]	6,9	0,81	5,58
Desinfection [l]	1,3	1,76	2,29
Total costs [Euro]			32,41

Heating energy	Consumption	Price/Unit [Cent]	Costs [Euro]
1. Step 45°C [kWh]	85,2	1,55	1,32
2. Step 65°C [kWh]	221,6	1,55	3,42
Total costs [Euro]			4,74

Approx. Costs for the cleaning of one tank	37,15 Euro

Simplified calculation

Classical Batch Fermentation					
Fermentation time	Tank size	Costs per tank cleaning	Tanks/day	CIP costs/day	300 days production/a
5 days	100%	37,15 Euro	2	74,3 Euro	22.290 Euro/a
4 days	80%	29,72 Euro	2,5	74,3 Euro	22.290 Euro/a
3 days	60%	22,29 Euro	3,3	74,3 Euro	22.290 Euro/a
2 days	40%	14,86 Euro	5	74,3 Euro	22.290 Euro/a
1 day	20%	7,43 Euro	10	74,3 Euro	22.290 Euro/a

Continuous Fermentation					
Fermentation time	Tank size	Costs per tank cleaning	Tanks/day	CIP costs/day	365 days production/a
5 days	100%	37,15 Euro	0,16	6,19 Euro	2.229 Euro/a
4 days	100%	37,15 Euro	0,13	4,95 Euro	1.783 Euro/a
3 days	100%	37,15 Euro	0,1	3,72 Euro	1.337 Euro/a
2 days	66%	24,52 Euro	0,1	2,45 Euro	883 Euro/a
1 day	33%	12,25 Euro	0,1	1,23 Euro	441 Euro/a

Conclusion

Plant concept with focus on simplicity with focus on brewery yeast demands

Technological advantages

- **Low stress for yeasts**
- **Fractioniszation of particles, gas and organisms possible**
- **Yeast can live through the same cycles like in batch process**

Economical and ecological advantages

- **Less tanks = less needed space, lower investment costs, less equipment- , control-, and cleaning efforts necessary**
- **Less waste / consumption (beer, water, gas, CIP, yeast, energy, cooling…)**
- **Constant product quality**

Continuous Fermentation

But: not everything can be calculated or prdicted…

Open questiones:

For which drinks is such a technology suitable?
Can realistic conditions be achieved in small scale?
How should experiments be conducted in order to allow scale up?
What are the ideal parameters for a fast fermentation?
How does standard yeast react?
How can the physiological condition of the yeast be measured simple?

Can a small scale plant be built and be run under similar conditions?
How does such a product taste like?
How stable can such a plant be run?
How does the system react to infections?
How can the performance be optimized?

http://t1.ftcdn.net/jpg/00/40/70/26/400

Continuous Fermentation

1. Investigation in order to evaluate the process suitability

In total **278** !!!

different fermented beverages where investigated

152 Drinks where made out of cereals or pseudo-cereals

56 Drinks where milk-based

17 Drinks where fruit-based

53 beverages where made out of different ingredients

Name of beverage	Raw material & additives	Origin	Fermentation time	Fermentation temp.	MO	Literature

Continuous Fermentation

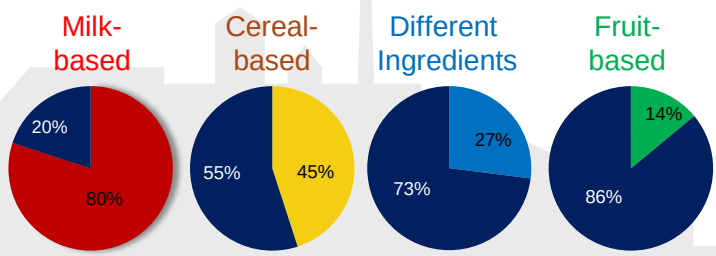
Name Getränk	Rohstoff u. Zusätze	Fermentation				Quelle
		Land	Dauer	Temperatur	MO	
Bananen-Bier						
Isongo	Bananensaft, gerösteter Sorghum	Burundi	48-96 h	14-25 °C	Sac1	30, 105, 18 (S.89)
Lubisi	Bananen, Sorghum	Uganda	18-24 h	14-25 °C	Sac1	106, 105, 18 (S.89)
Mbege	Bananen, Fingerhirse	Tansania	96-120 h	14-25 °C	Sac1	107, 108, 105, 18 (S.89)
Mwenge	Bananen, Sorghum	Uganda	18-24 h	14-25 °C	Sac1	106, 105, 18 (S.89)
Urwarwa/Urwagwa	verdünnter Bananensaft, gerösteter Sorghum	Burundi, Rwanda	48-96 h	14-25 °C	Sac1	30, 106, 105, 18 (S.89)
Urwaga	Bananen, Sorghum, Hirse o. Mais	Kenia	18-24 h	14-25 °C	Sac1	106, 105, 18 (S.89)
Bananenwein						
Malkia	Bananen	Tansania	2-8 Wochen	k. A.	k. A.	108, 109
Meru	Bananen	Tansania	2-8 Wochen	k. A.	k. A.	108, 109
Raha	Bananen	Tansania	2-8 Wochen	k. A.	k. A.	108, 109

Continuous Fermentation

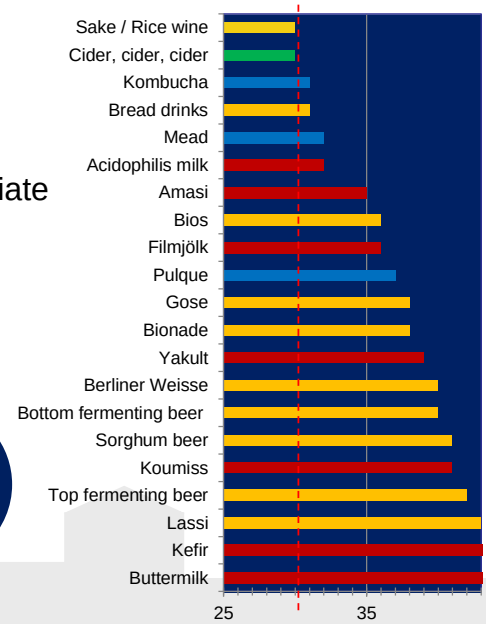
Assessment of 49 types of beverages

1. Raw materials
2. Sales volume
3. Production period
4. Fermentation time
5. Production site
6. Sales area / Market

≥ 40 P = good
30-39 P = suitable
20-29 P = not appropriate
< 20 P = not suitable



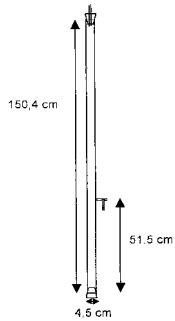
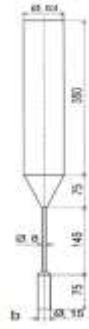
= not suitable



Continuous Fermentation

2. Can small scale fermentations reflect realistic situations?

3. How should they be done in order to allow a scale up?

EBC fermenter	Lietz fermenter	Laboratory fermenter	Weinfurter. fermenter
			

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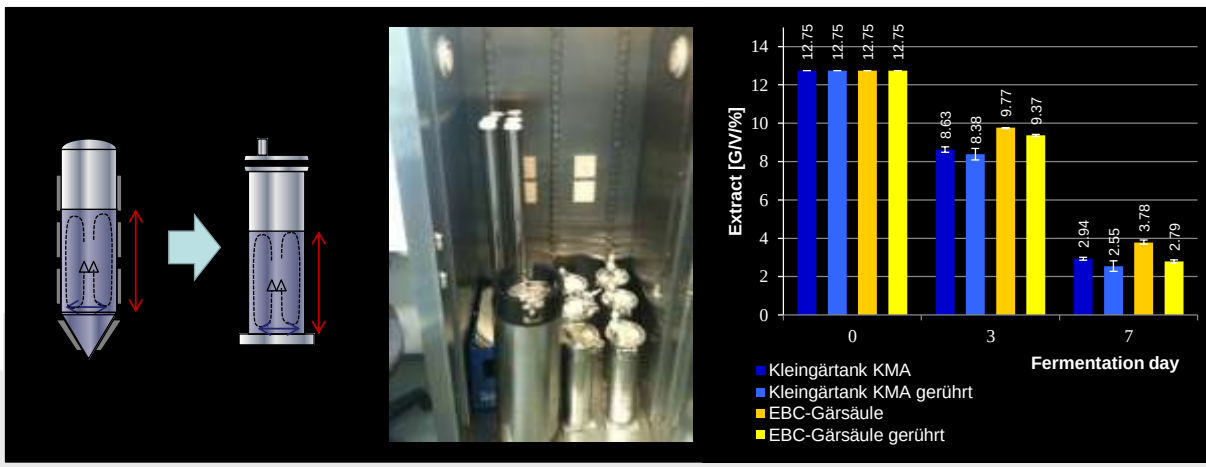

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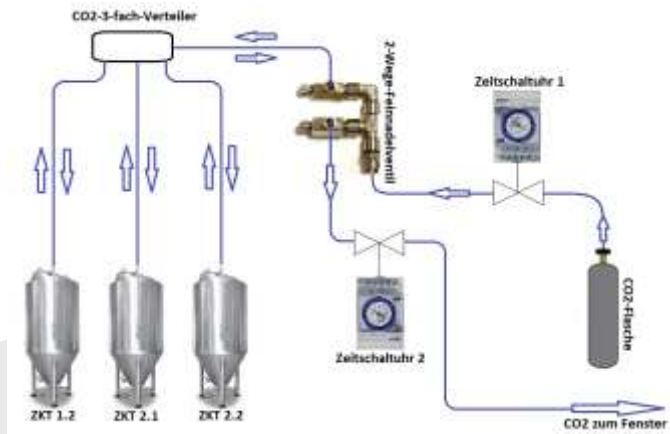


Continuous Fermentation

2. Can small scale fermentations reflect realistic situations?

3. How should they be done in order to allow a scale up?

Tests in order to check different substrates for their suitability

Richtwerte	Normwert	W	E1	E 2	E 3	E4	E 5	E 6	G1	P 1	P 2
FAN [mg/l]	200 - 240	208	153,8	101,7	42,9	89,1	23,2	49,2	170,5	133,2	89,8
Summe AS [mg/l]	1600-2000	1694	1249	826,3	348,5	723,5	188,7	399,4	1384,7	1082,3	729,2
pH- Wert	5,2	5,2	5,07	5,28	5,53	5,71	4,77	5,5	5,33	5,26	5,75
Ges. Lösl. N [mg/l]	900 - 1100	1056	1303	1071	450	721	875	544	980	1302	651
noch koagl. N [mg/l]	< 25	21	34	43	15	57	36	19	9	53	64
Scheinbarer Extrakt [G/V%]	12	12,18	11,98	12,08	12,1	12,26	12,17	12,18	12,53	12,58	12,52
Farbe	5 - 15	12	13	15	19	25	77,5	19	55	31,3	11,25
TBZ	< 45	29,5	119,5	116,8	283	66,6	1239	94,9	82,7	280	47,5
Fructose [g/l]	1-2	1,52	1,9	1,68	0,71	0,1	0,51	0,1	0,5	0,49	0,02
Glucose [g/l]	10-12	10,86	13,09	12,41	8,31	2	10	2	3,51	3,03	1,5
Saccharose [g/l]	2-4	3,01	3,08	2,55	0,88	1,5	0,25	1	2,5	0,41	1,7
Maltose [g/l]	56-80	70,61	61,04	66,19	57,45	4,92	12,3	18,03	18,87	16,4	5,73
Maltotriose [g/l]	14-17	15	13,75	18,58	22,89	4,02	2,5	6	7,51	6	5,01

Continuous Fermentation

4.& 5. Reactions to different situations

Fermentations under the variations of

- Cell amount (4 different)
- Aeration (aerated/not aerated)
- Temperature (3 different)
- Pressure (3 different)

Additional tests

- Alkohol stress
- Pressure stress
- High-Gravity-Stress
- Pressure variationes

3 usages, different steams

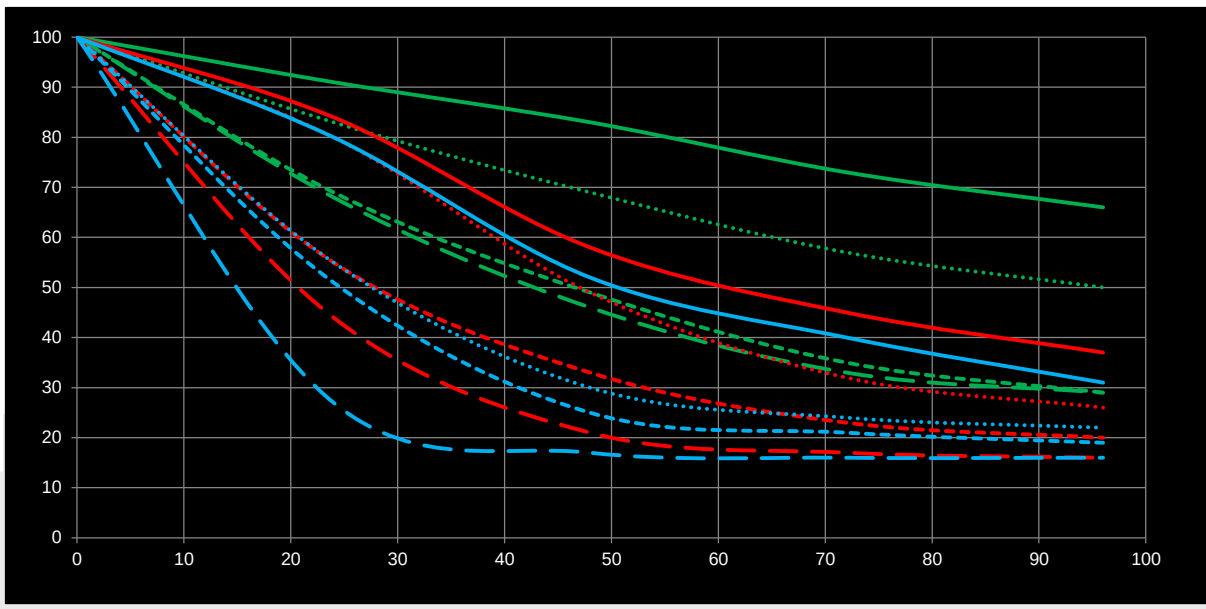
Tests for over one year!!!

Analyses

Extrakt
pH-Value
Alkohol
FAN (alleAA!)
VDK
Biomass/Cell count
GCs

Continuous Fermentation

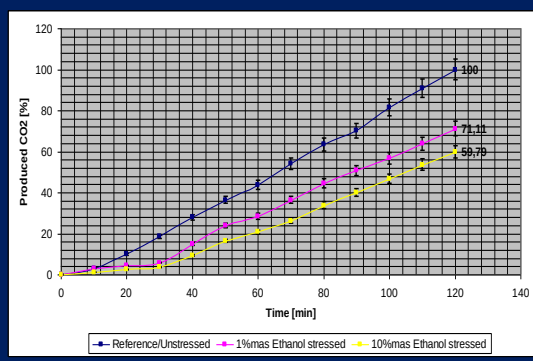
4.& 5. Reactions to different situations



Continuous Fermentation

6. Simple method in order to determin the yeast vitality

Via CO_2-built up



Via particle sice analysis

Continuous Fermentation

Technology: Possibilities in small scale

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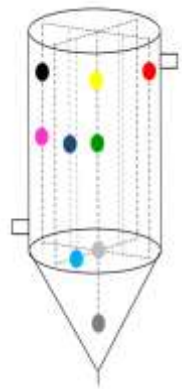
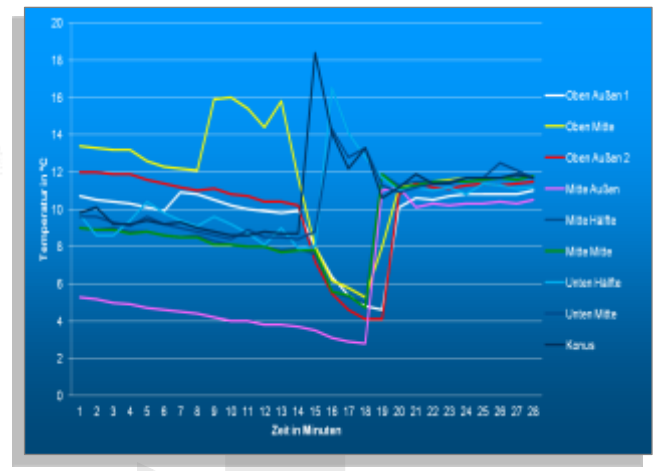
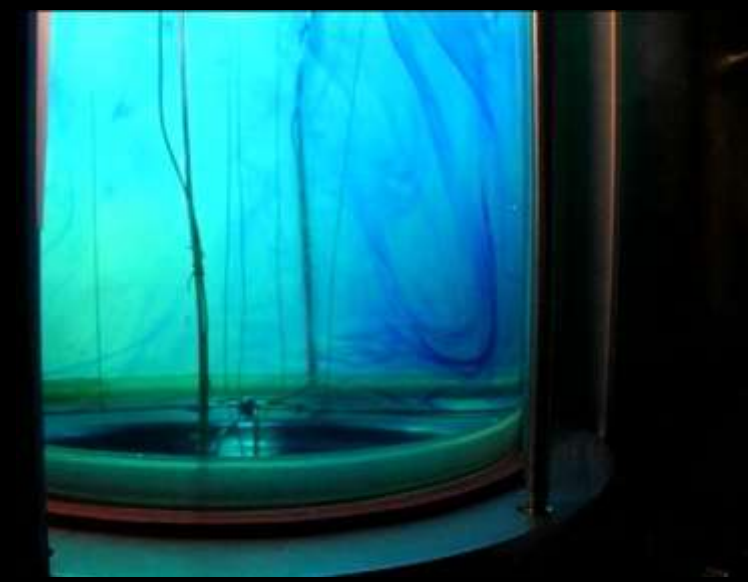




Continuous Fermentation

Technology: Possibilities in small scale



Continuous Fermentation

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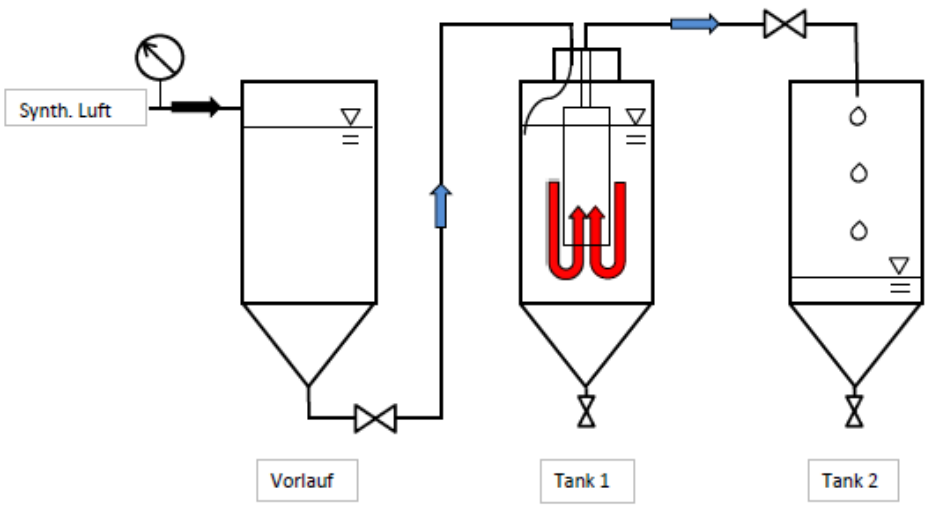
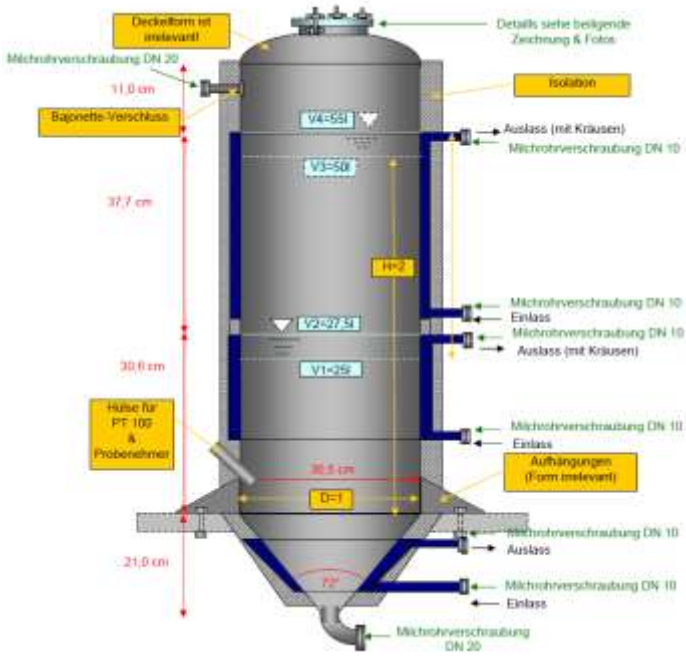
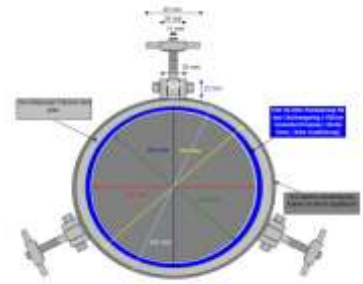
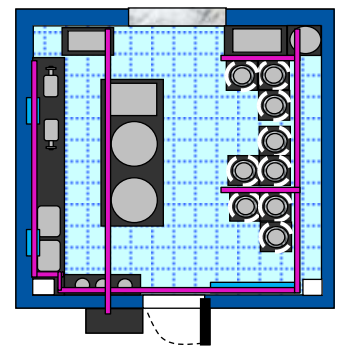


Continuous Fermentation

Continuous Fermentation







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Experiments & Results

1-Tank Process (6 days)

- No bigger process problems
- Currency tests sucessfull
- Only small changes/simplifications necessary

3-Tank Process (33 days)

- No process problems
- Extract, Alkohol, pH-Value relatively constant
- Taste: constant good
- Contamination with wort bacteria: No long term problem!

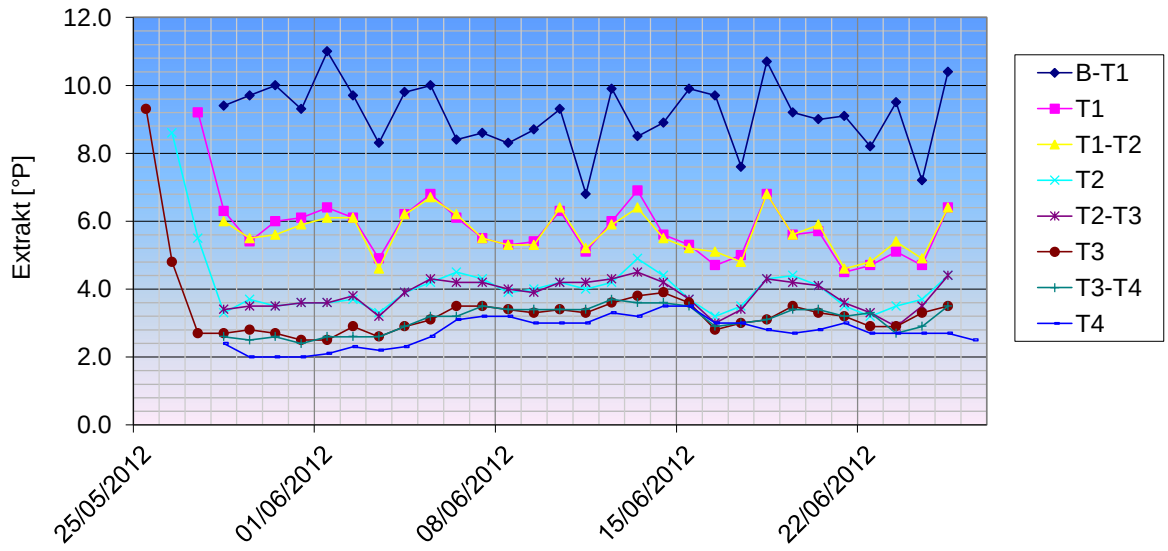
10 filling, discharging and CIP processes per tank less!!!
= totally 30-40x less!!!

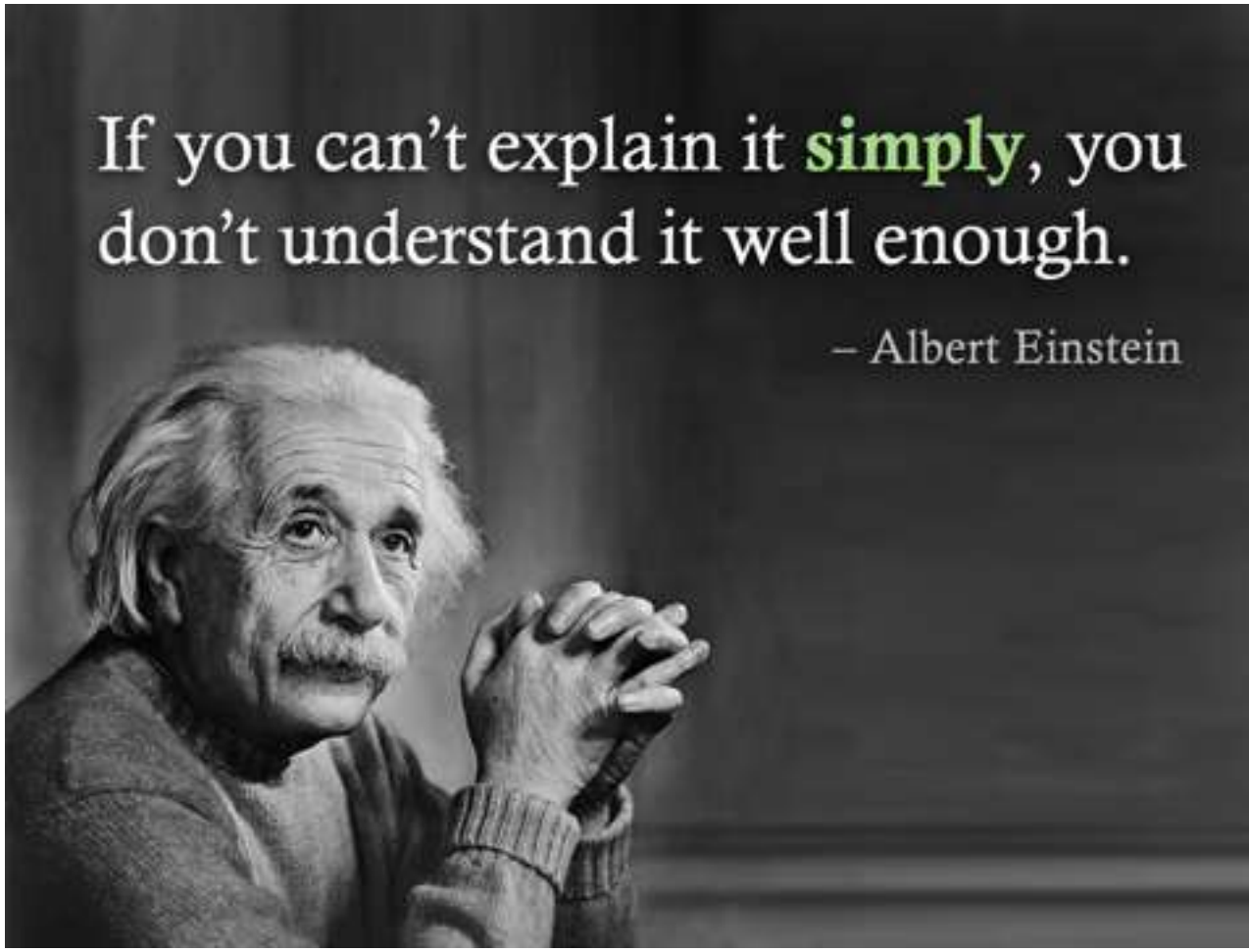
4-Tank Process (35 days)

- No process problems
- Extract, Alkohol, pH-Value relatively constant
- Taste: constant good
- Contamination with different bacteria: No long term problem!

Continuous Fermentation

Results




If you can't explain it simply, you don't understand it well enough.
– Albert Einstein

Thank you for your attention!

Dipl.- Ing. Konrad Müller-Auffermann

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Future trends in the beverage industry

- Energy efficiency
- Sustainability
- Transparency
- Individuality
- Funktionality
- Economy // Price

Continuous fermentation