Small bubbles and bubble bags: a scientific knowledge valorisation

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This is the story of a PhD project that turned into a spin-off company on ultrasonic cleaning and advanced chemical processes. The basics of sonochemistry and process intensification are also introduced.

As a scientist trained in Cuba, the word *entrepreneur* had a different meaning to me than for colleagues abroad. Its accurate interpretation is debatable, and it is beyond the scope of this work. Thus, let it be an individual with the drive to bring knowledge or a given solution to the broader society, with or without financial or altruistic motivations. I want to share some of my steps to valorise results obtained during my PhD project. My hope is to illustrate, and inspire other scientists to consider the possibility to start their own business, join a start-up, or transfer their experience and knowledge in the most efficient way to society.

Microfluidics and Ultrasonic Sonochemistry

Microfluidics can be roughly understood as devices and methods to control and manipulate fluids at length scales bellow the millimetre, and flow rates not exceeding $\sim 1\,\mathrm{mL}\cdot\mathrm{min}^{-1}$. Ultrasonic sonochemistry encompasses the chemical and physical effects caused by applying ultrasound to multiphase systems. Cavitation, the growth and implosion of gas/vapor bubbles in a liquid, arises mostly from the collapse of bubbles in the sonicated liquid [1].

The implosion of bubbles enhance numerous chemical reactions. Each bubble functions as a microreactor with a high-energy environment (temperatures of 5000 °C and pressures of 2000 atm), which in turn produces a plethora of excited chemical species. My PhD's main task was to improve the energy efficiency of sonochemistry with microreactors, and while I was relatively familiar with microfluidics, [2, 3], the sonochemistry community did not think it possible.

Scaling Up Cavitation

This story started by demonstrating how a significant gain in efficiency is obtained when the location of the nucleation of bubbles, which later cavitate due to ultrasound, is accurately controlled [4]. Such feat was achieved with silicon surfaces on which pits were micromachined to entrap gas. Upon ultrasonic excitation, the entrapped gas bubble emits a stream of chemically active microbubbles at powers well below the required in conventional reactors.

The lack of reproducibility and very low energy efficiency values of $X_{US} \sim \mathcal{O}(10^{-6})$ (see Eq. (1)), are the main cause of a poor adoption of the "green" advantages of sonochemistry by the chemical industry.

$$X_{US} = \frac{\Delta H(\Delta N_{rad}/\Delta t)}{P_{US}} \qquad (1)$$

where ΔH is the energy required for the formation of OH· radicals, which is equal to the enthalpy of formation of the chemical reaction with a value of 5.1 eV per molecule:

$$\mathrm{H_2O} \overset{\Delta H = 5.1 eV}{\rightleftharpoons} \mathrm{OH}\cdot + \mathrm{H}\cdot \qquad (2)$$

P_{US} is the electric power absorbed by the transducer which can be obtained from the measured voltage, current and their phase difference.

Such control over the spatial distribution of cavitation, and the actual volume of liquid exposed to sonochemical effects, enabled us to demonstrate that there was a possibility to number up and scale up the original microreactor into a novel type of sonochemical reactor: the Cavitation Intensifying Bags, CIB [5, 7, 6]. The main contribution of our design, was later interpreted as a process intensification approach by changing the *structure* of the reactor walls (see Figure 1).

Entrepreneur or academic?

About a year before finalising my PhD, I was working with a friend and scientific collaborator in the lab. We had published some work on the potential uses of the microreactor introduced above, for removing bacteria biofilm from glass and other materials. In a classical "Friday afternoon" experiment, we coloured a contact lens with a permanent marker and exposed its surface to the ultrasonic bubbles. After seeing that without any detergent the ink was removed, no damage to the lens was made, and consulting with our supervisors, we knew we were onto something good.

The University of Twente (UT), has a motto that translates as: *the entrepreneurial university*. For years I biked in front of that banner, without paying much attention to its meaning. But with the uncertainty of what would happen after my PhD was over, and the exciting results, we founded BuBclean (`www.bubbclean.nl`) and became entrepreneurs.

With the support of the UT's valorisation office, we applied for a patent, took a couple of courses as go-to-market training, and got exposed to the "real world" outside the university walls. We applied to a small government subsidy that allowed us to get our first

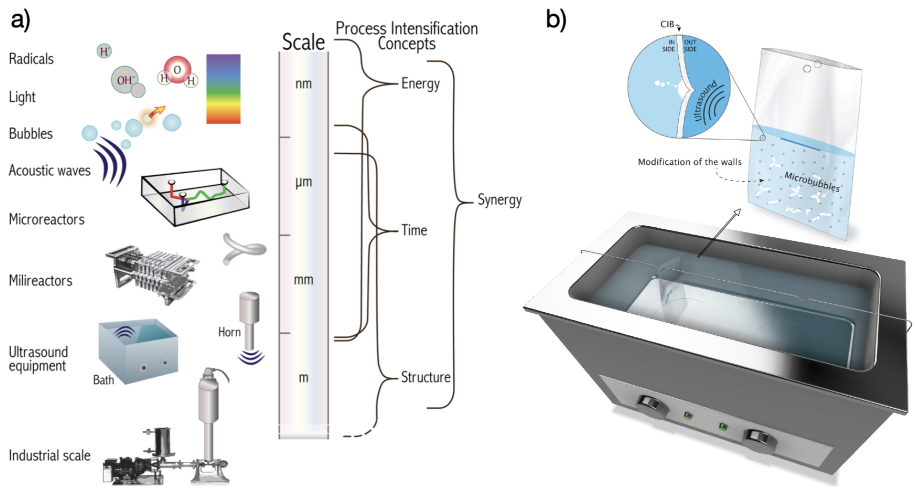

Figure 1: a) Terms and concepts with corresponding relative sizes of the items described in this work, linked to process intensification concepts [9] b) The Cavitation Intensifying Bag CIB (top) is positioned inside an ultrasonic bath (bottom) above one of its transducers (Copyright 2013, with permission from Elsevier [7]) .

customers, mainly from consultancy services. In parallel, we designed, manufactured and started to commercialise what is now the BuBble Bags [10]. We even had to develop a method to convince customers on the advantages of using our product [8] (see Table 1).

Case	Factor	Normal	CIB	IF
Jeweller	Time [min]	10	2.5	
	Volume [L]	3	0.05	240
3D printed	Time [min]	8	1	
	Volume [L]	100	50	16

Table 1: The superiority of Cavitation Intensification Bags evidenced by larger Intensification Factor (IF) values in ultrasonic cleaning [8].

Conclusions and recommendations

To those who want to embark on the fascinating path of commercialising one scientific idea: it is better to "fail fast" and learn, than to wonder what might have been. If you have no "idea", you can join an existing start-up. In some countries creating a company might be complicated, but entrepreneurial attitudes within existing organisations is an option (often termed "intrapreneur"). The biggest challenge is building the right team; therefore, skills and personalities should be complemented.

Lastly, persistence is your best ally if you really believe in your dream, and you must be flexible to adapt to changing priorities. It is wise to have a strategy, both for the company and for your personal situation, e.g. have a back up plan in case the entrepreneurship fails may make the leap more comfortable for some. I had the privilege to balance my academic career and entrepreneurial ambitions, and I know this is difficult to replicate; however, it is worth trying it.

Notes

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