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ENHANCED CO2 CAPTURE USING SODA SOLUTION

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Background & Motivation

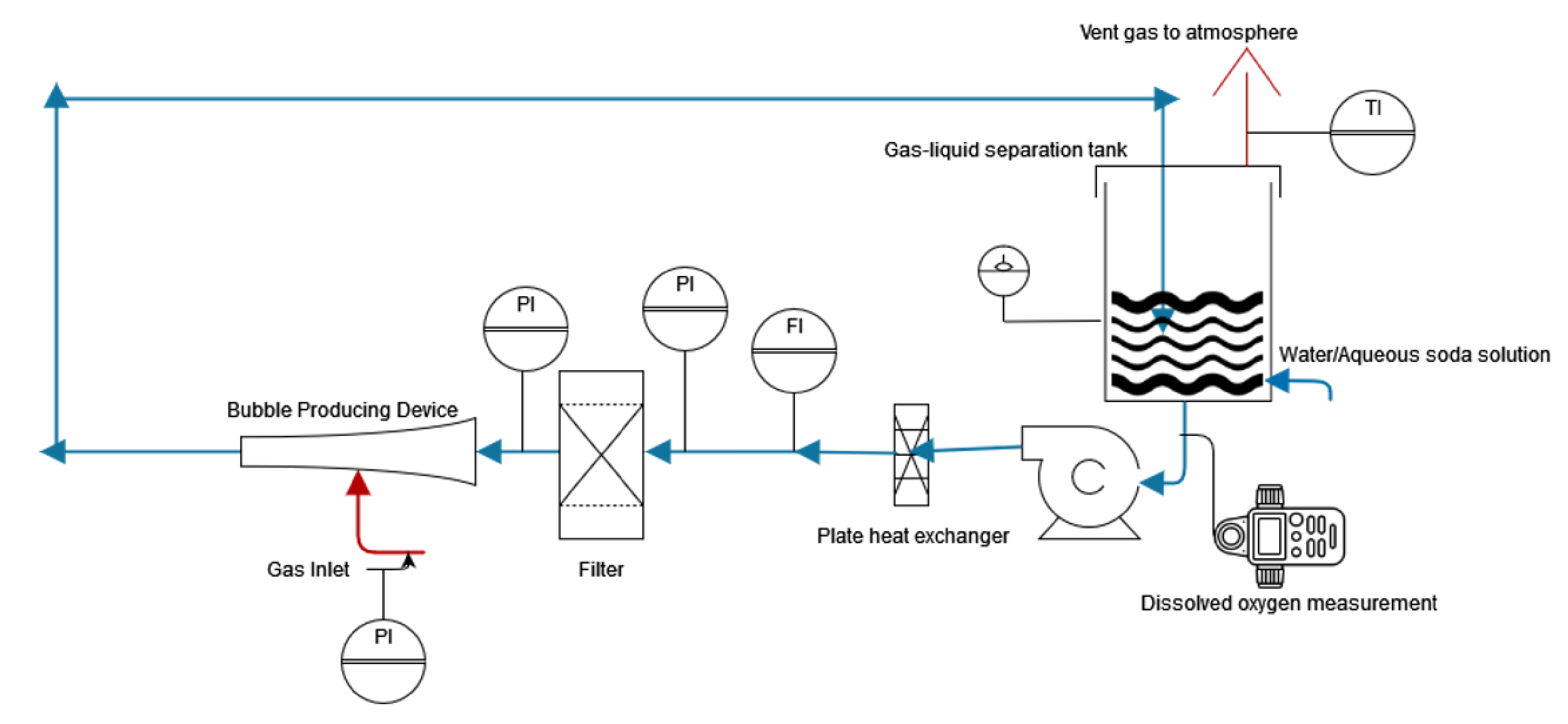
- CO_2 Capture by other methods are quite expensive and complex in treatment
- Na_2CO_3 solution is less corrosive and environment friendly than amines
- Na_2CO_3 solution can be regenerated using low temperature heat (< 70°C) in vacuum while amines need steam for regeneration
- 8 w-% Na_2CO_3 solution is better than water for absorbing CO_2 since absorption capacity of water is low and need cooling to lower temperature but the limitation of Na_2CO_3 solution is slow mass transfer than amines
- The knowledge of accurate absorption rate of CO_2 capture using soda solution employing a device to generate bubbles is not available in other research

Similar Processes

- Stockholm Exergy installed a pilot unit in Värtan's combined BECCS plant which extracts flue gases emitted out by KVV8 unit involving hot potassium carbonate technology (HPC). Capture rate was 80-95% [1]
- Addition of surfactant PPGME (poly propylene glycol methyl ether) into the carbonate solution to increase its absorption rate and to decrease the gas bubble size was tested in Michigan Technological university, 14 % increase in absorption rate was observed without any decrease in absorption capacity [2]
- Self aerated gas sparger developed by Outotec (Filters) Oy was tested and the aeration capacity, bubble sizing were measured using high speed camera, oxygenation efficiency was compared with similar systems [4]

Experimental setup and Methods

- Nitrogen is purged into the system for some time and dissolved oxygen is measured until it is close to zero.
- The nitrogen valve is closed and air valve is opened, dissolved oxygen is measured.



Mass transfer rate – with no chemical reaction

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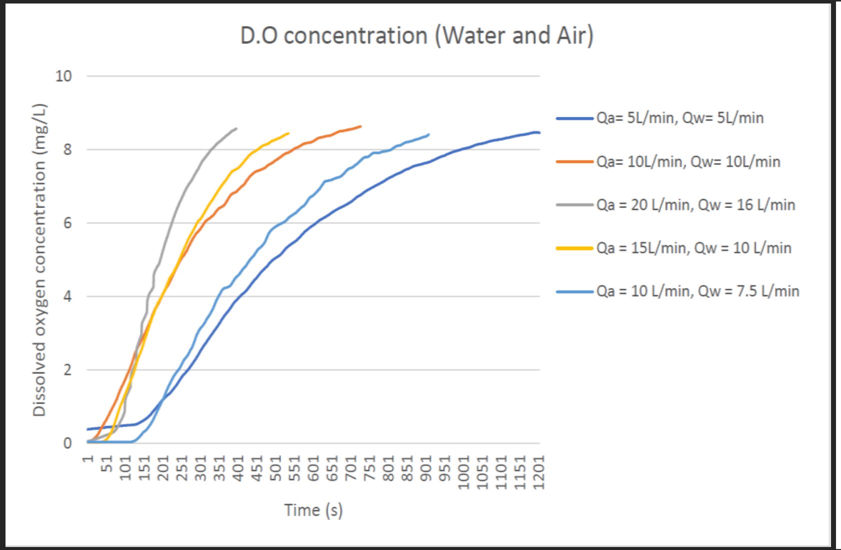
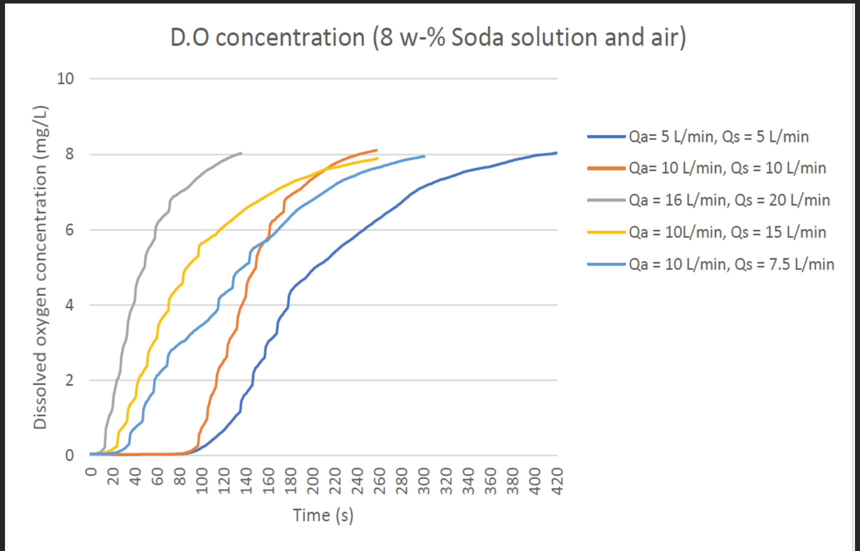
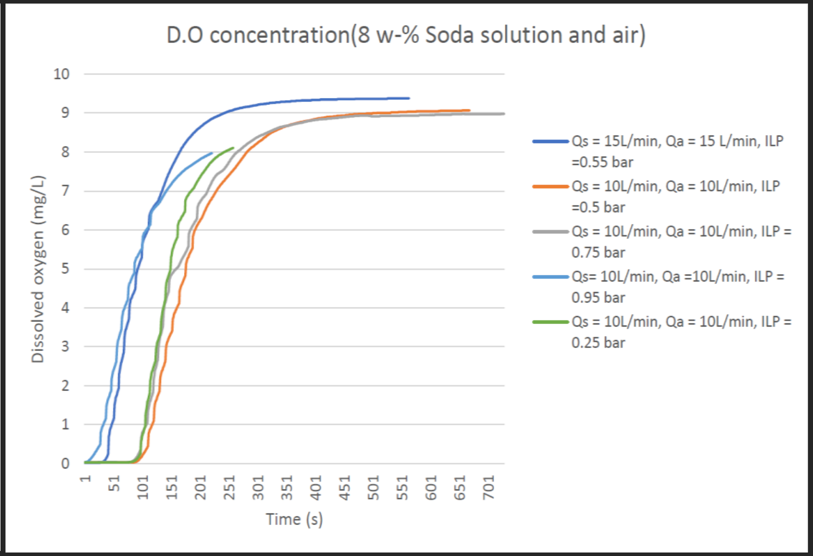
- Time lag/ response time measurements were performed for the DO probe which is used in modelling of mass transfer rate
- Dissolved oxygen concentration was measured after the gas-liquid separation tank and after the bubble producing device for water and air, 8 w-% Na_2CO_3 solution and air using DO probe (YSI Pro ODO)







Mass transfer rate – with no chemical reaction

$$\frac{d}{dt}C_g = -\frac{Q_g}{\varepsilon_g S}\frac{d}{dx}C_g - \frac{k_L a\,(C_g - C_L)}{\varepsilon_g S}$$

$$\frac{d}{dt}C_L = \frac{Q_L}{(1-\varepsilon_g)S}\frac{d}{dx}C_L + \frac{k_L a\,(C_g - C_L)}{(1-\varepsilon_g)S}$$

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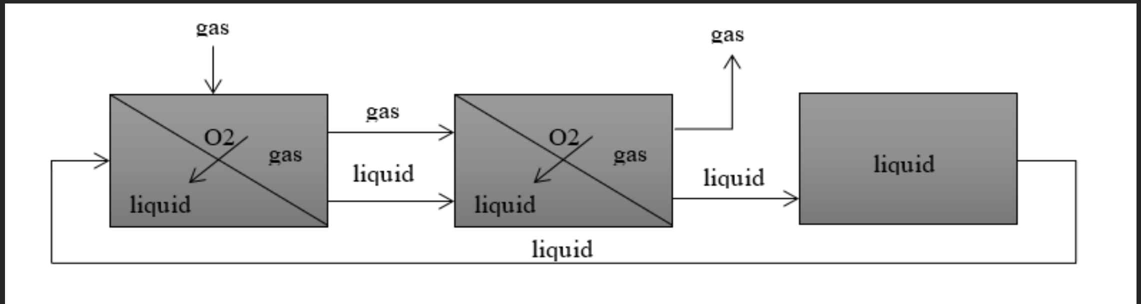
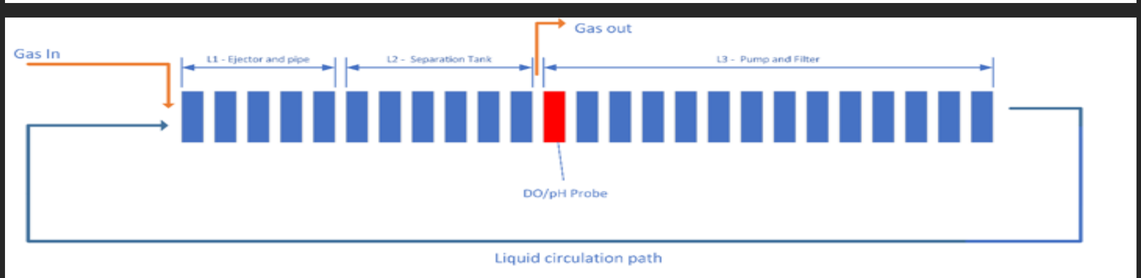
- Diffusion of dissolved oxygen in the solution changes the concentration of oxygen in the liquid over time and distance, data fitting was performed in estimating the dynamics of oxygen changing the K_La so that deviations between model data and measured dissolved oxygen data are minimized
- The experimental setup was assumed to be a continous loop reactor with plug flow reactor properties
- K_La modelling was performed in MATLAB assuming no mass transfer in gas-liquid separation tank





Q_{air} (L/min)	Q_{water} (L/min)	$k_L a$ (1/s)
5	5	0.0054
10	7.5	0.0033
10	10	0.0113
10	15	0.0111
16	20	0.0147

Q_{air} (L/min)	$Q_{8\,w\text{-}\%\,Na2CO3}$ (L/min)	$k_L a$ (1/s)
5	5	0.015
10	7.5	0.0167
10	10	0.0139
10	15	0.0342
16	20	0.0634

$$Na_2CO_3 + CO_2 + H_2O \rightleftarrows 2\ NaHCO_3$$

Mass transfer rate - with chemical reaction

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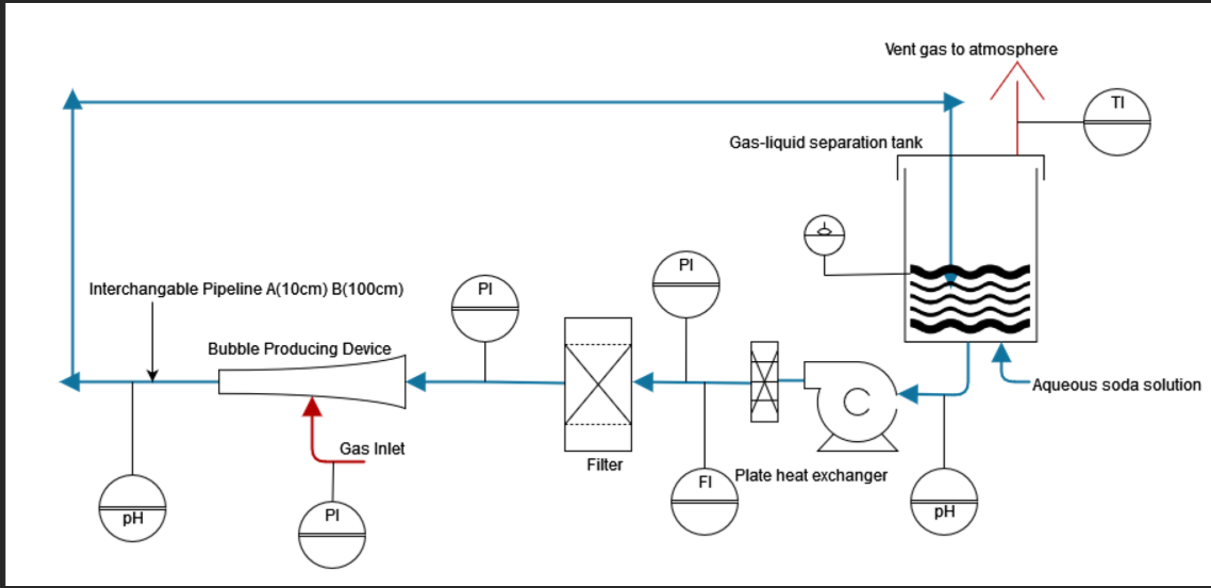
- Experimental setup was arranged in 3 ways to measure the efficiency of the system for CO_2 absorption using 8 w-% Na_2CO_3 solution
- Testing with pipe A (small) and pipe B (large), testing with low liquid level in the gas-liquid seperation tank using pipe A, testing with vertically mounted ejector using pipe A

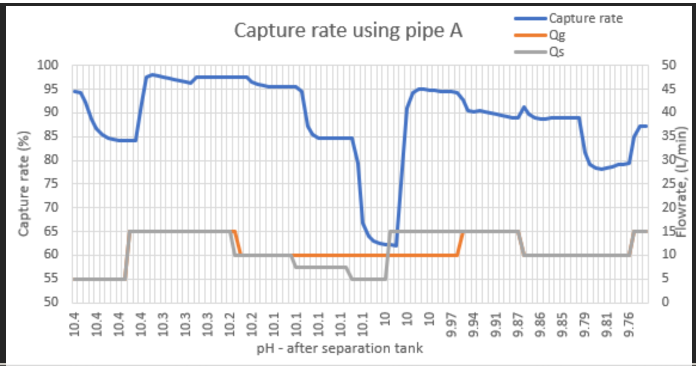


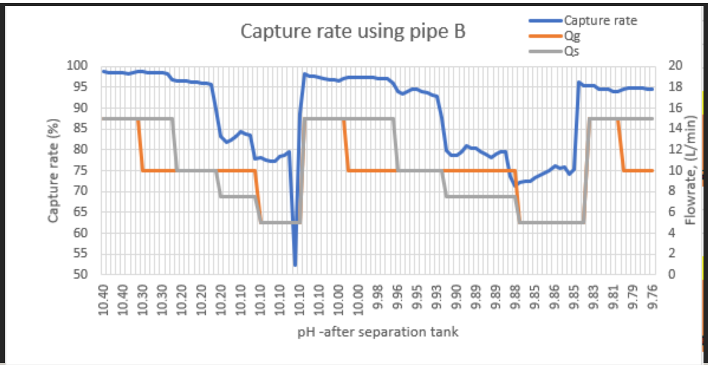
- pH was logged after the bubble producing device and after the gas-liquid separation tank, CO_2 lean gas was analysed and recorded

Mass balance and capture rates

Experimental Setup	CO_2 in (g)	CO_2 out (g)	Run Time (min)	Capture rate (%)	pH – after gas-liquid separation tank
Using Pipe A (small)	571.3	44.76	149	92	11.4 – 9.76
Using Pipe B (large)	636.3	86.35	191	86	10.4 – 9.37
Low liquid level in gas-liquid separation tank	656.8	135.15	164	79	11.2 – 9.03
Vertically mounted bubble producing device	214.65	0.93	69	99	11.6 – 10.3

Experimental Setup	CO_2 in (g)	CO_2 out (g)	Run Time (min)	Capture rate (%)	pH – after gas-liquid separation tank
Using Pipe A (small)	396.81	43.09	120	89	10.4 – 9.76
/Using Pipe B (large)	381.42	34.72	111	91	10.4 – 9.76
Low liquid level in gas-liquid separation tank	220.64	26.23	62	88	10.4 – 9.76
Vertically mounted bubble producing device	40.19	0.25	17	99	10.4 – 9.76





$$CR(\%) = \frac{y(CO_2)_{in}\ \dot{v}_{in} - y(CO_2)_{out}\ \dot{v}_{out}}{y(CO_2)_{in}\ \dot{v}_{in}}$$

Mass Transfer rate estimation-with Chemical reaction

- Mass transfer rate was estimated by assuming no CO_2 is present in the bulk of the solution, so that the reaction is sufficiently is fast. This assumption is valid by passing the condition 1
- Condition 1: $k_L a \ll \alpha_L K_2 C_B^0$ Condition 2: $\left[\frac{D_A K_2 C_B^0}{k_L^2}\right] \ll 1$ There is a sufficient amount of reaction happening in film, verified by condition 2 [4]
- An excel model was developed based on the assumptions and K_La values for corresponding flowrates was estimated using the data of vent gas mixture.

Scenario	with pipe A	
Q_{gas} (L/min)	Q_{liquid} (L/min)	Liquid mass transfer coefficient with reaction (1/s)
5	5	0.13
10	10	0.24
10	7.5	0.15
10	15	0.8
10	10	0.11
10	7.5	0.11
10	15	0.3

Scenario	with pipe B	
Q_{gas} (L/min)	Q_{liquid} (L/min)	Liquid mass transfer coefficient with reaction (1/s)
5	5	0.19
10	10	0.19
10	7.5	0.21
10	15	0.5
5	5	0.08

Enhancement and Pumping Energy Input

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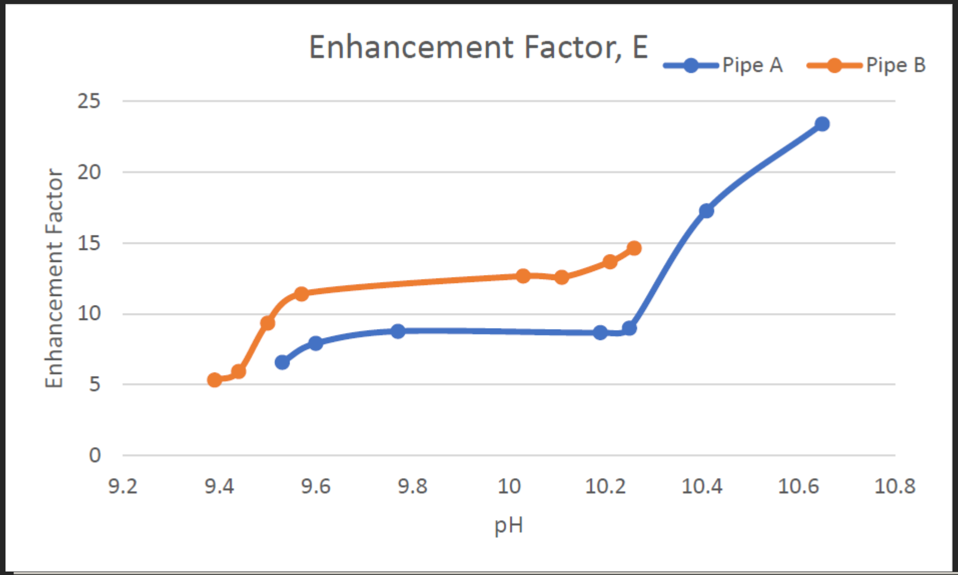
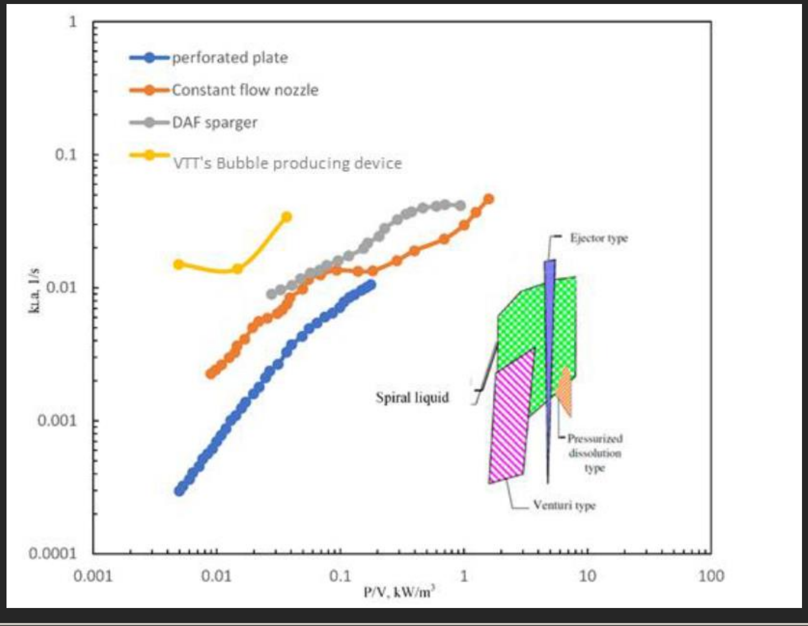
- Enhancement Factor, by comparing the mass transfer rate with reaction and without reaction. Mass transfer is enhanced by roughly 10 times due to chemical reaction happening around a pH 10 in the solution
- VTT's bubble producing device is in a bit higher position in terms of mass transfer efficiency as a trade off for pumping energy input





- Adopted from : Dmitry Gradov, Auto-Aspirated DAF Sparger Study on Flow Hydrodynamics, Bubble Generation and Aeration Efficiency, 2021

Conclusions & Remarks

- L/G ratio appears to be more important since it affects the mass transfer, ideal L/G ratio and residence time will be 1.25 (8 w-% Na_2CO_3 solution =15L/min, synthetic gas mixture 10L/min) and
- Pipe A (short pipe) is more efficient than pipe B (longer pipe) since in pipe B bubbles start to agglomerate soon and mass transfer is limited
- With soda solutions due to chemical reaction absorption is enhanced approximately 10 times
- Commercializing of this VTT's novel soda process was started by Kleener Power Solutions Ltd.

Acknowledgements

- My sincere thanks to Dr. Kristian Melin (Assistant professor, LUT University) Tuula Kajolinna,, VTT (Technical Research Centre of Finland) for providing a conducive atmosphere to experiment and learn.
- In the photo: Test group of VTT and LUT at the test facilities in VTT Espoo, August 2021. Persons in the picture are Mohankumar Narayanasamy (LUT), Tuula Kajolinna (VTT), Kristian Melin (LUT), Andrey Saren (LUT) and Johannes Roine (VTT). Picture: VTT

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Thanks for listening!

Questions?

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Blog from VTT: https://www.vttresearch.com/en/news-and-ideas/novel-eco-friendly-technology-capture-co2