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Monitoring and control of bioprocesses using non- invasive tools

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Passive Acoustic Emission (PAE)

Receiver only principle → only detects the energy a process/ material releases itself.

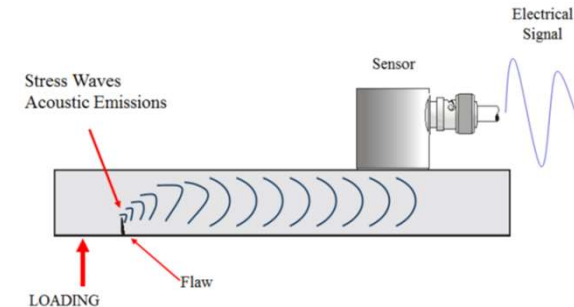
Traditionally applied to monitor material fatigue and corrosion over time and to detect leakages.

Popular technique in chemical engineering for pressure vessel monitoring.

Most popular execution as Distributed Acoustic Sensor (DAS).

(Dis)Advantages:

- + Affordability.
- + no restrictions in pipe size/ shape.
- + no need to add additional energy sources.
- + long history in construction engineering.
- + cheap scale up.
- Highly complex and noise-rich signals.
- New technology within fluid flow

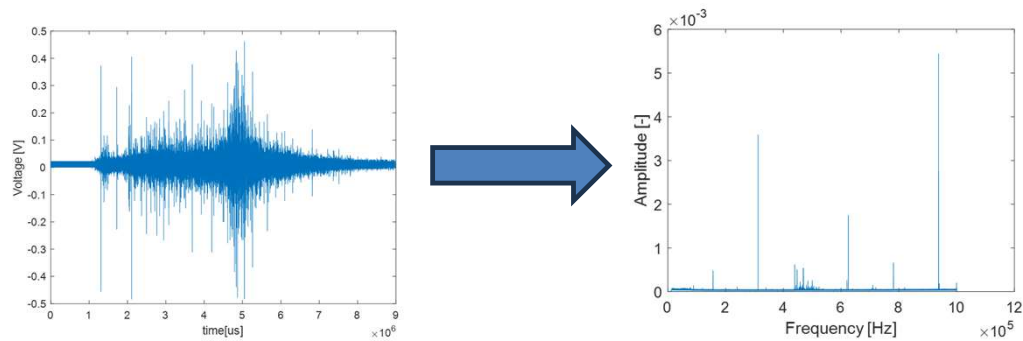
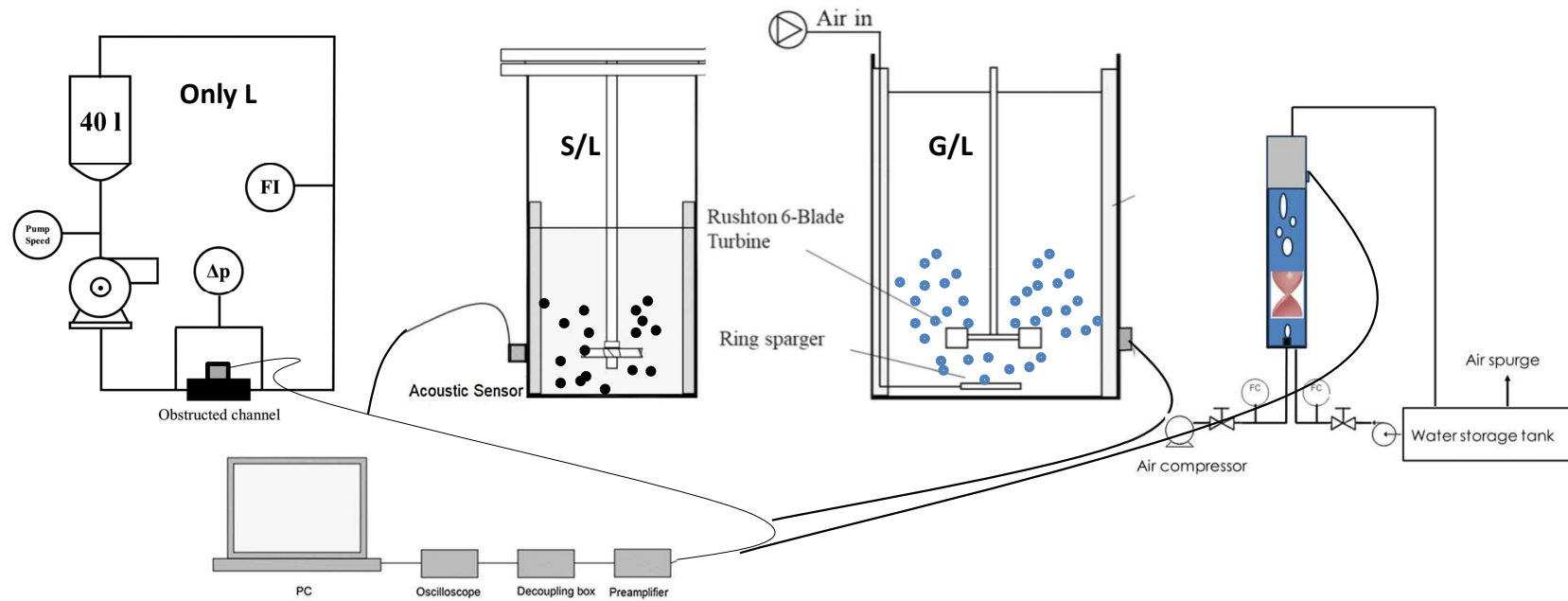


http://www.shipstructure.org/SHM_1_Lee.pdf

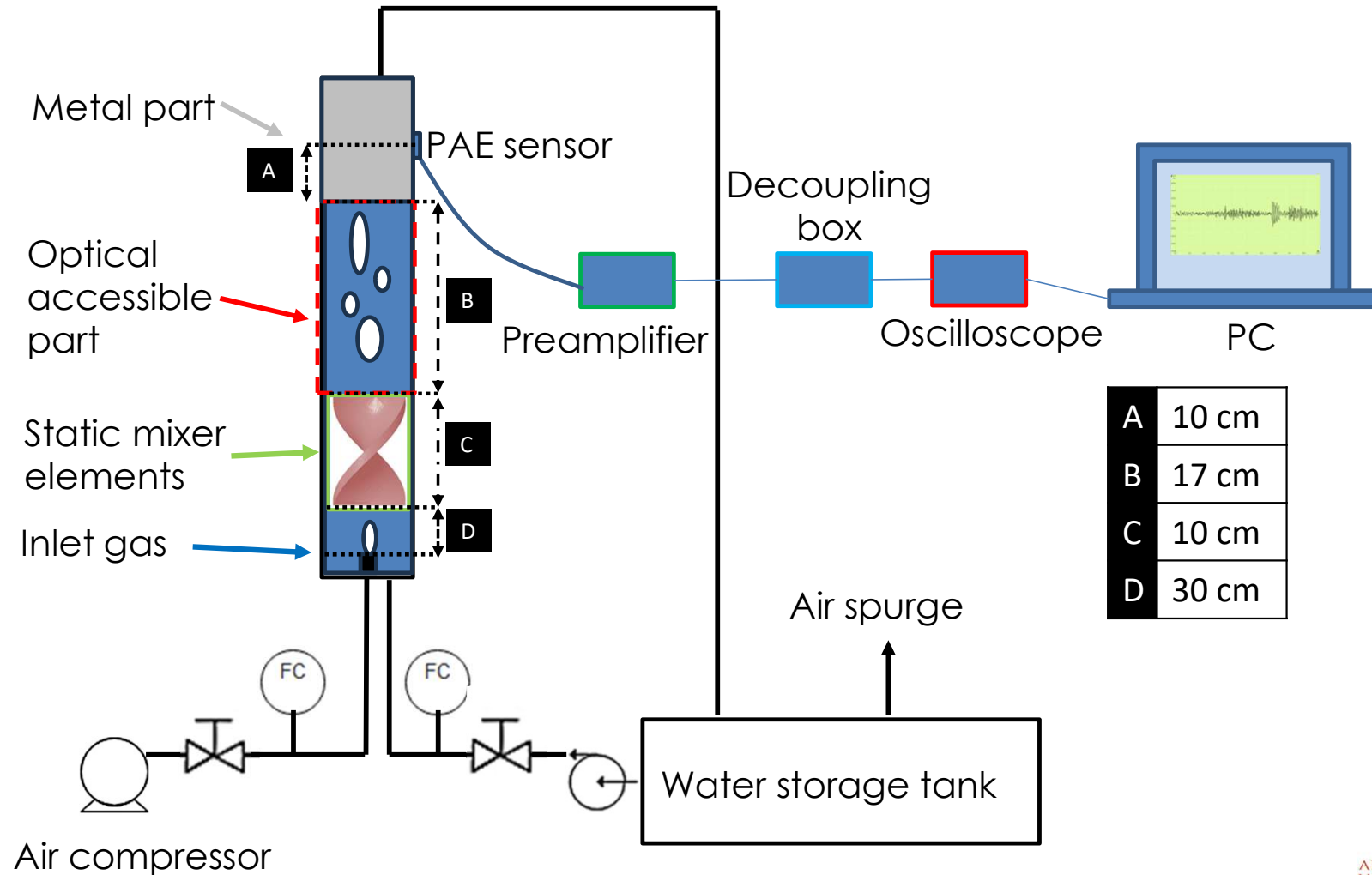


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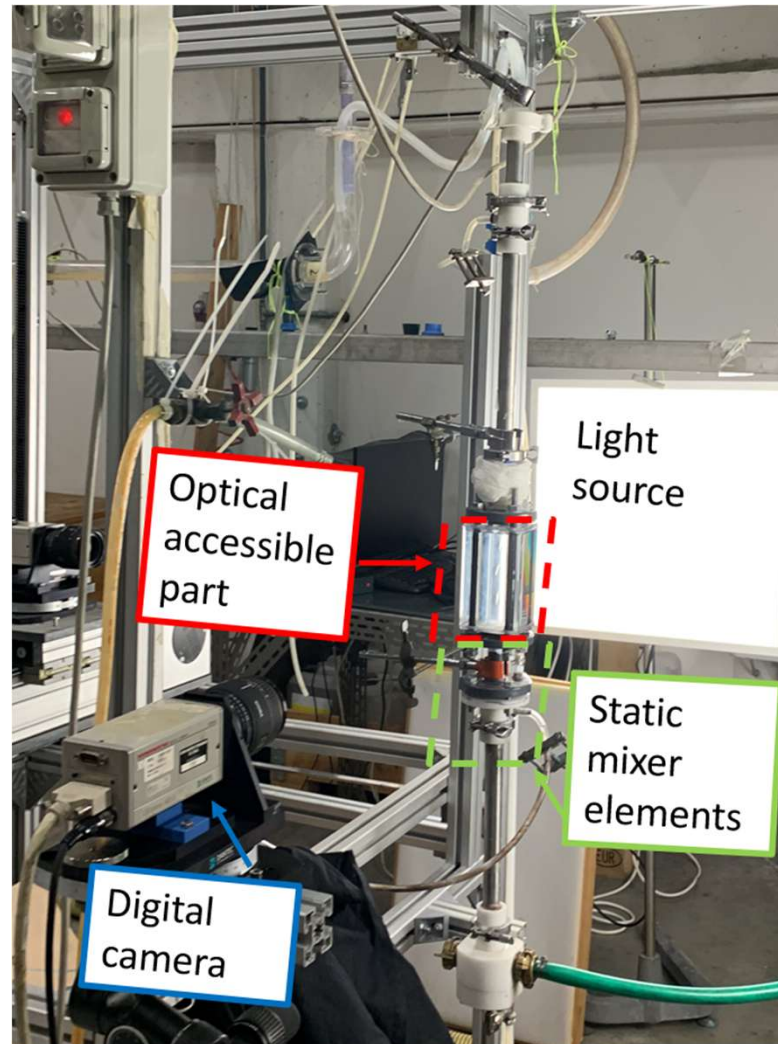
Previous works: Passive Acoustic and fluid flow

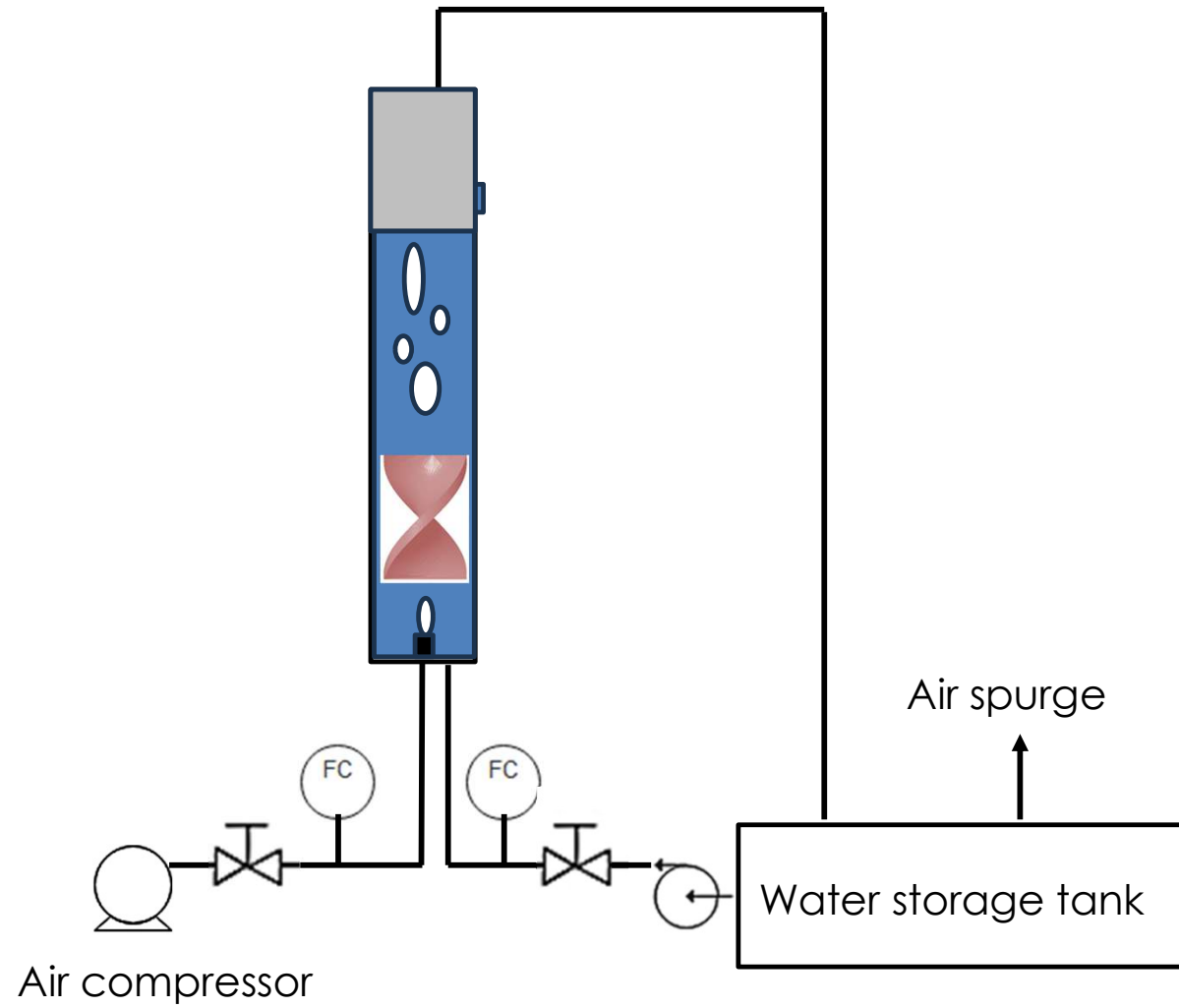


Experimental rig and measurement technique

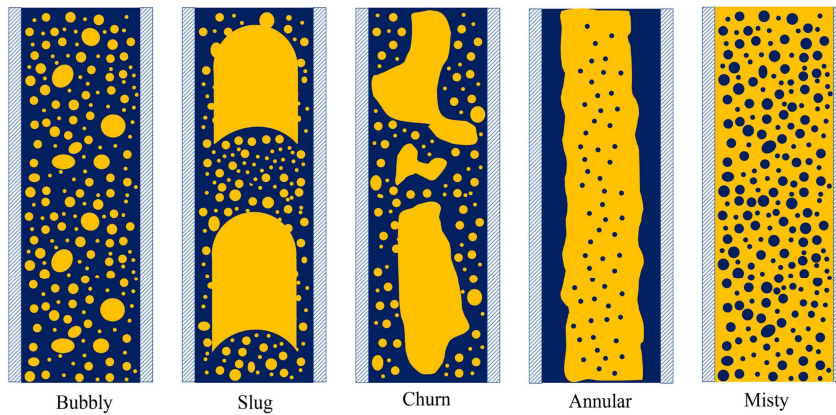


Experimental rig and measurement technique

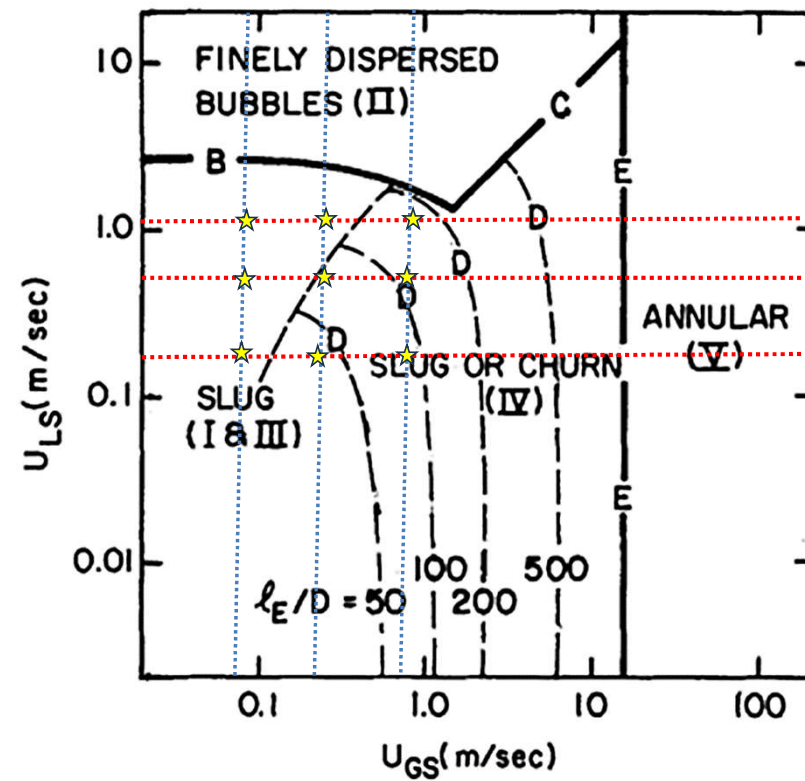




Experimental Gas/Liquid flow rates



Holagh S, Ahmed W (2024)



Taitel Y, et al. (1980)

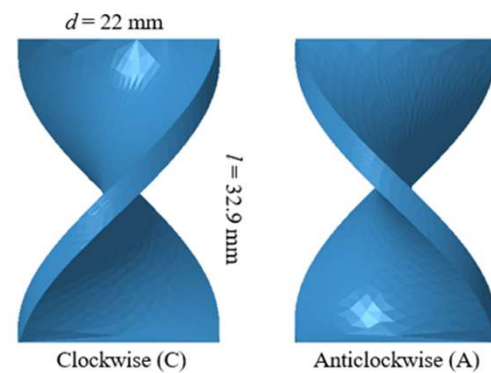


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Selection of static mixer and configurations

For this work we have investigated the following configurations:

- ❑ no static mixer (called lately empty pipe)
- ❑ C-C-C: enhance separation particularly when the system is in bubbly flow, due to centrifugal forces which separate the two phases.
- ❑ C-A-C: enhance dispersion particularly when the system is in bubbly flow

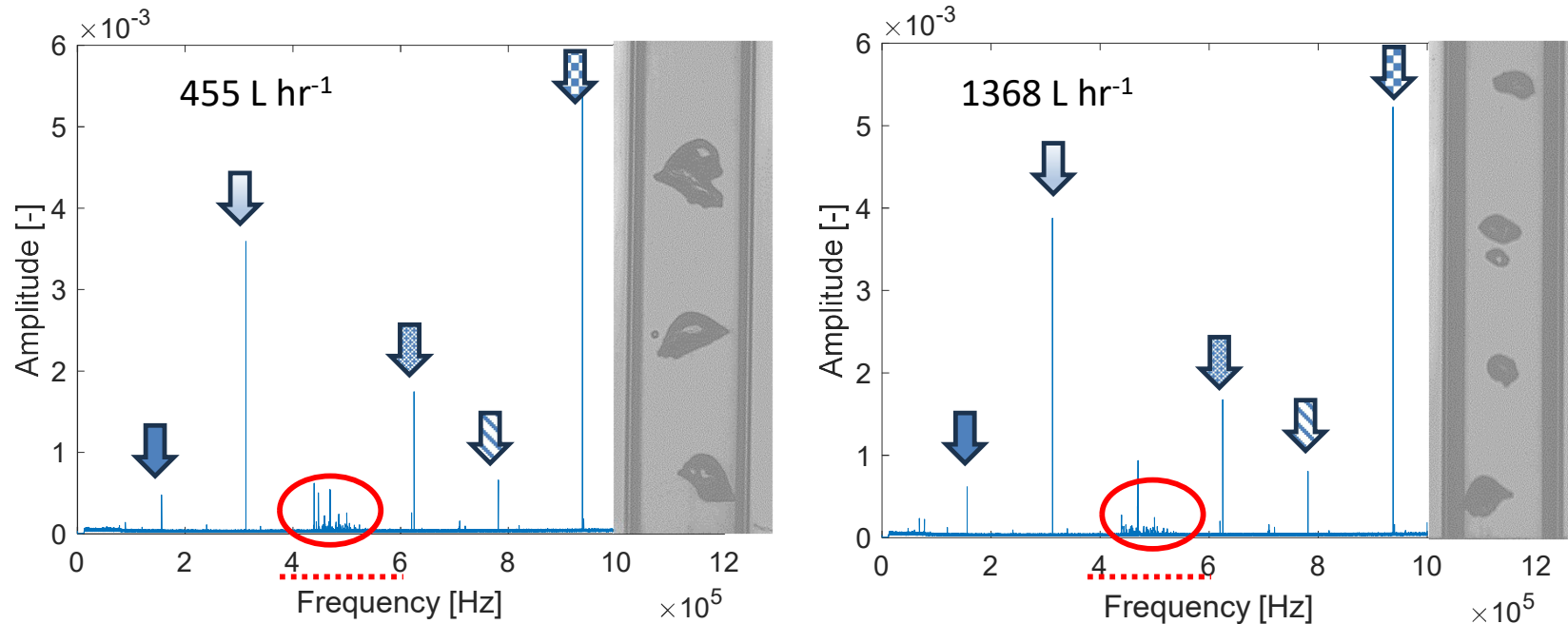


Adapted from Yao Z. et al. (2023)



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Empty pipe: constant gas flow rate 1.5 L min⁻¹, varying liquid flow rates; *ENTIRE SPECTRUM (E S)*



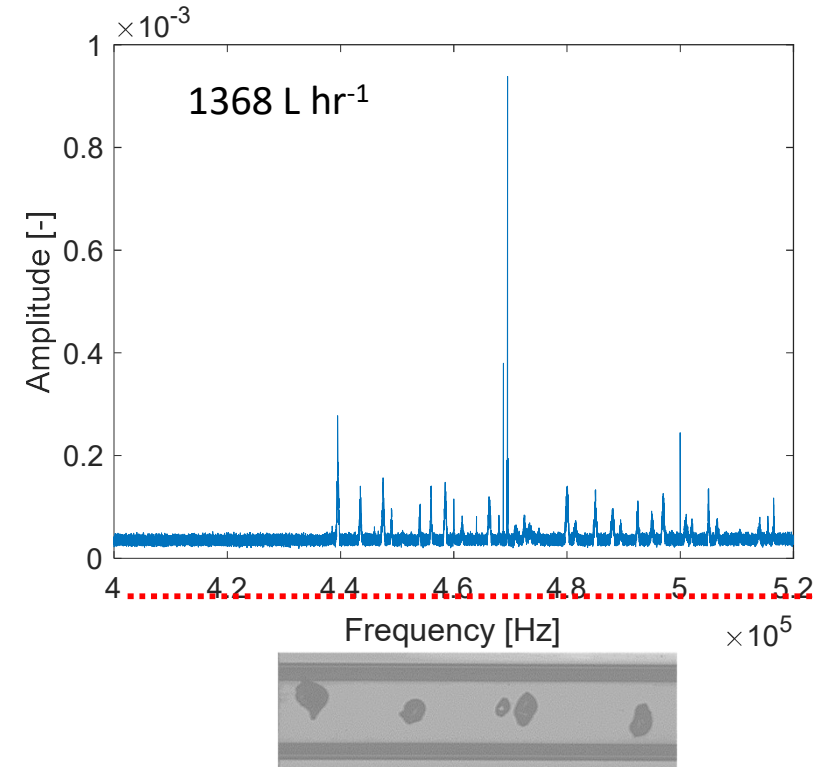
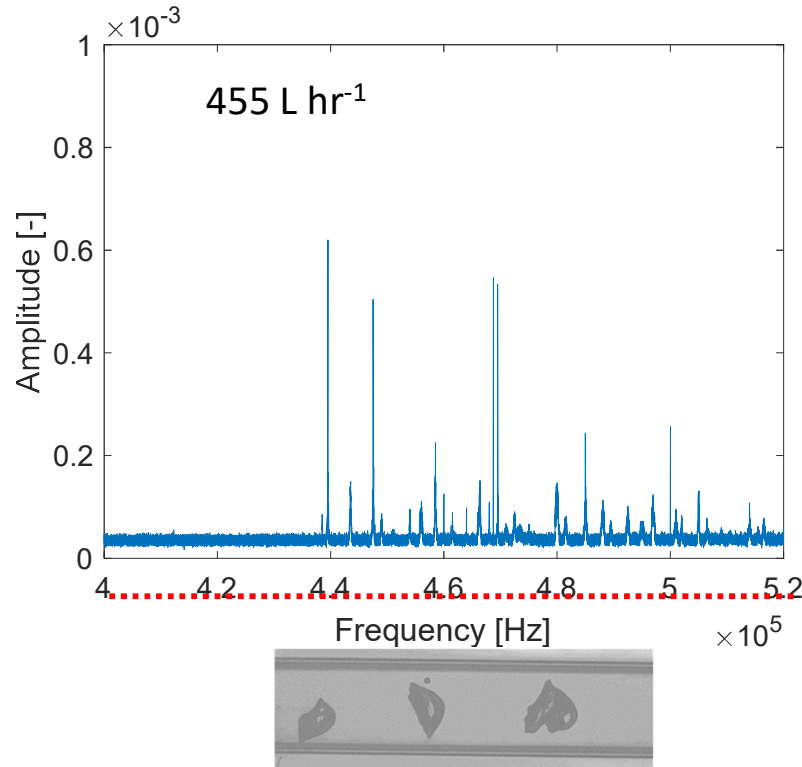
↓ Arrows represent specific frequencies which are identical at given **gas** flow rate and different liquid flow rate.

○ Circled range of frequencies is where the signal in the frequency domain changes mostly varying the shape and size of the gas bubbles



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Empty pipe: constant gas flow rate 1.5 L min^{-1} , varying liquid flow rates; *ZOOMED SPECTRUM (Z_S)*.

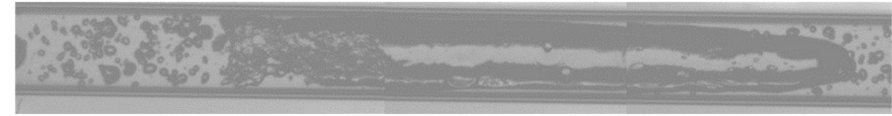
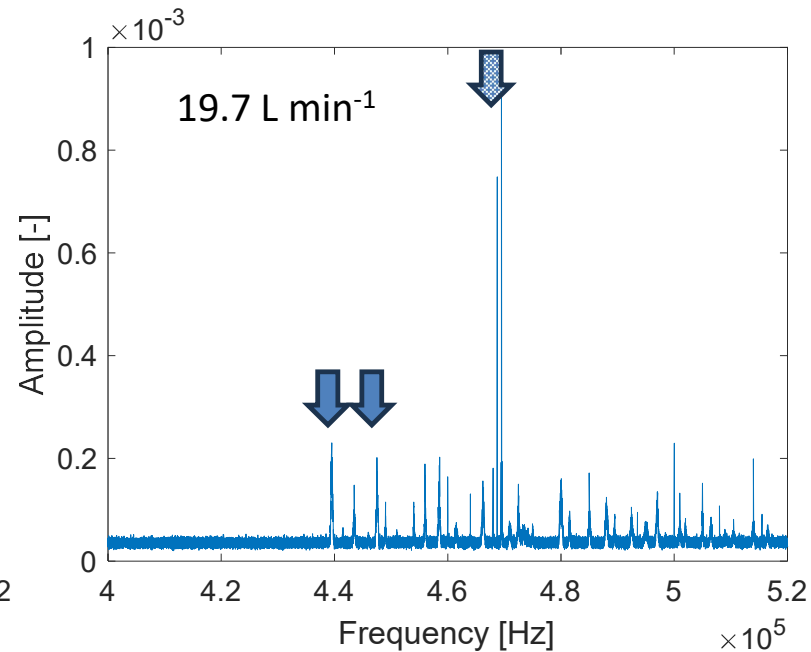
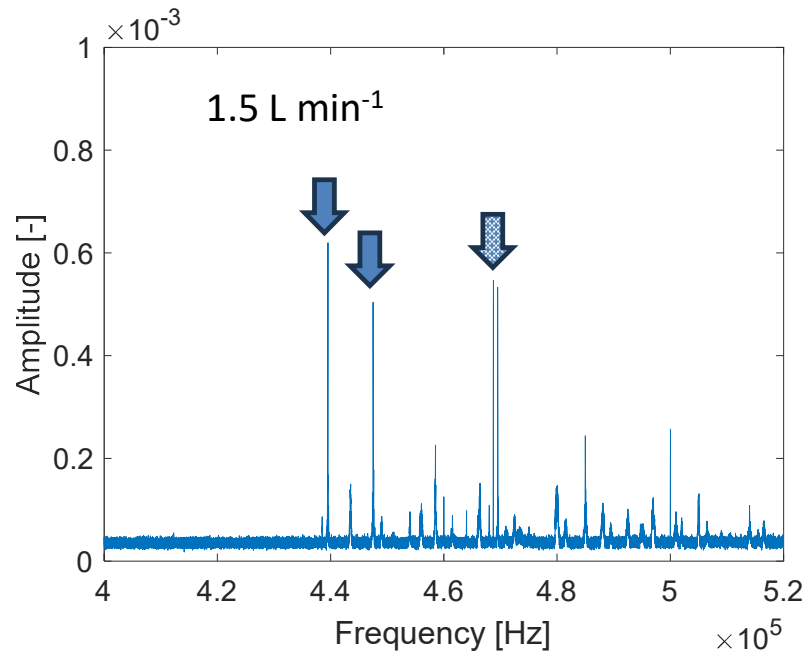


Tendency of shifting peaks towards higher frequencies which follow the decrease in sizes of the bubbles



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Empty pipe: constant liquid flow rate 455 L h⁻¹, varying gas flow rates; (Z S)



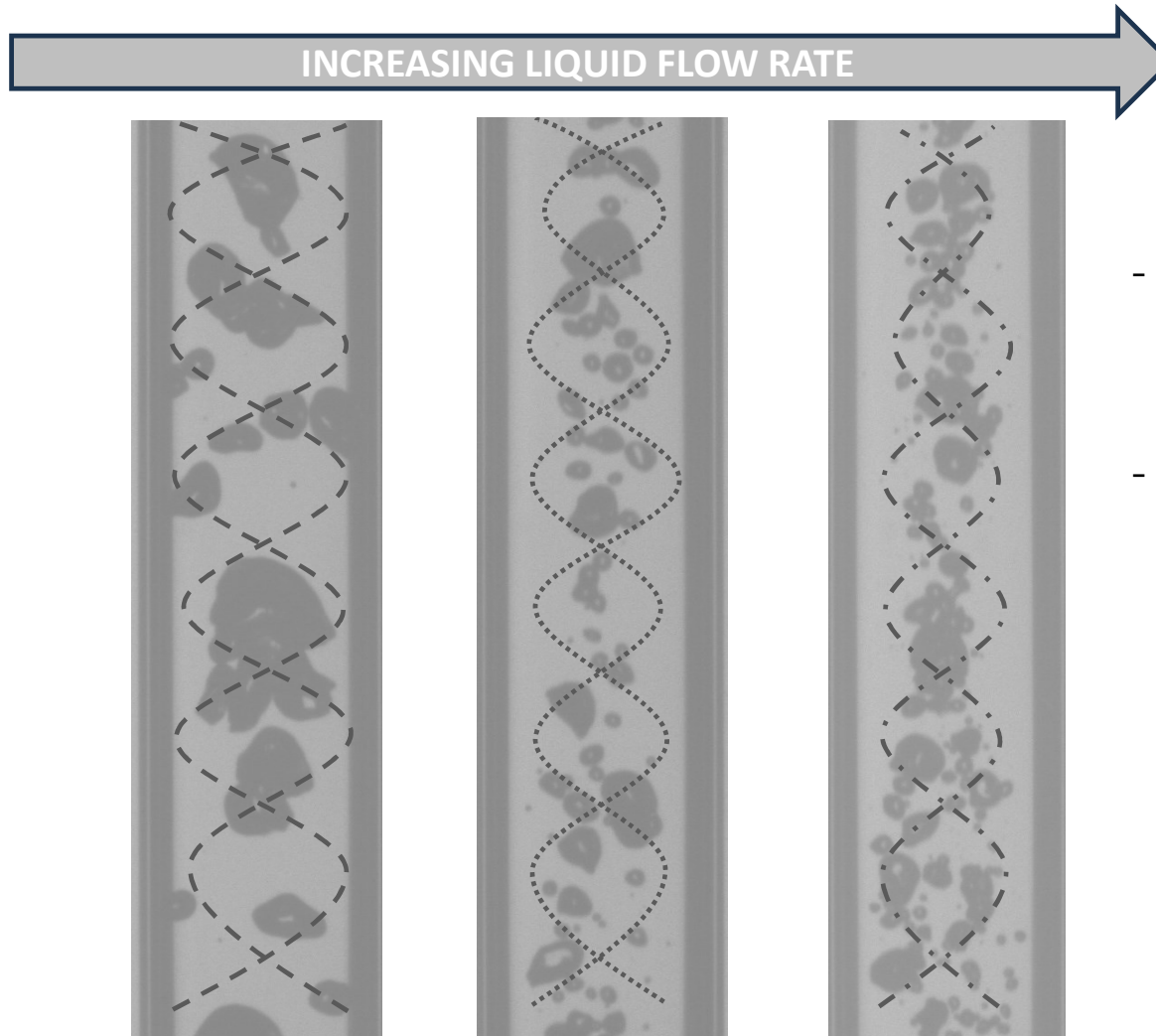
At higher **gas** flow rate, the peaks ,  , appear to decrease in amplitude with the **gas** flow rate.

While the peaks,  , appear to increase in amplitude with the **gas** flow rate.



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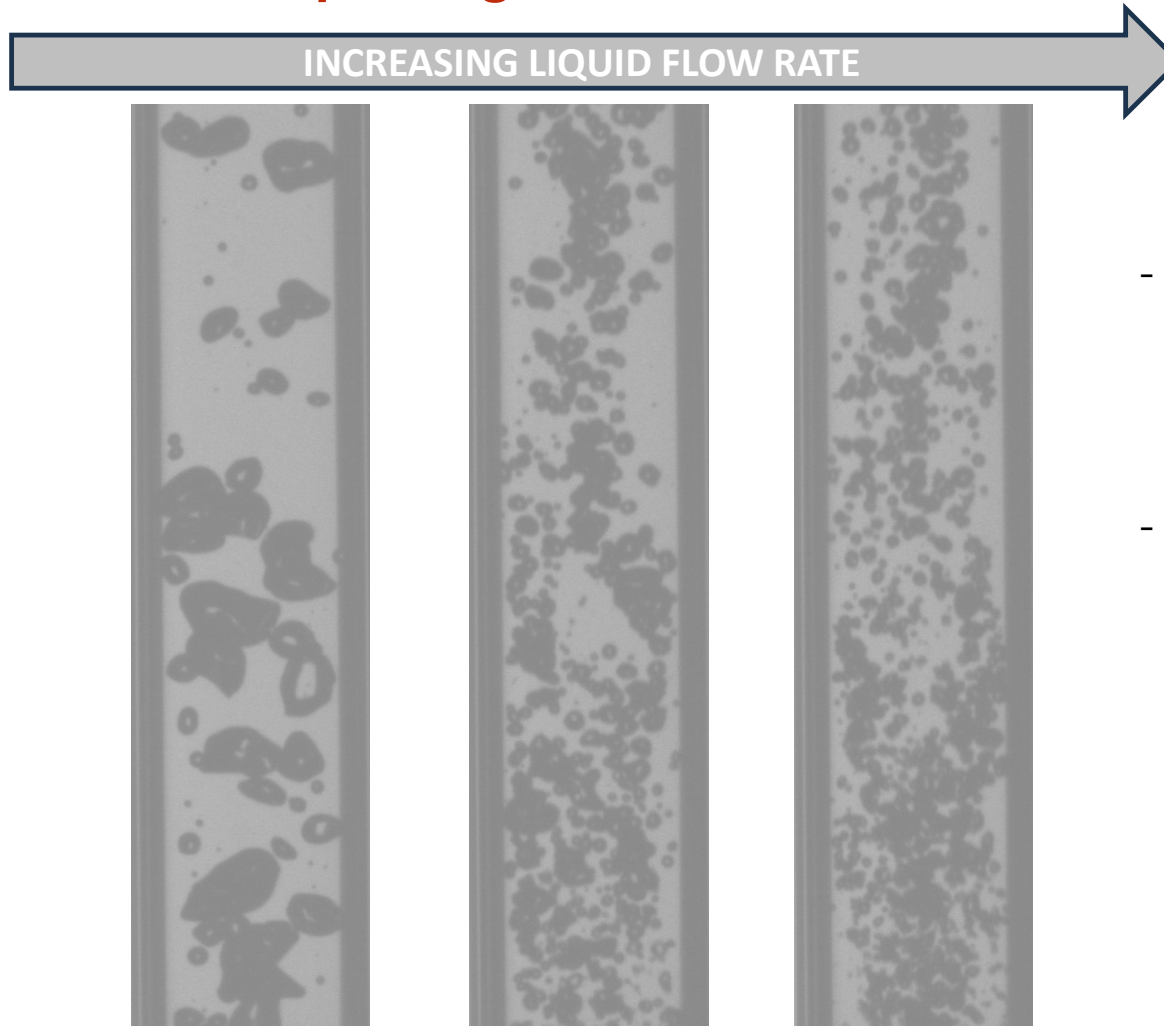
Effect of the presence of CCC: constant gas flow rate 1.5 L min^{-1} , varying liquid flow rates, swirling effect.



- Centrifugal forces are enhanced with the flow rate.
- Similar behavior is noticeable increasing the number of static mixer at fixed flow rate.



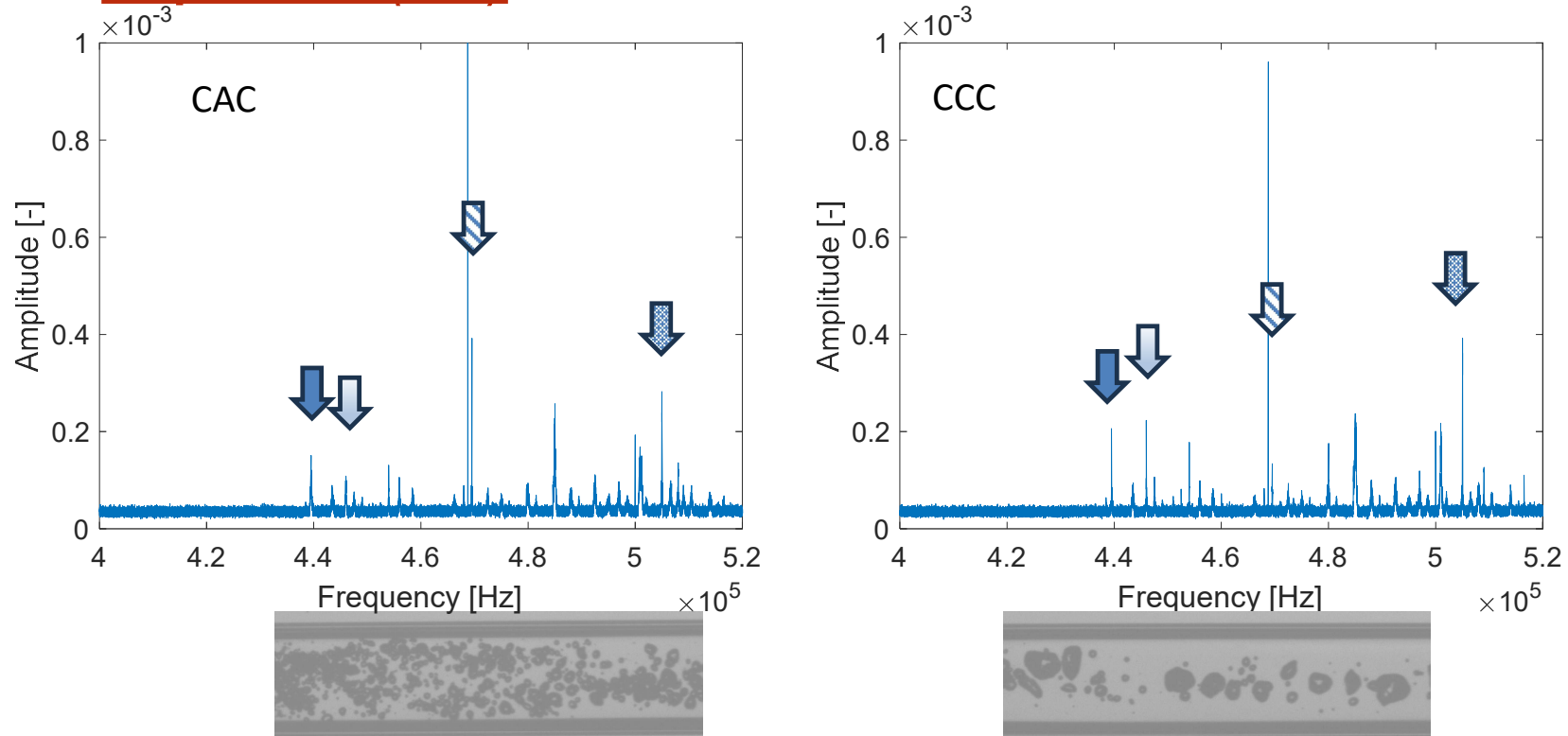
Effect of the presence of CAC: constant gas flow rate 1.5 L min^{-1} , varying liquid flow rates, dispersing effect.



- Bubble sizes decreases with the increase of liquid flow rate.
- Bubbles are spread almost on the entire section of the pipe in contrast with CCC configuration



Static mixer CAC vs CCC: constant liquid flow rate 1368 L h⁻¹ and constant gas flow 1.5 L min⁻¹; swirling vs dispersion, (Z S)



Arrows identify the most significant changes in term of amplitude for selected frequencies, might induced by the different G\L flow structure.



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Conclusions

- An innovative measurement methodology has been proposed to identify changes:
 - ✓ Combinations of Gas& Liquid Flow Rate in a tubular reactor
 - ✓ Type of G-L pattern
- “*Fingerprints*”, on the frequency spectrum of the signal, have been identified for the different flow patterns.
- A specific range of frequencies is identified where changes in the fingerprints are more evident.





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Thanks for your attention....

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