CARBON DIOXIDE

Superhero or Supervillain??

Illustration of "Supercritical Girl" by Ms Amelia Ong

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Mention carbon dioxide and images of exhaust coming out from chemical plants and transportation vehicles comes to our minds. Carbon dioxide concentration in the atmosphere has been used as a key indicator of the plight of global warming. Surely, it seems like carbon dioxide is a supervillain that we have to face right now. However, if we take a look from another angle, we can see that carbon dioxide is also essential for life itself, being one of the key ingredients, together with sunlight and water, for photosynthesis in plants which is necessary for production of food.

The forms of carbon dioxide as we know include the solid phase, in the form of dry ice; liquid phase, in fire extinguisher cylinders; and gaseous phase, which is what we breathe out all the time. When we learnt about the phase diagram of pure compounds, we learn about the triple point and lines separating the solid/liquid, gas/solid and gas/liquid phases. We may also remember that there is a critical point of specific temperature and pressure where beyond this point, the substance will become a supercritical fluid. This sounds very much like the "Quantum realm" described in **<<Avengers: Endgame>>** where time, space and reality works differently. It is indeed in this special regime, where carbon dioxide also behaves as a supercritical fluid, where it possesses many unique and useful fluid properties, allowing several cleaner, greener and more sustainable products and processes to be developed. Although time travel is currently still not possible.

We can imagine supercritical carbon dioxide to be like a superhero. If you are familiar with the character in **<<Shazam>>**, a normal teenage boy can transform into a superhero with superpowers such as wisdom, strength, stamina, power, courage and speed, in an instant by saying the name "Shazam". In supercritical carbon dioxide process, a very similar scenario is observed. Liquid carbon dioxide, upon pressurizing and heating to above its critical conditions, transforms into a supercritical fluid once crossing the critical conditions, transiting to a phase where it possesses supercritical fluid properties. This includes enhanced solubility, low viscosity, high diffusivity and antimicrobial properties.

Carbon dioxide has been widely misunderstood and unappreciated at times. It is a really useful compound that has so many applications in green chemistry and sustainable processing. In fact, there are already several products that we

see around us in our daily lives that already use supercritical carbon dioxide as the processing medium for sustainable production.

Supercritical carbon dioxide is a good replacement for harmful organic solvents in traditional processes. One of the earliest example is the decaffeination of coffee beans using supercritical carbon dioxide. Conventional decaffeination process uses organic solvents which may be harmful to health and to the environment to extract caffeine from coffee beans. Supercritical carbon dioxide decaffeination uses supercritical carbon dioxide as the extraction solvent to remove caffeine from coffee beans, but leaving the beans intact and most of the coffee aromas and flavor remaining in the beans. This is due to the high diffusivity and high solubility of supercritical carbon dioxide. This reminds us of "Captain America" taking out all the bad guys whilst making sure there is minimal damage to the civilians and surrounding.

Another classic, but lesser known example is in the dyeing of textile. Textile dyeing industry has been known to produce massive amounts of waste water. Chemical dyes used for dyeing textiles were dissolved in water which will subsequently be used for soaking textile materials as a means of transferring the dyes onto the textile. A lot of water is required for the dyeing and subsequent washing steps. There is also the need to dry the finished product which again requires heat and energy. Supercritical carbon dioxide offers a much cleaner and less energy intensive water-free dyeing process that allows the chemical dyes to be deposited onto the textile material, leaving behind a dry product which do not require additional washing or drying steps. How is this done? Well, supercritical carbon dioxide has a high density and solubility, allowing it to dissolve the chemical dyes. Due to its high diffusivity, supercritical carbon dioxide can penetrate deep into the matrix of the textile material, carrying and depositing the dyes onto the textile. When depressurized, the dyes will separate from the carbon dioxide because of the sudden change in solubility from supercritical to gas phase, and most of the carbon dioxide used in the process can be recycled. No extra heat or energy is required to dry the textile. This is very much like "Ant Man" who can change its size and move at high speeds within the target, getting his job done inside the target area and then leaving swiftly before changing back to his original form and size.

Supercritical carbon dioxide has many other useful applications such as preparing powdered formulations for active ingredients. It is also useful for drying food matrices such as fruit, vegetables and herbs to improve their shelf-lives. There are also many opportunities in supercritical carbon dioxide research which can be applied to extract valuable ingredients from waste material, or to turn waste material into useful materials, in a clean and sustainable manner. We can agree that carbon dioxide is a problem, but supercritical carbon dioxide technology has the potential to turn a problem into a solution. This is the beauty of substance that possess great properties. I hope that more can be done by industries to harvest the potential of supercritical carbon dioxide for a cleaner, greener and more sustainable development.

Looking closely around us, we can already find many products that are already using supercritical carbon dioxide technology as a greener and cleaner alternative to conventional processing. Oils and nutraceutical products such as fish oils has been extracted using the supercritical carbon dioxide extraction process. Decaffeinated coffee from supercritical carbon dioxide extraction can also be found in the market. Waterless textile dyeing technology is adopted by International brands in sportswear. However, there is still a lot more to be done to promote widespread acceptance and adaptation of the technology and process in order to make a difference in the global landscape. It is true that the technology comes at a cost. This is reflected in the higher capital investments required, which is the barrier to entry for most industries and businesses. However, the environmental benefits, the cleaner and high quality product, and the long-term operating cost savings of using such technology outweighs the cost consideration.

The challenges in the present world may be too big to be solved with a single solution. This is where we can learn from the many recent superhero movies such as **<<The Avengers>>**, or **<<The Justice League>>**, or even **<<The X-Men>>** where superheroes with different abilities have to work together to solve bigger problems. A multidisciplinary approach and a combined effort from various parties will be essential in approaching and tackling global sustainability issues. We do not need to be a superhero to be able to make a difference to the world. With collective effort and a wider appreciation and acceptance of cleaner and greener processes, even

consumers can play a part in shaping the decisions of industries and the processes used.

With supercritical carbon dioxide, there lies many opportunities for developing better and greener products, as well as opportunities for cleaner and more sustainable processes. As our friendly neighborhood superhero may say:

"With Great Properties, Come Great Opportunities!"

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