Approaches for carbon dioxide degassing unit automation

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RAS4.0

Talking about degassing costs in Nofima:

Aquaculture Europe 09, August 14-17 2009, Trondheim, Norway

The bio-economic costs and benefits of improving fish welfare in aquaculture: utilising CO_2 stripping technology in Norwegian Atlantic salmon smolt production

Nofima

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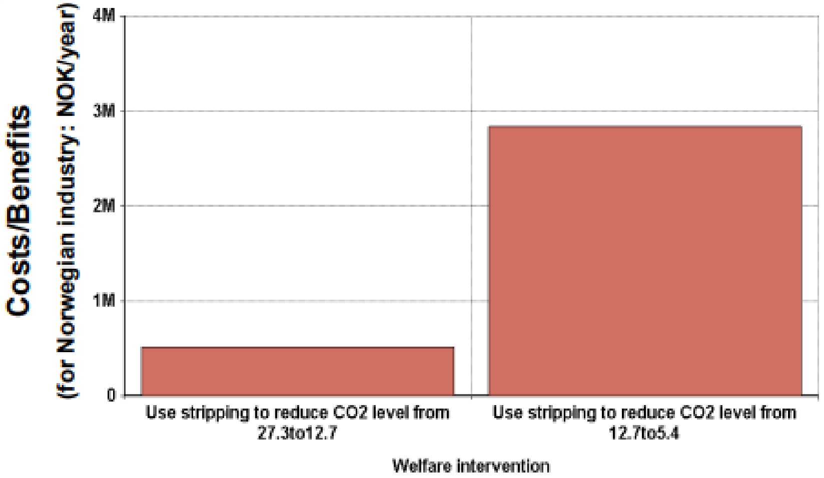
benefish

Noble, C., Kankainen, M., Setälä, J., Berrill, I. K., Ruohonen, K., Damsgård, B., & Toften, H. (2012). The bio-economic costs and benefits of improving productivity and fish welfare in aquaculture: Utilizing CO2 stripping technology in Norwegian Atlantic salmon smolt production. Aquaculture Economics & Management, 16(4), 414-428.



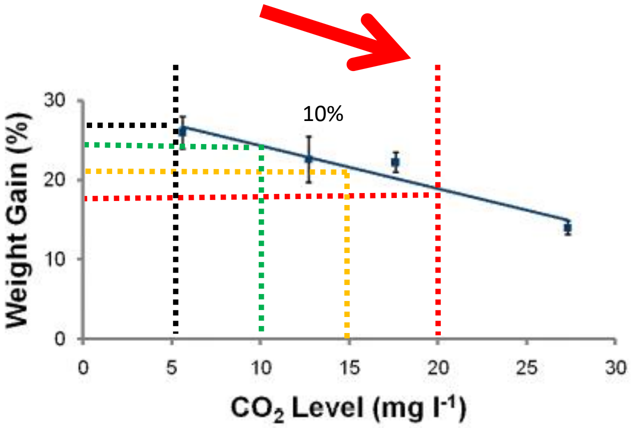


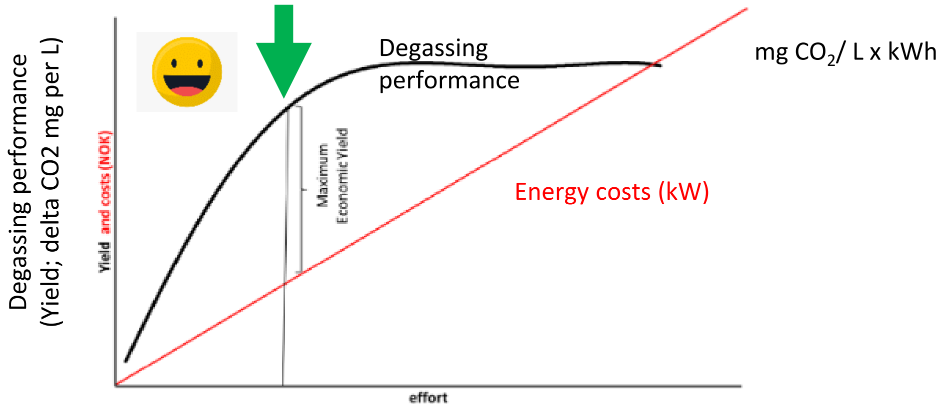
Fig. 1: The relationship between CO_2 level and weight gain (%) in Atlantic salmon pre-smolts held in flow through tanks. Values represent mean ± S.D.

CO_2 Degassing costs are a old topic, but there where always more important topics. Energy will be expensive enough at some point.

A Franatech sensor was coupled to fan that removed the CO_2 form the degasser/production Hal.

Energy and degassing

Optimising energy usage by matching degassing efforts with requirements.



Blower and pump Degassing usage (effort; h)

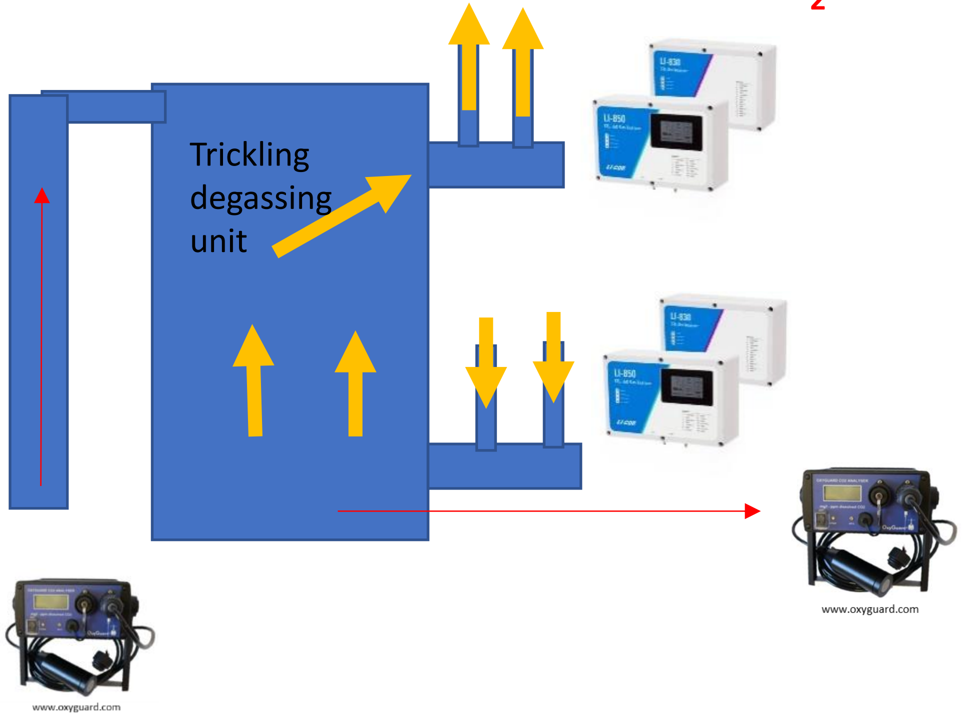
There is this point where you have the highest degassing to lowest energy consumption.

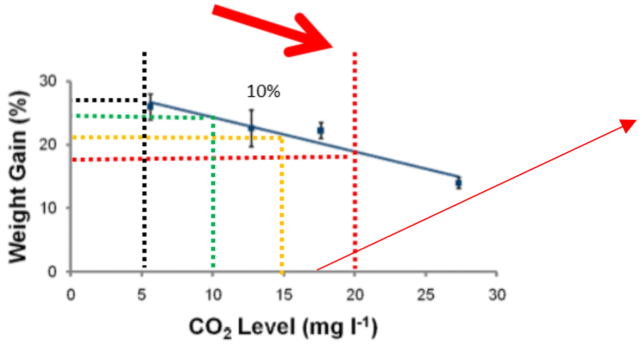
Variables for Automation

2. Air Flow

1. Water Flow

”4. Air CO_2 ”





3. Water CO_2

Automation and perhaps AI leaning tools need data

Specifications: Li-850 versus Oxyguard

AIR

•**Measurement range:** 0-20,000 ppm (see table below)
•**Accuracy:**
Within 1.5% of reading
•**Sensitivity to water vapor**
<0.1 ppm CO_2/mmol mol^{-1} H_2O
•**Lower limit of detection** 1.5 ppm

•**Output rate:** Up to 2 measurements per sec
•**Response time (T90):**
- **CO_2:** <3.5 seconds from 0-375 ppm

WATER

•**Measurement range:** 0-50 mg/L
•**Accuracy:**
+/- 1 mg/L
•**Sensitivity to water vapor**
XXX
•**Lower limit of detection** 1 mg/L

•**Output rate:** 5 measurements per min
•**Response time (T90):**
- **CO_2:** 5 (using the provided mixer) to 15 min (still water)

Around 600 measurements in 5 min

input	12	salinity (ppK)
input	12	oC
input	1013,25	atmos pressu
input	20000	ppm or uatm
output	41,614269	mg/l
output	2	%
output	2,091503943	kPa
output	0,020641539	bar

www.oxyguard.com

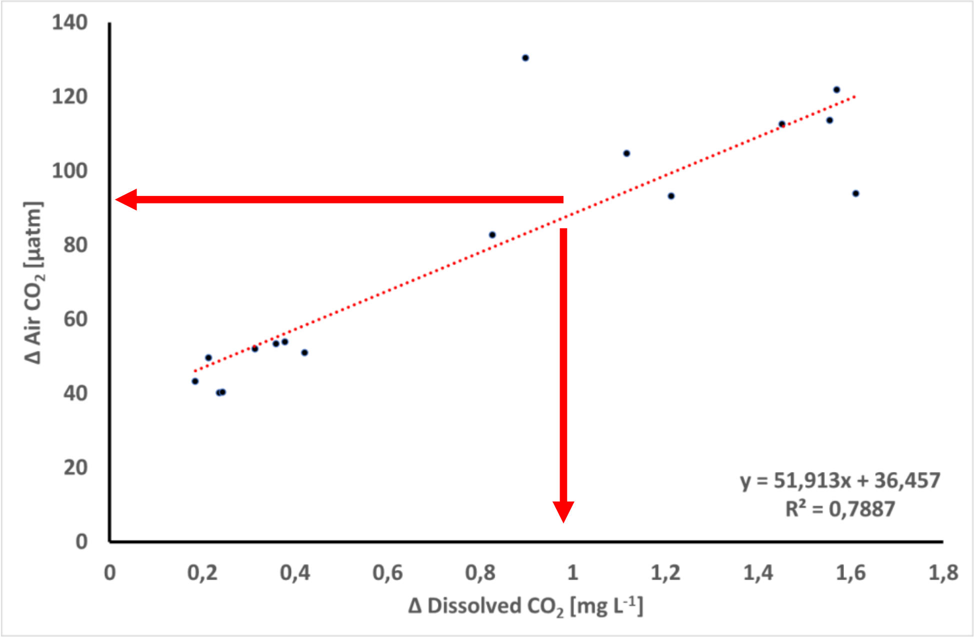
1 measurements in 5 min under best circumstances
Low accuracy in lower CO_2 concentratons (< 10%)

Mass balance degassing preparation:

CO_2 removal in Water to Air

As expected **dissolved CO_2 removal** from water and **CO_2 increase in air** leaving the degasser were proportional.

In our system, removing **1 mg L^{-1} dissolved CO_2 in water**, **air CO_2 increased by about 89 µatm**

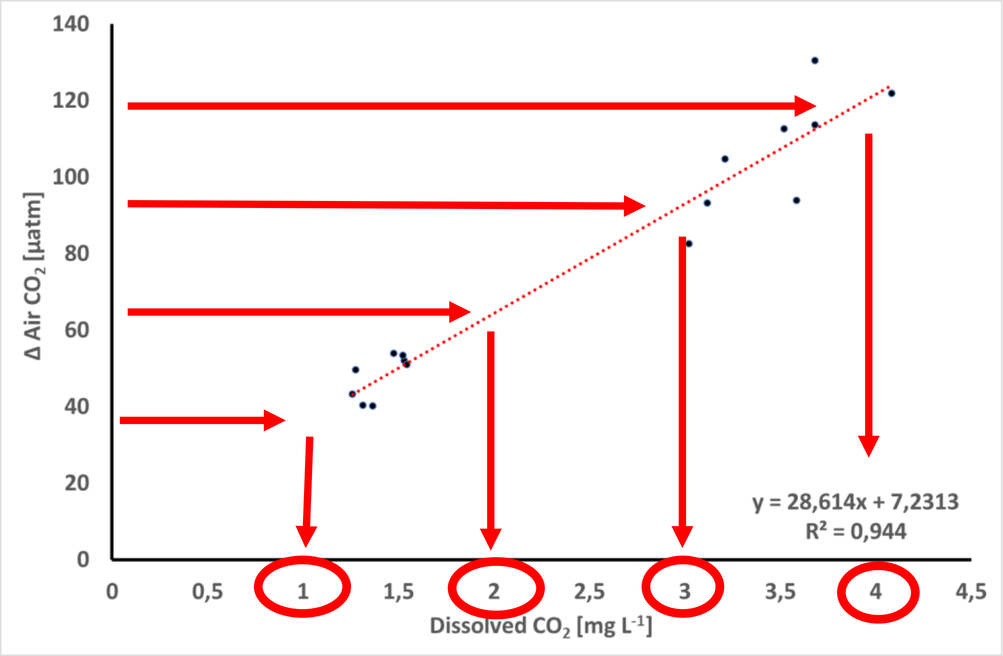


Removal efficiency “amount of incoming CO_2 that been degassed”

CO_2 removal increased with increasing dissolved water CO_2 levels into the degasser

In our system, an increase of **1 mg L^{-1} dissolved CO_2** into the degasser unit **increased CO_2 concentrations in air by about 36 µatm.**

The air removal values can be used to predict the incoming concentration of dissolved CO_2 into the degassing unit.



Carbonate system

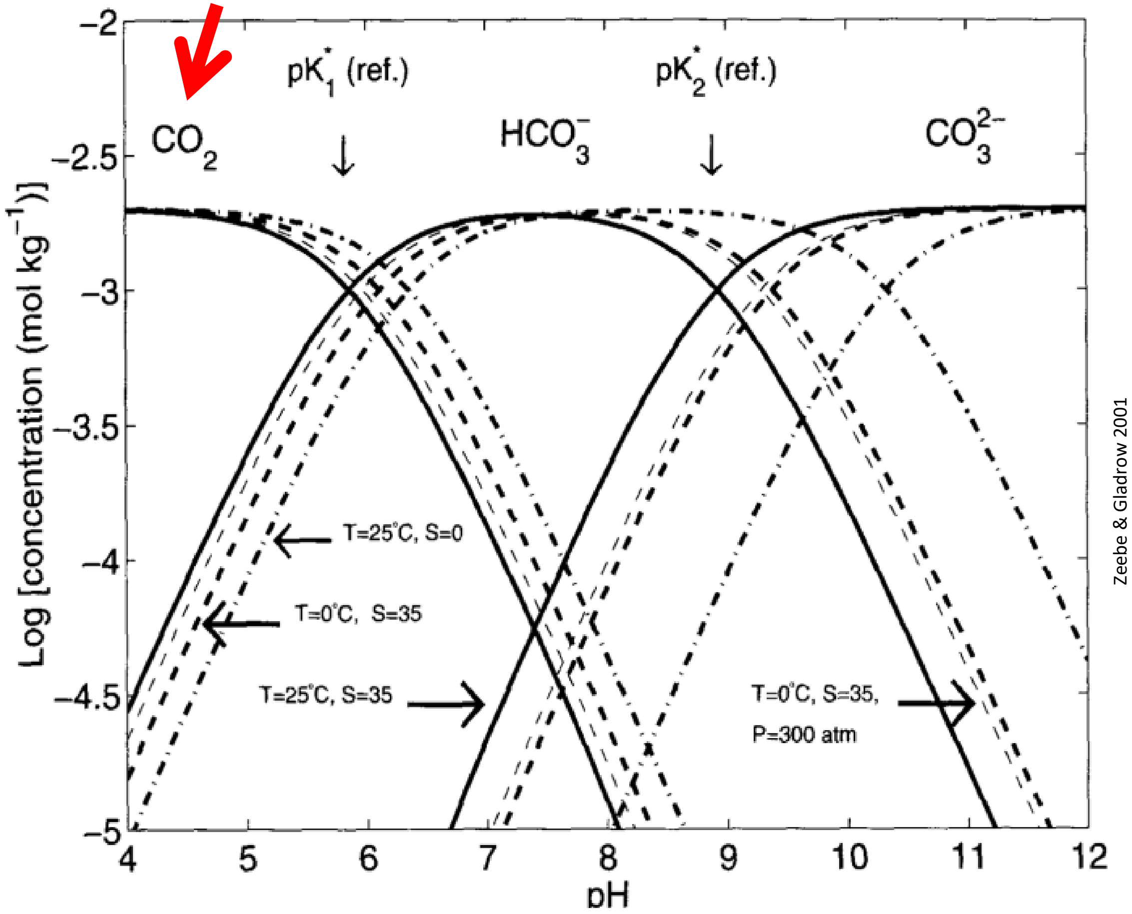
Background

Faktors we need to work with

Temperatur

Salinities

Alkalinities



Zeebe & Gladrow 2001

www.xylemanalytics.com

Total Alkalinity

$$= \underbrace{[\boldsymbol{HCO_3^-}]}_{76.8\%} + 2\underbrace{[\boldsymbol{CO_3^{2-}}]}_{18.8\%} + \underbrace{[\boldsymbol{B(OH)_4^-}]}_{4.2\%} + \underbrace{[\boldsymbol{OH^-}]}_{0.2\%} + [HPO_4^{2-}] + 2[PO_4^{3-}] + [SiO(OH)_3^-] + [NH_3]$$
$$+ [HS^-] + \ldots\ldots - [H^+] - [HSO_4^-] - [HF] - [H_3PO_4]$$

Salinity

- .

Salinity effect	0.5 ppt	2.5 ppt	5 ppt
pH	7	7	7
Temperature (oC)	14	14	14
Alkalinity (mg/L)	50	50	50
Dissolved CO2 (mg/L)	8.4	6.6	6.0

Salinity effects for 0.5, 2.5 and 5 ppt on the dissolved CO_2 concentration in water with a constant alkalinity, pH and temperature.

The solubility coefficient K_0 (10^{-2} moles/l · atm)

	Salinity (‰)								
T(°C)	0	10	20	30	34	35	36	38	40
−1	—	—	7.273	6.903	6.760	6.724	6.689	6.620	6.551
0	7.758	7.364	6.990	6.635	6.498	6.465	6.431	6.364	6.298
1	7.458	7.081	6.723	6.382	6.251	6.219	6.187	6.123	6.060
2	7.174	6.813	6.469	6.143	6.017	5.986	5.955	5.894	5.833
3	6.905	6.558	6.229	5.916	5.795	5.766	5.736	5.677	5.619
4	6.650	6.317	6.001	5.701	5.585	5.557	5.528	5.472	5.416
5	6.408	6.088	5.785	5.497	5.386	5.358	5.331	5.277	5.223
6	6.178	5.871	5.580	5.303	5.196	5.170	5.144	5.092	5.040
8	5.751	5.469	5.200	4.945	4.846	4.822	4.797	4.749	4.702
10	5.366	5.105	4.857	4.621	4.529	4.507	4.485	4.440	4.396
12	5.017	4.776	4.546	4.327	4.243	4.222	4.201	4.160	4.119
14	4.700	4.477	4.264	4.062	3.983	3.964	3.945	3.906	3.869
16	4.412	4.205	4.008	3.820	3.747	3.729	3.712	3.676	3.641
18	4.149	3.958	3.775	3.600	3.533	3.516	3.499	3.466	3.434
20	3.910	3.732	3.562	3.400	3.337	3.322	3.306	3.275	3.245
22	3.691	3.526	3.368	3.217	3.158	3.144	3.130	3.101	3.073
24	3.491	3.337	3.190	3.050	2.995	2.982	2.968	2.942	2.915
26	3.307	3.164	3.027	2.897	2.846	2.833	2.821	2.796	2.771
28	3.138	3.005	2.878	2.756	2.709	2.697	2.685	2.662	2.639
30	2.983	2.859	2.741	2.627	2.583	2.572	2.561	2.540	2.518
32	2.840	2.725	2.615	2.509	2.468	2.457	2.447	2.427	2.407
34	2.708	2.601	2.498	2.400	2.361	2.352	2.342	2.323	2.305
36	2.587	2.487	2.391	2.299	2.263	2.254	2.246	2.228	2.211
38	2.474	2.382	2.292	2.207	2.173	2.165	2.157	2.140	2.124
40	2.370	2.284	2.201	2.121	2.090	2.082	2.074	2.059	2.044

Effect of Salinity and Temperature on the solubility of carbon dioxide. From Weiss (1974)

Mini RAS Experiment

(3 weeks)

1. Air flow rate (Fan feed 1,2,3)

2. hydraulic loading rates (HLR) 10, 20, 30 L/m^{2}s (Water flow rate equal 1000 (21.50 hz), 2000 (22.70 hz) and 3000 (24.30 hz) L/h).

3. Alkalinity 50, 200 mg/L $CaCO_3$

4. Air CO_2 concentration

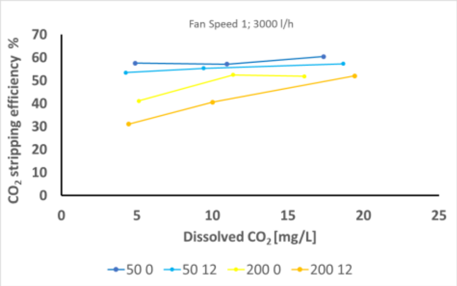
5. Water CO_2 concentration 5, 10, 20 mg/L dissolved CO_2

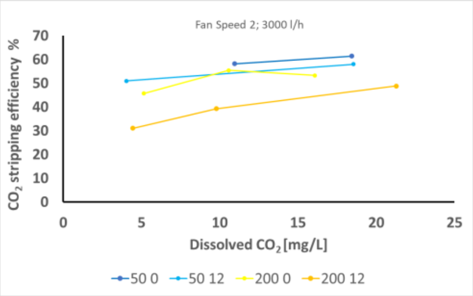
6. Salinity 0 ppt, 12 ppt

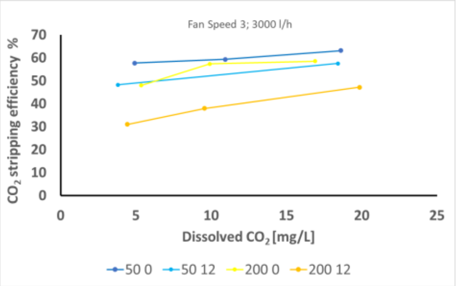
Model feeding

Fan Speed 1 | Fan Speed 2 | Fan Speed 3

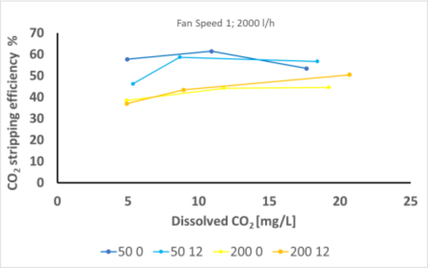
3000 l/h

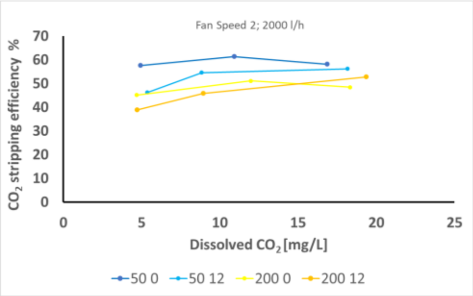


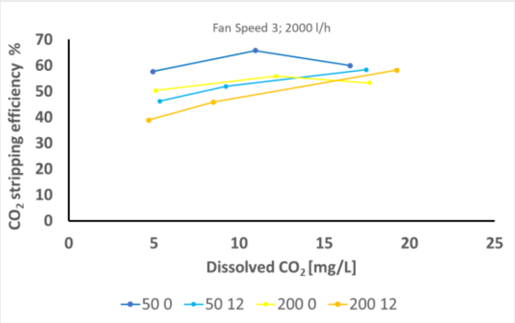




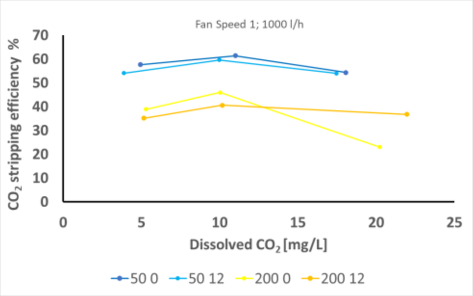
2000 l/h

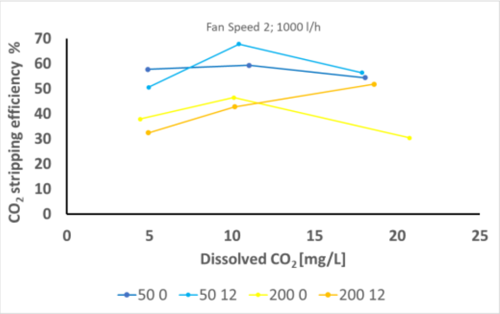


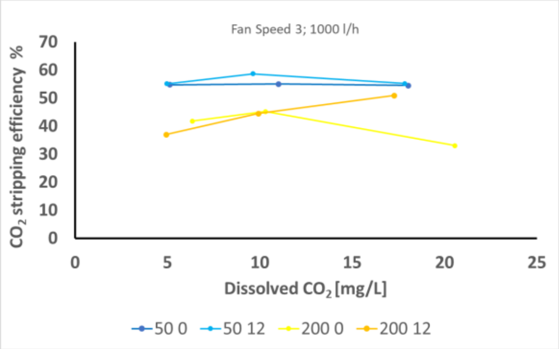




1000 l/h

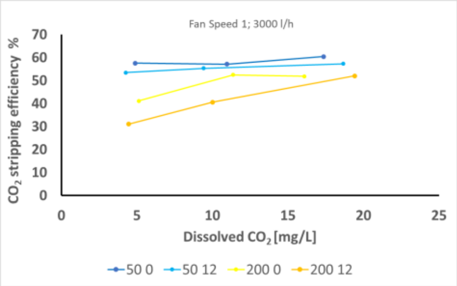


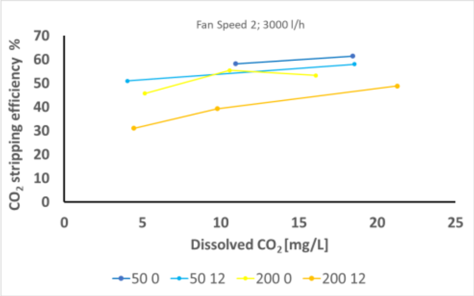


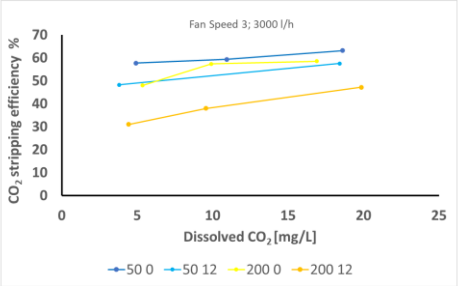


Fan Speed 1 | Fan Speed 2 | Fan Speed 3

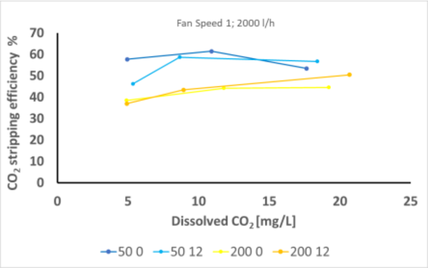
3000 l/h

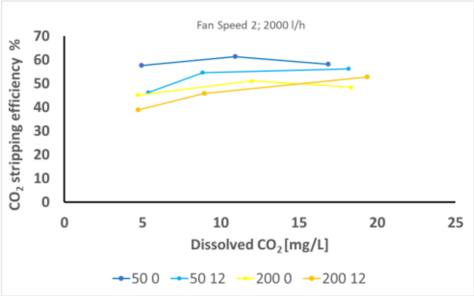


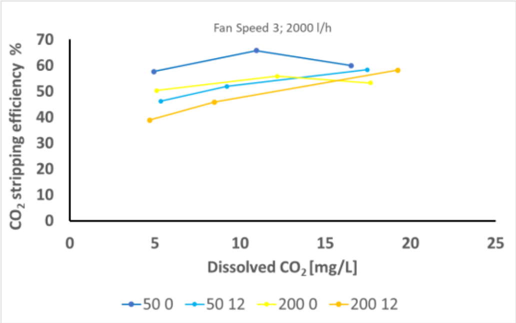




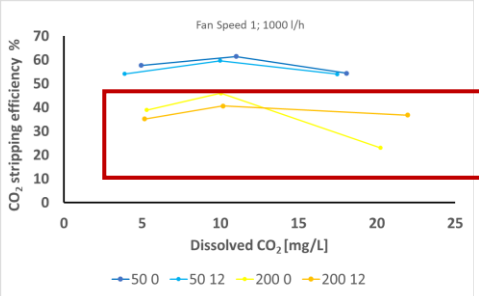
2000 l/h

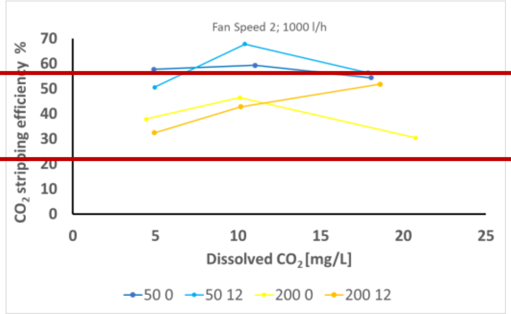


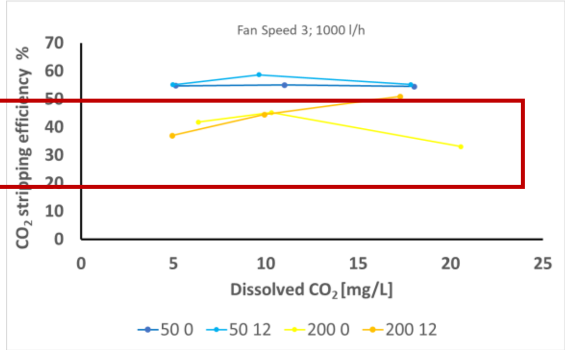




1000 l/h



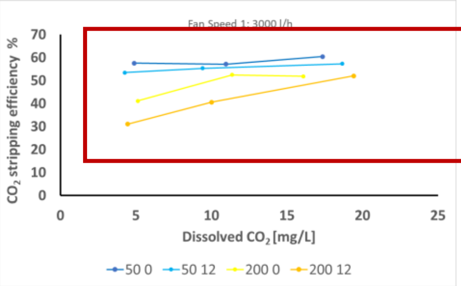


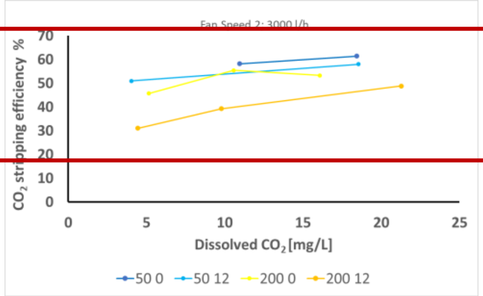


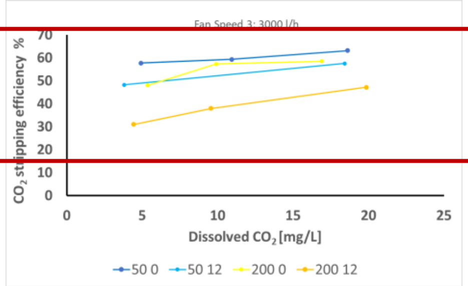
It seems that high alkalinity tend to have a less higher degassing efficiency at higher retention times. Reformation from the carbonate pool likely.

Fan Speed 1 | Fan Speed 2 | Fan Speed 3

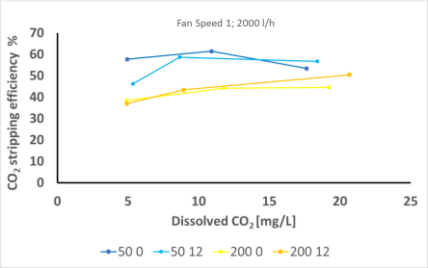
3000 l/h

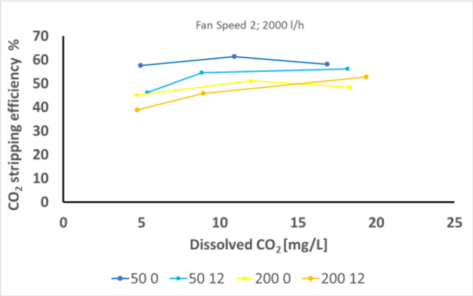


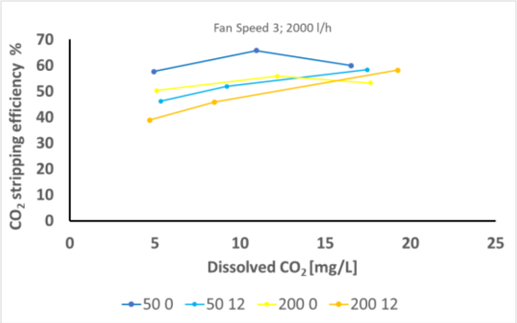




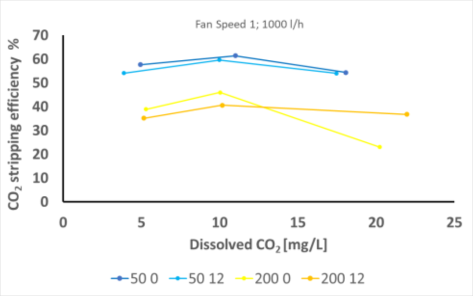
2000 l/h

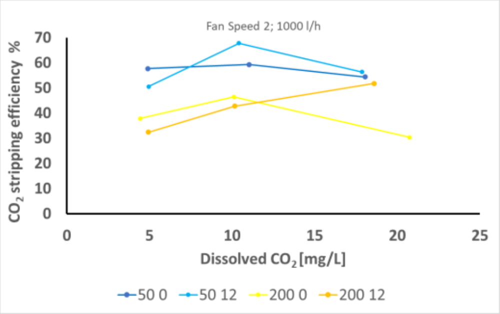


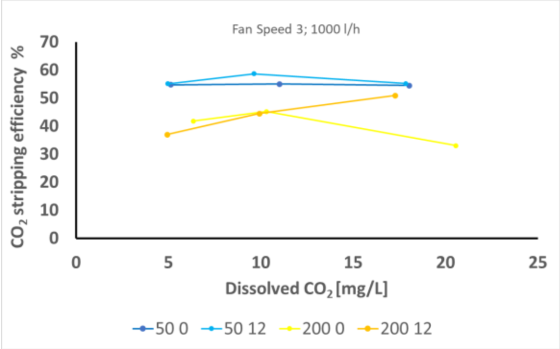




1000 l/h







Salinity effect was difficult to determine. It seems that high alkalinity and brackish water under high water flow rates gave a lover degassing performance.

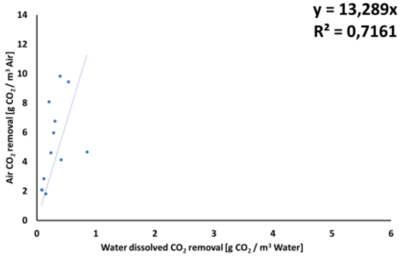
G:L

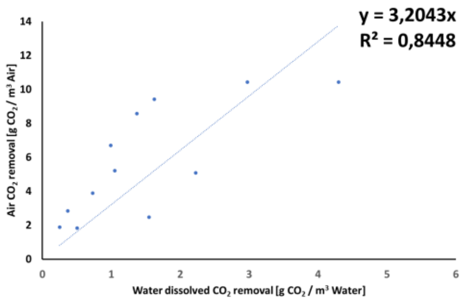
1000 l/h

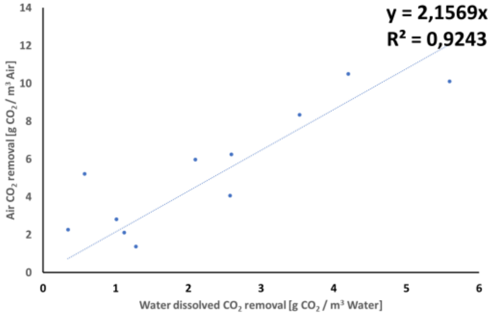
2000 l/h

3000 l/h

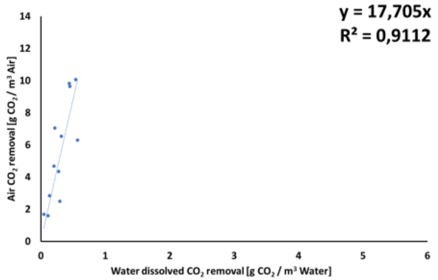
Fan Speed 1

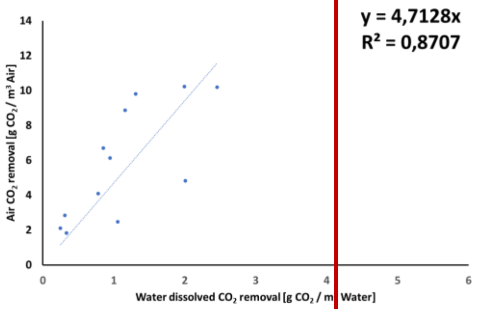


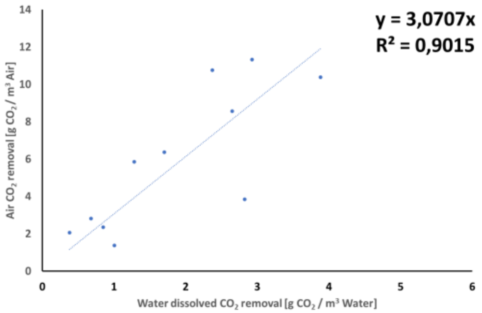




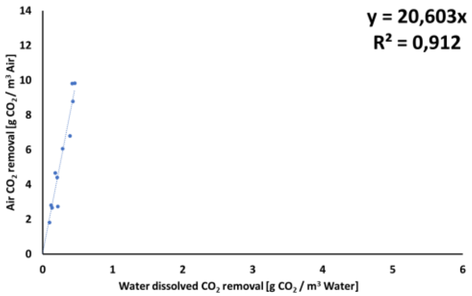
Fan Speed 2

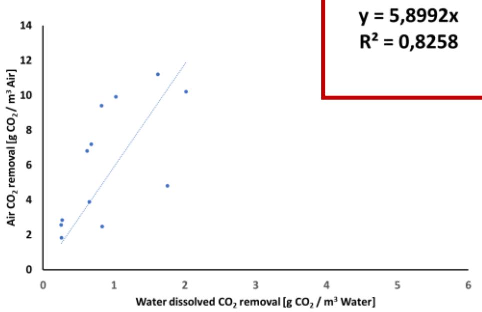


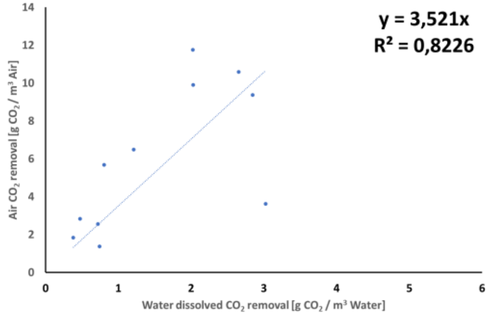




Fan Speed 3







Degassing performance AIR to WATER gives you the GL without having the airflow

RAS Energy modeling

$$P = \Delta p \cdot q \cdot f_{conv}/c$$

Major energy consumers are circulation pump and stripper fan

We assume both can be modelled using the algebraic equation

In the equation:

P [W] is power

Δp [Pa] is the difference between the inlet (suction) and the outlet (discharge) pressures

q [m3/s] is the liquid (for the pump) or air (for the fan) flow rate

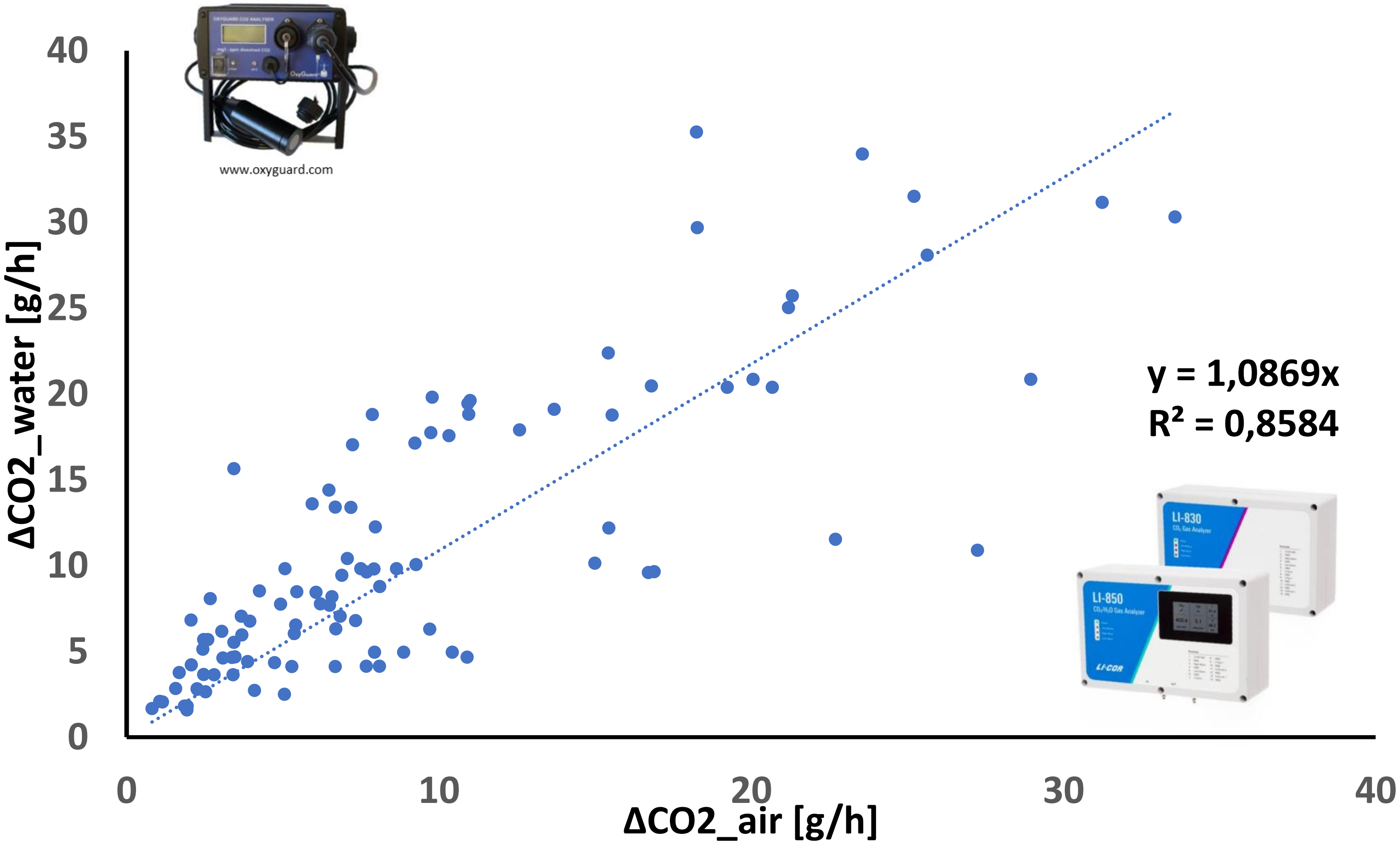
f_conv is a conversion factor:

for the pump we convert from m3/min to m3/s

for the fan we convert from mol/min to m3/s

c is the pump or fan efficiency; in our study we use c=0.8

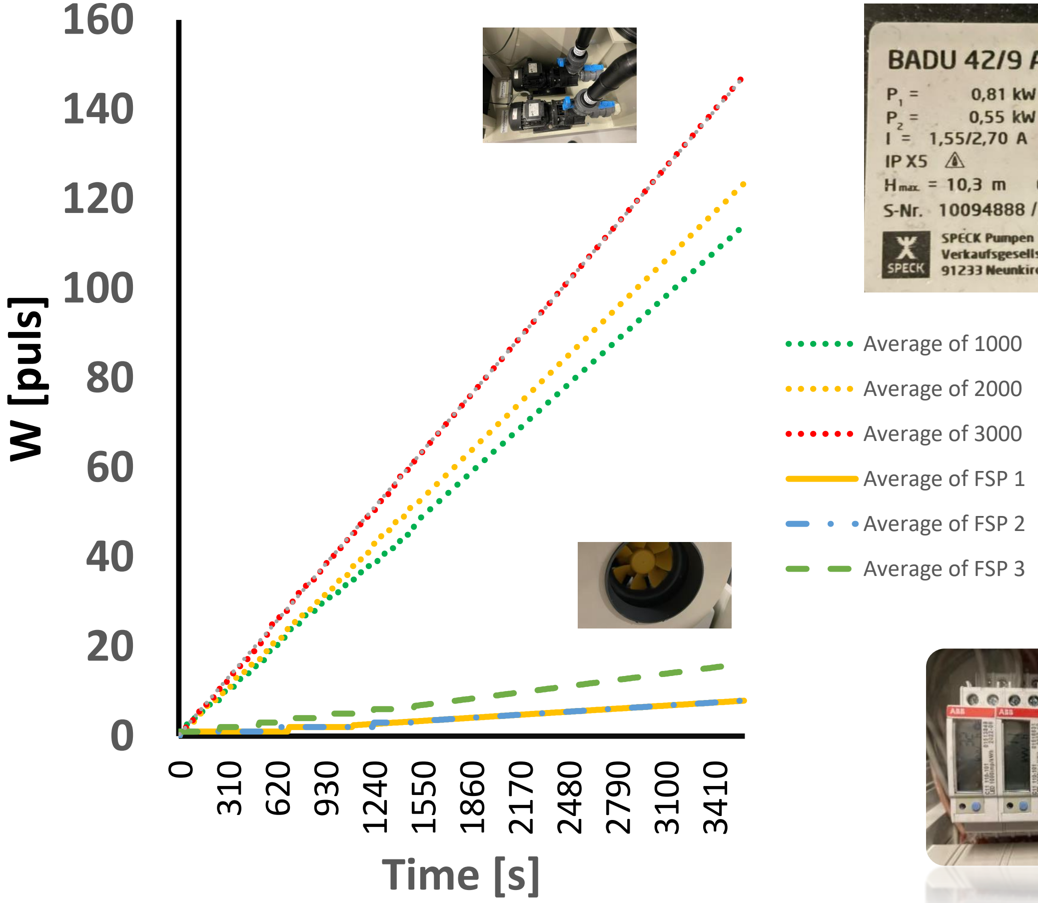
Mass balance degassing g CO_2/h

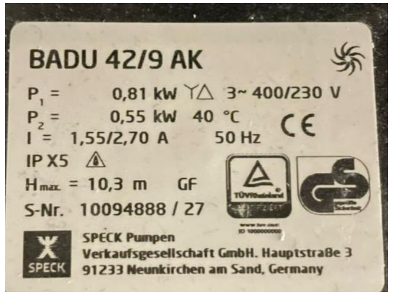


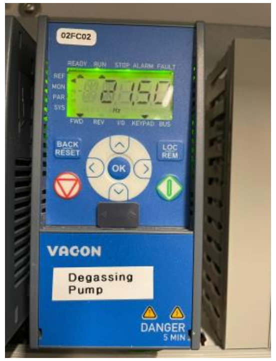
Energy logging ….

1000 (21.50 hz), 2000 (22.70 hz) and 3000 (24.30 hz) L/h water flow rate

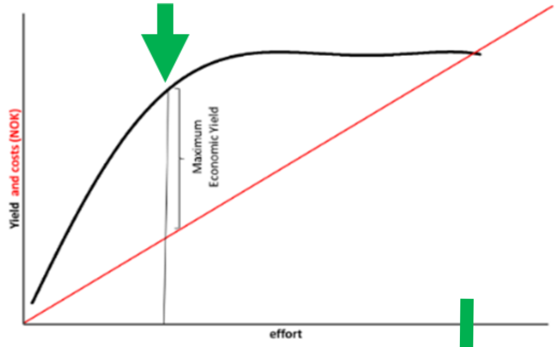
In trickling designs the pumps consume around 10 times the energy than the blower

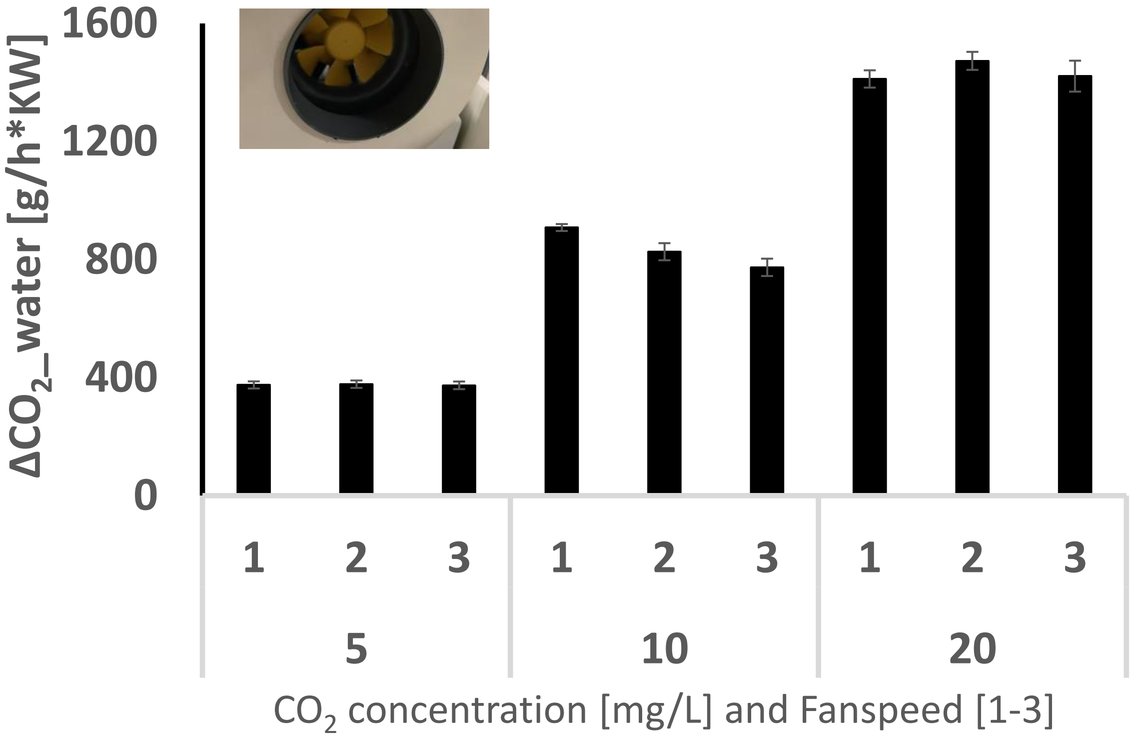


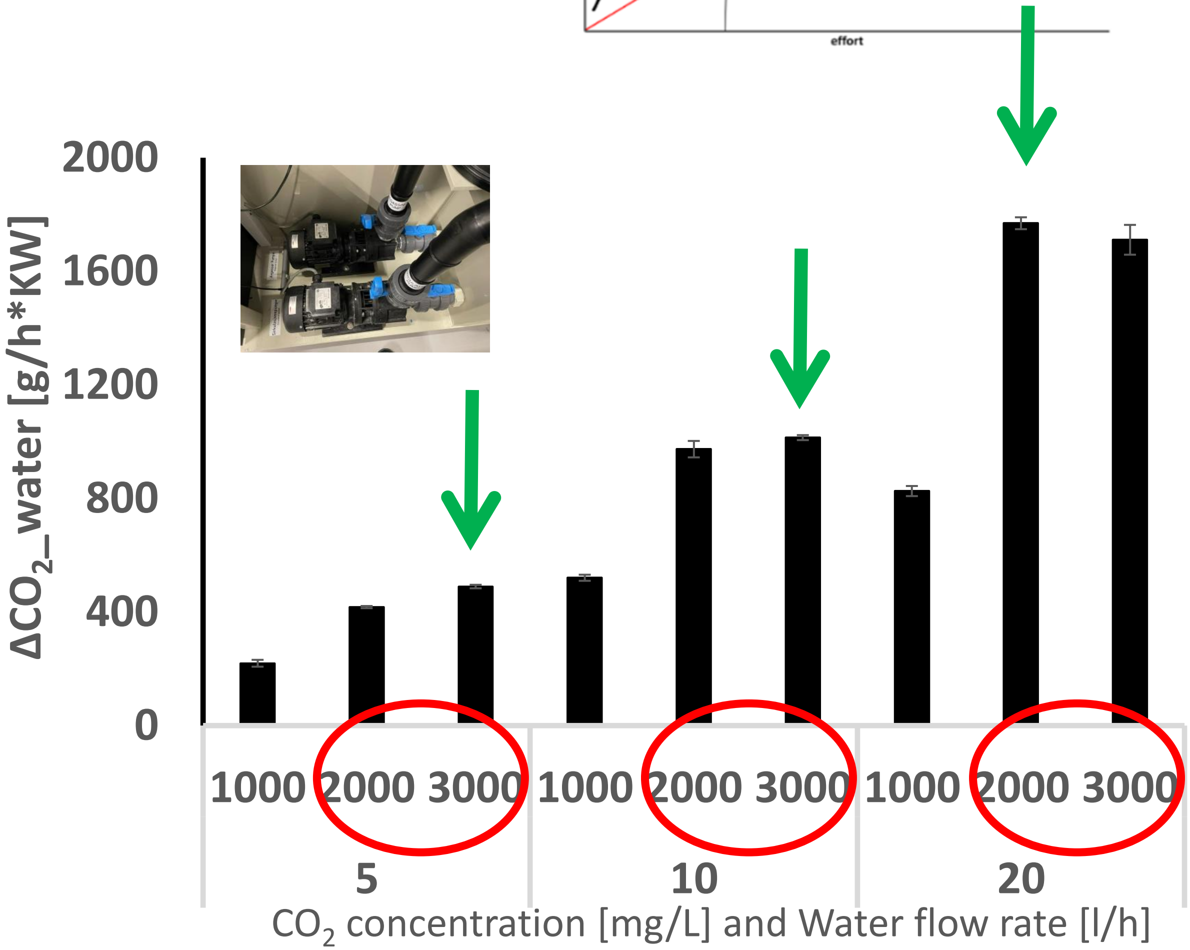

BADU 42/9 AK
P_1 = 0,81 kW Y△ 3~ 400/230 V
P_2 = 0,55 kW 40 °C
I = 1,55/2,70 A 50 Hz
IP X5
H_{max} = 10,3 m GF
S-Nr. 10094888 / 27
SPECK
SPECK Pumpen
Verkaufsgesellschaft GmbH. Hauptstraße 3
91233 Neunkirchen am Sand, Germany



Mass balance degassing: g CO_2/h per KW
You can pick the best energy efficiency to remove CO_2

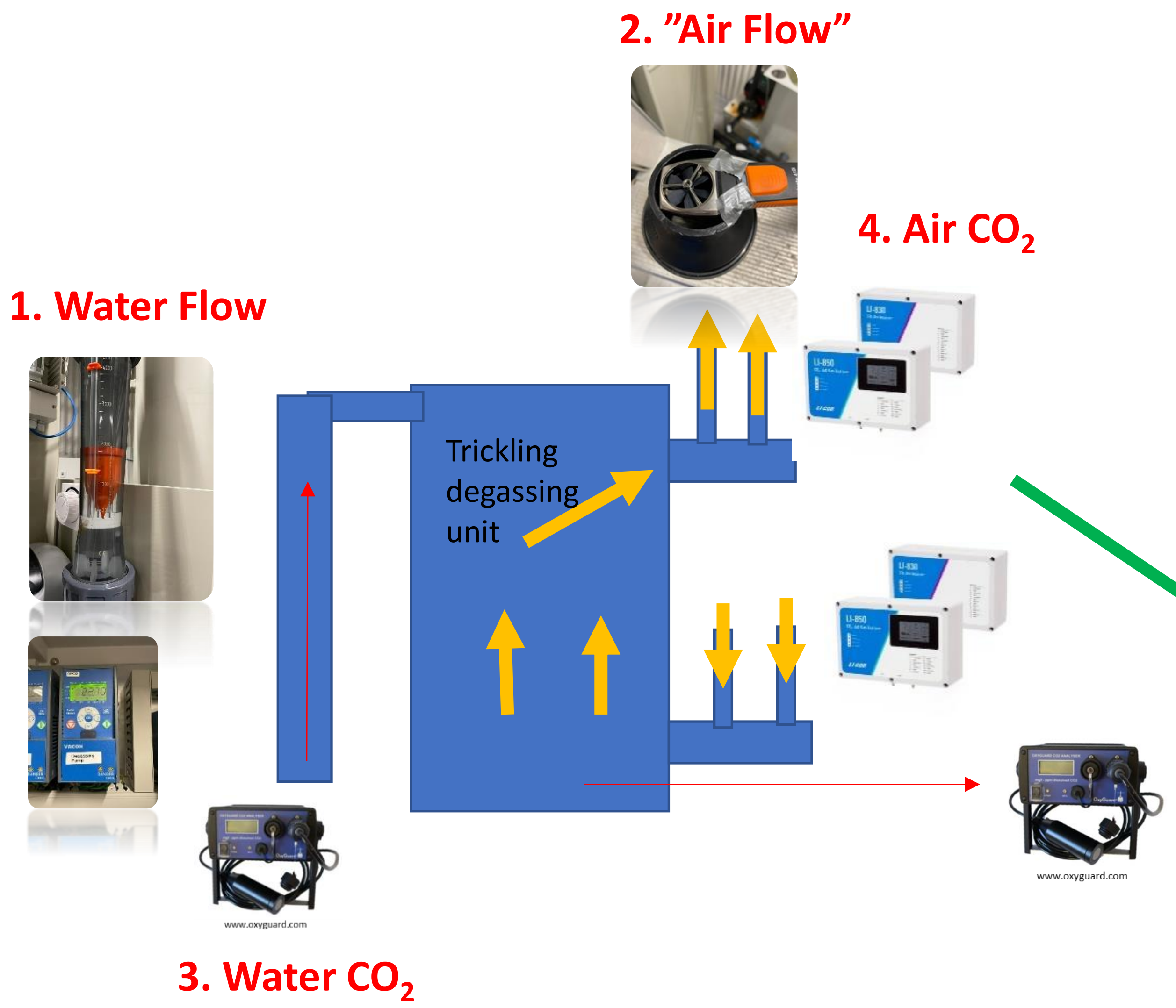




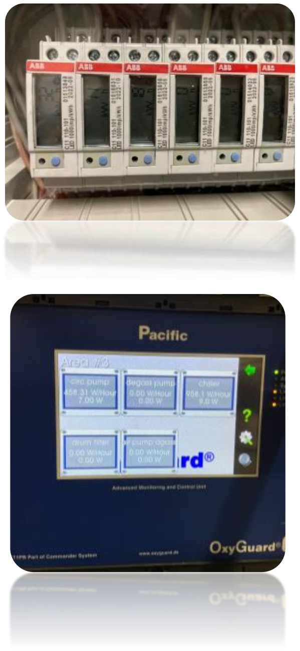


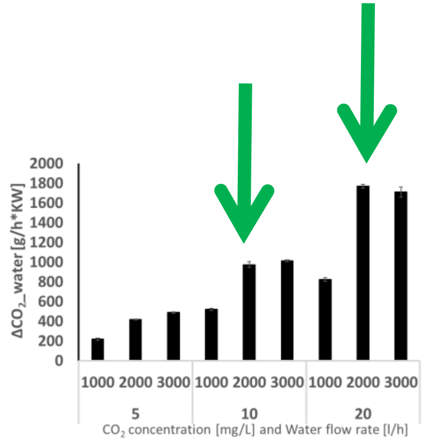
Possible automation feedbacks (in work):

1. «Air» + water + energy measruements = Mass balance degassing
2. Only water or air measurements + energy measruments

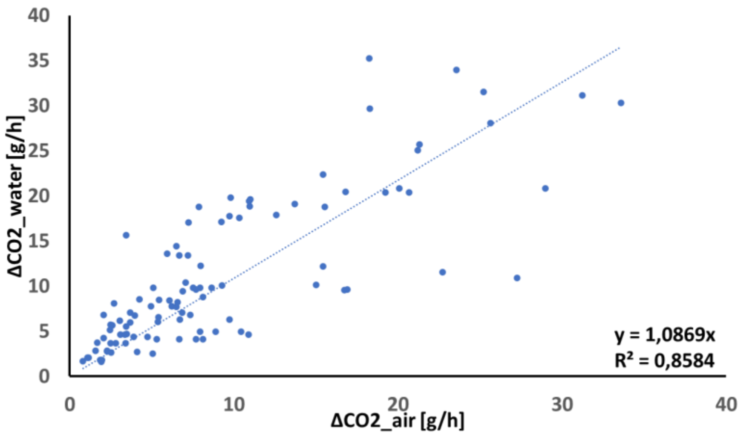


Energy Feedback

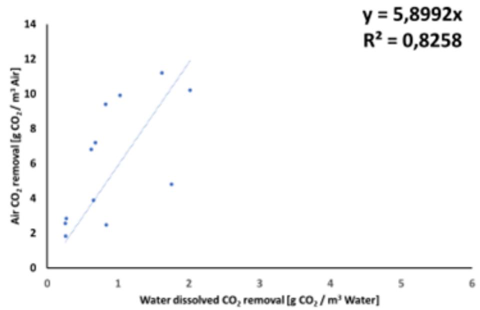




Automated Mass Ballance Degasssing



Discussion and conclusion

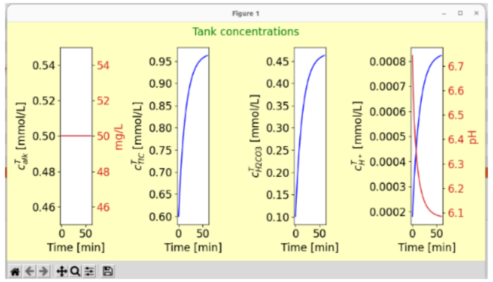


Air vs Water based measurements:

- Companies start working with these approaches
- online air **measurements in milliseconds** of the CO_2 concentrations make the LICORE unit more reliable controlling the degassing unit.
- However, automation would also just work with a submerged units or faster equilibrate units (also air measurements).

NORCE

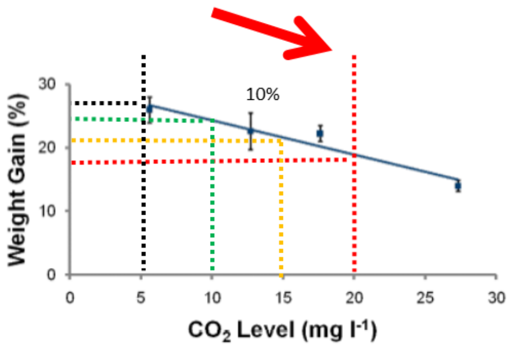
Geir Nævdal

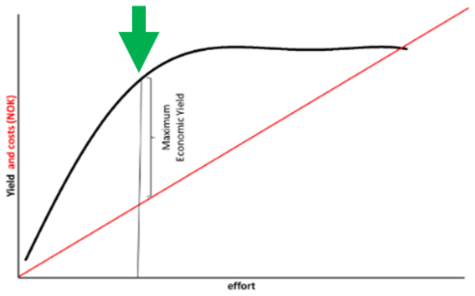


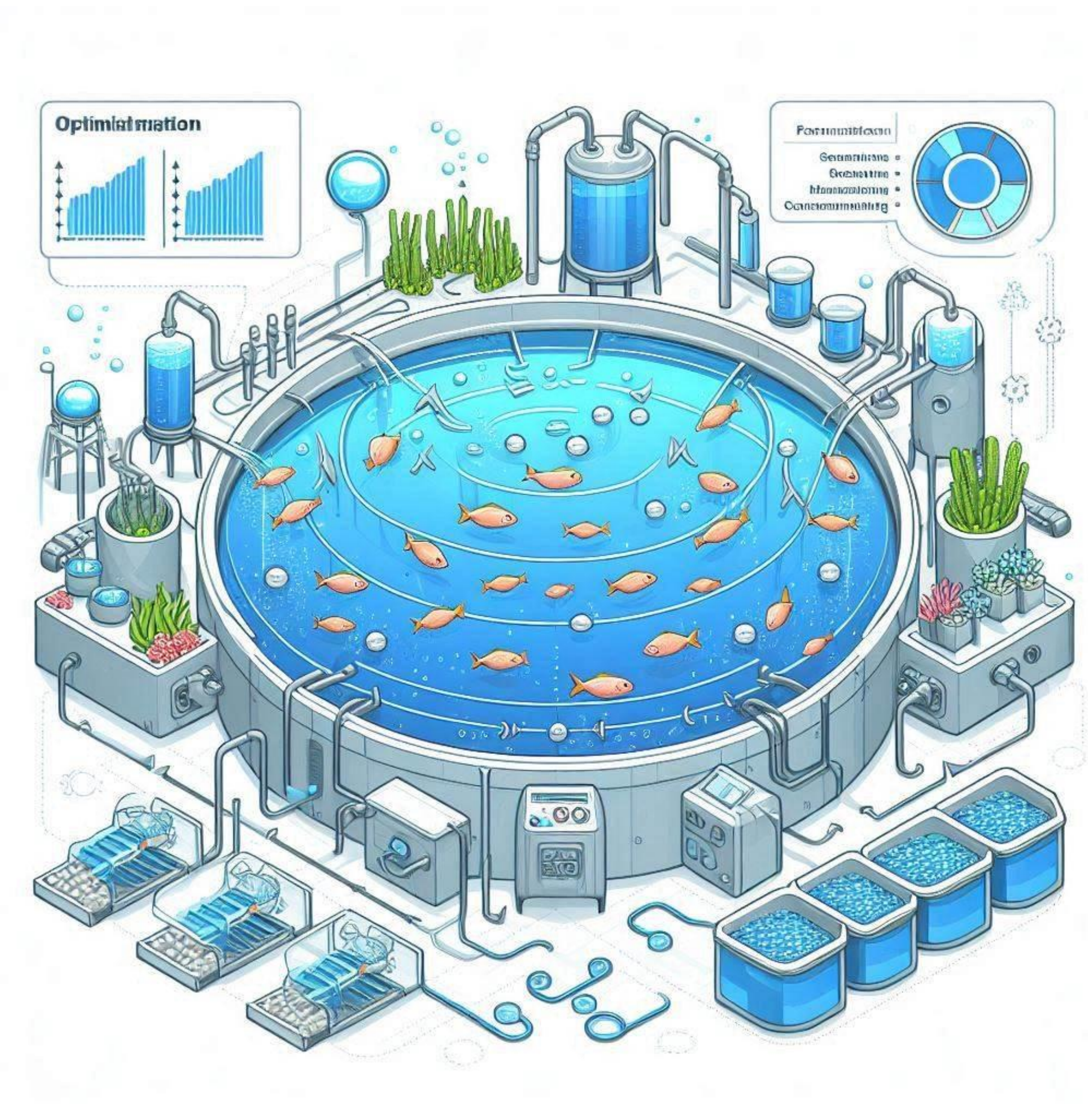
Dos Santos, A. M., Bernardino, L. F., Attramadal, K. J., & Skogestad, S. (2023). Steady-state and dynamic model for recirculating aquaculture systems with pH included. *Aquacultural Engineering*, *102*, 102346.

Energy adjusted automated Mass balance online degassing

- Possible as online measuring technologies are not expensive compared what can possibly be saved on energy over longer time periods.
- Is useful for future energy and degassing efficiency approaches.
- #RAS4.0. Working on model for automation coupled with machine learning. Working at tank threshold concentration at the inflection point energy usage of degassing performance to adjust the degassing pump and blowers.







RAS4.0

Thank you for your attention.

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