THE PARTICLE TECHNOLOGY FORUM (PTF) NEWSLETTER

An American Institute of Chemical Engineers (AIChE) Forum

A Glance at the Newsletter

Message from the Chair

Greetings!

Academics are wrapping up their semesters and summer is around the corner. My anecdotal survey confirms the obvious: Many of us are burned out. Each of us, whether academic, industrial, or at a national lab or institute, is taking on a broader swath of responsibilities. Recent graduates and job seekers are getting a brief respite, only to be thrown into an industry where supply chain stalls and misfires, an abundance of regulations, and human resource scarcity makes each of us wear that many more hats to accomplish our tasks. During the uncertainties during an attempted soft landing of the economy, the war in Ukraine, and social strife not seen in over 50 years, the word "progress" is hard to define.

Hopefully amongst the chaos you were able to send abstracts and secure plans to attend either the 9th World Congress on Particle Technology or the 2022 AIChE Annual Meeting this fall in Phoenix, AZ. Talks from my own research group will be featuring novel results in the area of granular flows (3c) for the first time since 2008 after moving toward complex fluids and suspensions. More than ever it is apparent that we need to come together as a community and share our successes. Last

Editorial

Dear Fellow PTF Members,

I hope you and your families are safe and healthy!

I hope you enjoyed the "hybrid" 2021 AIChE Annual Meeting, and are looking forward to attending the face-to-face World Congress on Particle Technology (WCPT9) in Madrid, Spain, in September 2022.

This newsletter provides key information on the conference. You will also find in this newsletter the contributions from three 2021 AIChE Particle Technology Forum (PTF) Award recipients, and a call for 2022 AIChE PTF award nominations.

Please feel free to reach out to me with your idea by if you would like to contribute to the 2022 Summer or Fall newsletter.

Stay safe!! Stay healthy!! Stay strong!! Stay positive!!

Regards,

Mayank Kashyap, SABIC

Editor - PTF Newsletter

year in Boston we had a fun, small, informal gathering of PTF members in lieu of the awards dinner. This coming fall, we are planning the first Particle Technology Forum Awards Dinner since 2019 and we sincerely hope to bring as many people together from our community to celebrate winners from 2020, 2021, and 2022. Please plan to purchase your ticket in advance as you register for the meeting this summer.

In this issue of the newsletter, prepared by Dr. Mayank Kashyap (who has my sincere gratitude), articles by the 2021 award winners are featured.

For the 2022 PTF awards, if you have not done so yet, please nominate a deserving colleague, do so now. You can reach out to Dr. Reddy Karri (reddy.karri@psri.org) or myself stating your brief intention of a nomination while you begin to prepare your nomination. We will both be happy to help clarify and simplify this process. Nominations are due May 31st and details can be found in this newsletter and at https://www.aiche.org/community/sites/divisions-forums/ptf/awards.

It is also not too early to express interest in leadership of our forum. Nominations and volunteer opportunities will be broadcasted soon.

Hope your summer gives you space to relax and reflect with gratitude for your many accomplishments, no matter where you are in your career.

Regards,

James Gilchrist, Ruth H. and Sam Madrid Professor, Lehigh University

Chair, The Particle Technology Forum of AIChE

Email, Website, Twitter: @Gilchrist_Lab, LinkedIn

Our Commitment on Diversity and Inclusion

Approved at 2019 AIChE Annual Meeting

The AIChE Particle Technology Forum is committed to maintaining a diverse and inclusive community of highly skilled chemical engineering professionals within the environment of the Institute and profession in which all members, regardless of characteristics such as gender identity and expression, race, religion, age, physical condition, disability, sexual orientation, educational level, socioeconomic class, nationality or ethnicity, are valued and respected."

As a global scientific and engineering society, we affirm the international principles that the responsible practice of science, free from discrimination in all of its forms, is fundamental to scientific advancement and human wellbeing, as outlined by the International Council for Science's (ICSU) Statute 51. We also affirm our commitment to an engineering and scientific environment that facilitates the planning, execution, review and communication of engineering and scientific work with integrity, fairness, and transparency at all organizational levels. This extends to our general scientific endeavors—including our professional interactions and engagement with other engineers, scientists, students, trainees, and the general public. We recognize that harm to our profession, our scientific credibility, individual wellbeing, and society at large is caused by not doing so.

To this end, the PTF will implement the principles of diversity, inclusivity, and equity within PTF leadership and membership to build a community across the chemical enterprise. We are committed to quantifying and monitoring our diversity at least annually at the Executive Committee and reported at the general business meeting.

2021 AIChE Particle Technology Forum Awards

Elsevier PTF Lifetime Achievement Award

Fluidization Centennial and Future Prospects

Jesse Zhu

Distinguished University Professor

Canada Research Chair

Particle Technology Research Centre

The University of Western Ontario, Canada

2021 marks the 100th anniversary of Fluidization and I feel very fortunate to be receiving the Elsevier AIChE PTF Lifetime Achievement Award at this historical moment. I would first like to thank the PTF Award committee and all the colleagues in the PTF community with whom I have had the pleasure to work with and

to learn from in the past 30+ years.

The concept of a fluidized bed (Wirbelschicht) began with Winkler's idea[1,2,3] as shown in his hand drawn sketch in Figure 1[2]: "While passing blowing air through a column containing coal powder,… the coal particles were suspended by the flow and the whole mass appeared to boil… and the whole mass became like a fluid."[3] It was already known by then that "Provided the flow of gas was not so high as to blow the powder out of the top of the reactor, the dancing fluid was characterised by excellent mixing and outstanding heat transfer."[3]

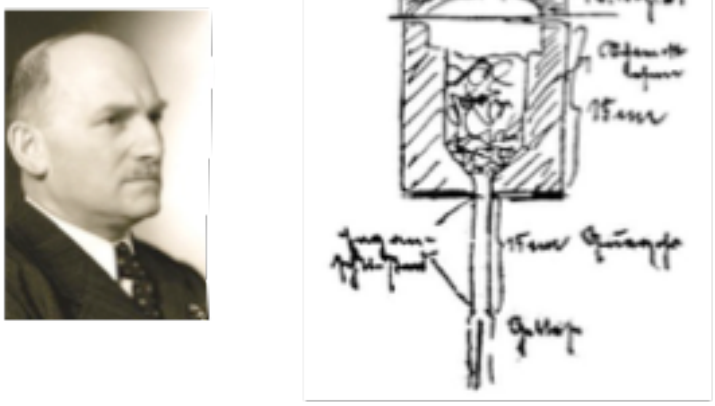


Fig 1. Frits Winkler's original sketch of his discovery of the fluidized bed[2]

Since then, many processes have used fluidization with enormous successes and the two largest ones were Fluid Catalytic Cracking (FCC) and (Circulating) Fluidized Bed Combustion (FBC or CFBC). I was fortunate enough to be a team member at UBC under the late Prof. John Grace and worked on a pilot-scale CFBC unit during my PhD studies (my project was to study tube erosion inside FBC) and then took on FCC as the main focus in my first industrial job at Shell Amsterdam in the last 1980s. Later on, I also had the opportunity to develop some fluidization technologies for materials[4,5], pharmaceutical[6], biomedical[7] and environmental processes,[8] beyond the traditional process industry. At this 100th year point, I would like to share with the fluidization community some of my thoughts on the development history of fluidization.

The Multiplicity of Fluidized Flow

Fluidization is considered a multiphase process and all the "angels and devils" come exactly from that. Figure 2 depicts a pipe flow situation through two identical channels. For a single-phase flow system (left), the flow conditions in the two channels must be the same because $Delta P_1 = Delta P_2$. For a two-phase flow system (right), however, even though $Delta P_3 = Delta P_4$, the flow conditions can have infinite pair of conditions: One channel with more particles and low fluid flow can have the same pressure drop as the other channel with fewer particles and high fluid flow. Such multiplicity can only escalate in a real fluidized process, which has given us all the challenges but also all the enjoyments.

Looking back at the earlier history of fluidization, one can see that most if not all studies were about the multiplicity: The classical work of Wilhelm and Kwauk in 1948[9] aimed to seek and quantify a criterion to distinguish the uniform particulate flow and the chaotic aggregate flow, or in other

words, to tell us when a fluidized bed is more like a single flow and when it must be treated as a two phase flow. Based on this, we can clearly see the two approaches that had been adopted by the earlier researchers, in the 1950s through earlier 1970s.

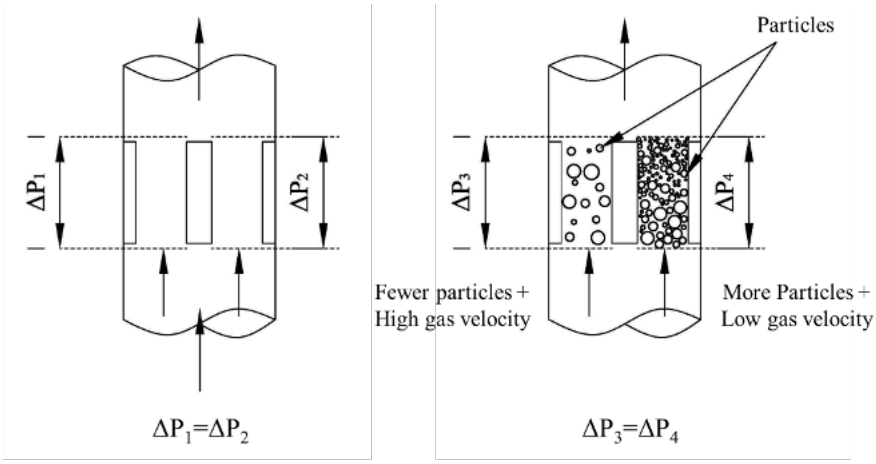


Fig 2. Flow diagrams of single-phase (left) and two-phase (right) flow – The multiplicity in multiphase flow systems

The American Single Phase Approach

The first group of researchers, represented by Lewis, Gilliland and Elgin, considered all fluidized bed flow to be uniform or pseudo-uniform.[10-14] This "American approach", if I may call it, therefore treats the fluidization system as a single phase flow. This certainly made things easier and has therefore dominated the earlier studies of fluidization. While this approach should have only been used for liquid-solid fluidization, it has also been used to treat the gas-solid fluidization system where aggregation does exist by assuming that the flow is nearly uniform. Though simple, one should not underestimate this methodology, as the earlier designs of the FCC unit heavily depended on such pseudo-particulate approaches.

But after all, even a perfectly uniform fluid-particle flow is not a single-phase fluid flow. For one, the density of the pseudo-fluid, the fluid-solid suspension density, would change with the fluid flow rate, adding another dimension, meaning that one cannot simply use the Reynolds flow equations to predict the flow even in an ideal particulate fluidized bed. Such deficiency was fortunately overcome by the introduction of the famous Richardson-Zaki equation,[15] which provided a correlation designed to relate the fluidized bed density, the density of the pseudo-fluid for the single phase system, with the fluid velocity, *epsilon* = f (V_f). With such a genius solution, Elgin and his colleagues[16] were able to generate a complete fluidization map, in terms of bed density vs fluid velocity (Figure 3), for a wide range of uniform fluid-solid fluidization operations, for seven different operating modes (Figure 4) as summarized by Wang et al.[17]

Another mapping method was developed to plot the particle velocity vs the fluid velocity, as shown in Figure 5. Lapidus and Elgin in 1957[16] and later on Kwauk in 1963[18] adopted a generalized fluidization concept that extended the use of R-Z equation to counter-current upwards/downwards and co-current downwards flow systems beyond the "basic" upright flow system. On such a map,

lines for equal solids holdups can be, in principle, plotted across the three quadrants, thus unifying the various fluidization modes. Figure 3 and Figure 5 set the most important foundations for many following works, such as regime map studies, although they themselves have been largely forgotten, perhaps due to their qualitative nature?

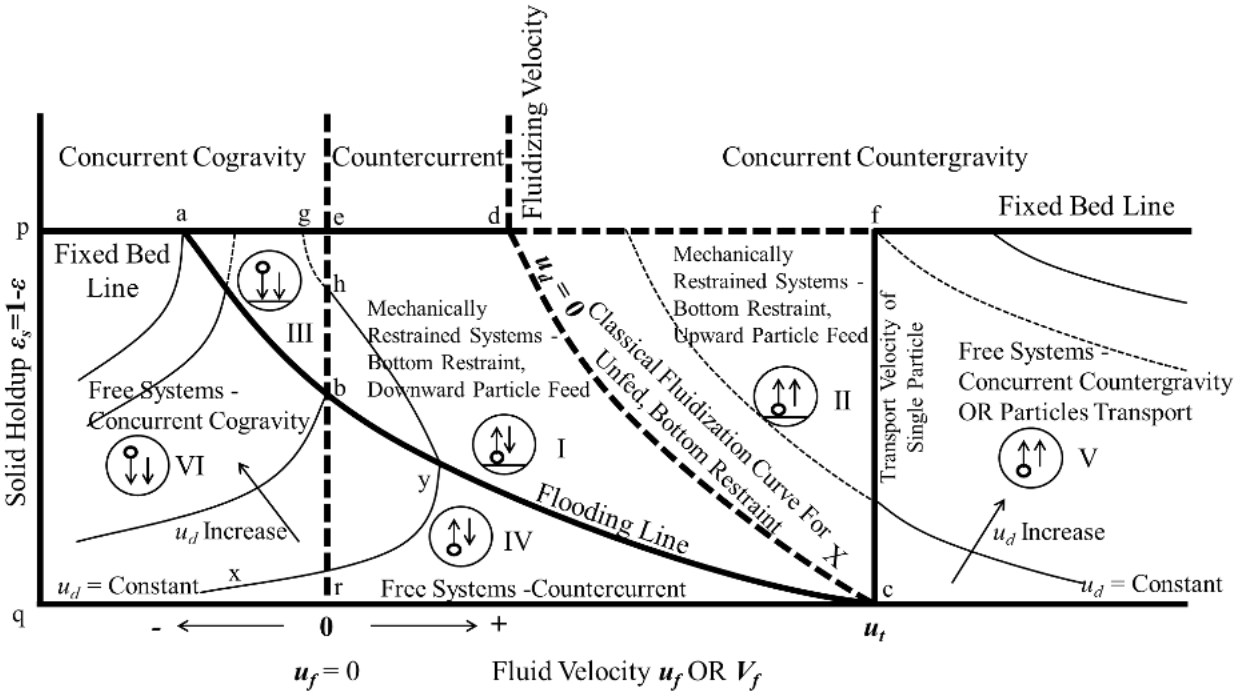
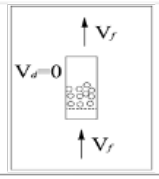
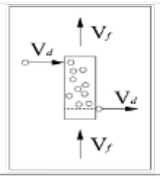
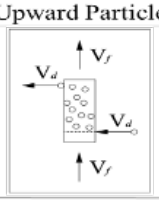
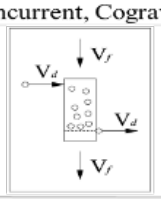


Fig 3. Fluidization operation modes and systems generalized via single phase flow system[16]

	X	I	II	III
	Unfed, Bottom Restraint	Bottom Restraint, Downward Particle	Bottom Restraint, Upward Particle	Bottom Restraint, Concurrent, Cogravity
Mechanically Restrained Systems				
	$V_s=V_f-(0)$	$V_s=V_f-(-V_d)$	$V_s=V_f-(V_d)$	$V_s=-V_f-(-V_d)$
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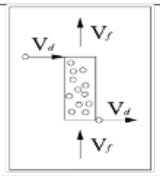
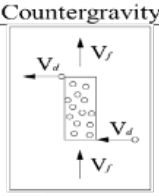
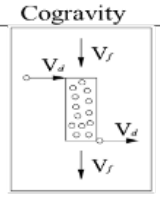
Free Systems				
		$V_s=V_f-(-V_d)$	$V_s=V_f-(V_d)$	$V_s=-V_f-(-V_d)$

Fig 4. Seven types of ideal vertical fluidization system[17]

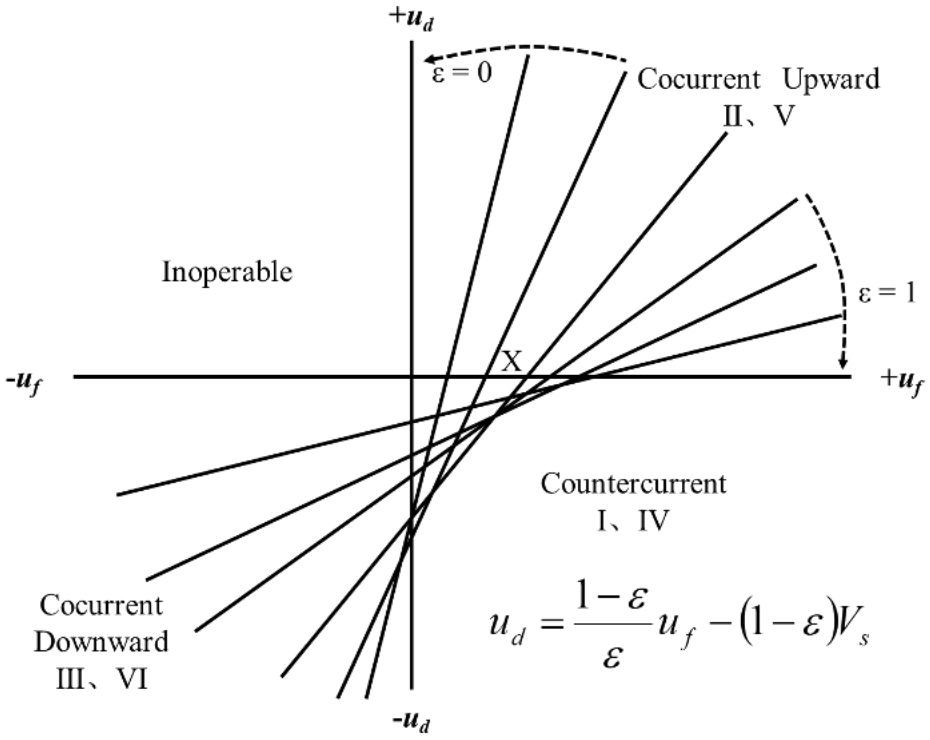


Fig 5. Speculations on expanded fluidization operation modes beyond conventional upright fluidization, superficial particle velocity u_d vs. superficial fluid velocity u_f under constant bed voidage ε [16]

The British Two Phase Approach

The second group of researchers, represented by Davidson, Rowe and Toomey, proposed the two phase flow theory that treat the bubble phase and the dense phase to be separate, for aggregative gas-solid fluidization.[19-21] This "British approach", if I may call it, spent enormous efforts devising many elegant and sophisticated experiments to measure and then correlate the bubble flow behaviours so that the details of the two phase flow can be quantified, in a typical bubbling fluidized bed (BFB).[18] Davidson and Harrison's two-dimensional bed tests and Peter Rowe X-ray tests were the most typical ones, producing some very beautiful and classical photos and sketches (Figure 6), while Toomey was the first to propose the two-phase theory in 1952,[20] advising the community that the bubble phase may be considered to be free of particles and the dense phase to be filled with particles remaining at the minimum fluidization state, should be treated separately. However, most studies were carried out under low gas velocity conditions, perhaps because it is more difficult to work with a higher velocity and/or the bubble flow became more chaotic and thus could not be captured clearly at a higher gas velocity. Therefore most studies remained in the laboratory while more and more beautiful studies were reported to the literature. However, how effective these bubble theories could aid the industry designs remained unclear, and many elegant equations remained more "academic", becoming very good textbook materials for teaching fluidization through the 1960s to 1990s.

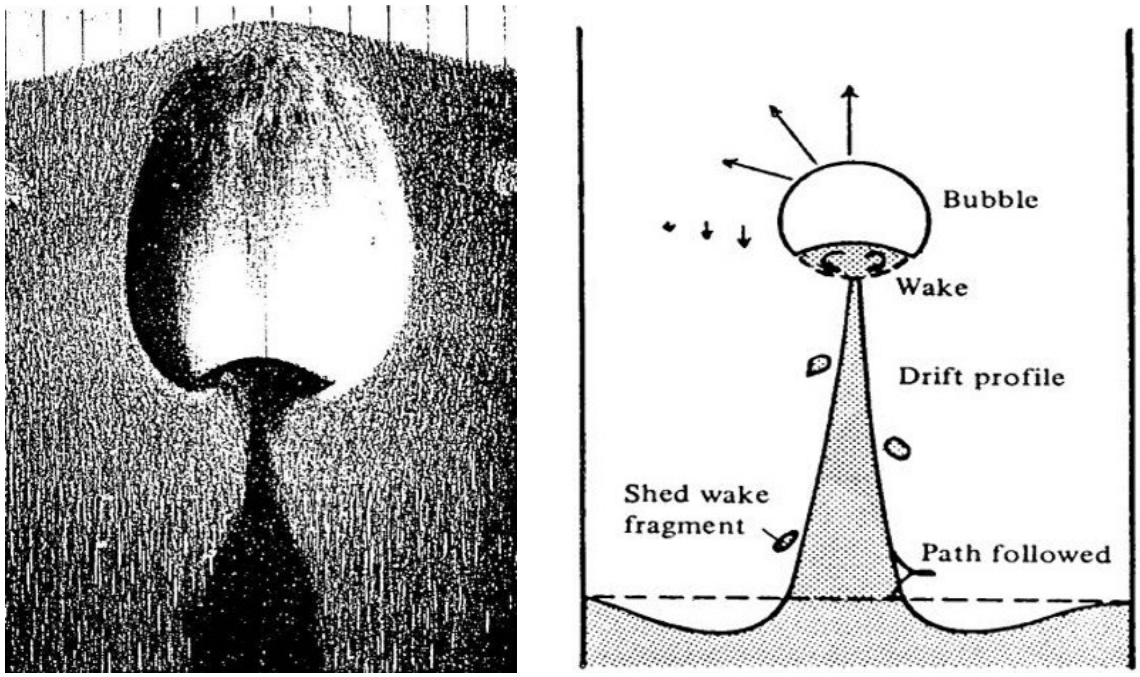


Fig 6. Photo of a single bubble (left) and the sketch of bubble rise and associated particle flow in bubbling fluidized bed[19]

Kunii and Levenspiel "solved" or rather went around this issue (of not getting the precise bubble size and bubble flow), by presenting a simple but practical "bubbling bed model", where they simply assumed that there is a uniform bubble size for the entire fluidized bed under each operating condition.[22] They would then conduct some lab tests under exactly the same condition as the real industrial unit, correlate "back" to an equivalent bubble size and then use that equivalent bubble size to estimate the fluidization behaviour and predict the productivity of the industrial unit. They reported that this approach had been successful in the design of many fluidized bed reactors.

The "British" studies also showed that there was significant gas back-mixing in the BFB – this happens when the rising bubbles bring some particles upwards in their wakes (Figure 6, right) and those particles, after spread across the bed surface as the bubbles erupt, would "return to" the bottom, to "replenish the vacancies" left by the entrained particles, bringing some gas to flow downwards. Van Deemter[23.24] was the first or at least the first who did extensively, develop mathematical equations that counted for gas backmixing or dispersion, by introducing a dispersion coefficient for the gas phase.

Such a gas dispersion coefficient was also introduced by Van Deemter[25] into the single phase "American" approach, and this method was used extensively in the earlier designs of some important fluidized bed reactors in the companies. By fitting the gas dispersion coefficients, and sometimes correlating the same, through a set of carefully designed precise reactor experiments inside their Amsterdam lab, the fluidized bed reactor performance could be estimated as the inefficiency caused by bubble flow and particle back mixing was counted for by the introduction of

gas dispersion (back-mixing). This "1.5 phase" approach", if I may call it, seemed to work reasonably well and deterred the industry from getting too much further into developing design criteria based the two phase flow model. Another factor was that it had become more clear to the industry that both gas dispersion and bubbling activities became weakened when the operating velocity was further increased in the bubbling fluidized bed reactors – unknowingly, the era of turbulent fluidization had come unannounced.

Newer Developments and Future Perspectives

Since the inception, the "original" gas-solid "conventional" fluidized bed has been expanded, to liquid-solid and three-phase fluidization by changing the fluidizing medium, to turbulent and circulating fluidization by changing (increasing) the fluidizing velocity, to downflow fluidization by changing the fluid flow direction, and to inverse fluidization by changing the relative fluid-to-particle density. Other than conventional L-S and G-L-S fluidized beds, most new developments have occurred since 1970s. Coming with those changes have been the development of various fluidization theories and/or postulations, including operating modes and regimes, analytic and numerical modelling, etc. As it would require another entire article to discuss those new development, I would only point to a few key things below. One can see many of the new developments are very much related to the two traditional approaches discussed above.

In gas-solid fluidization, the 1970s saw the invention or the "re-invention" of two new fluidization regimes, the turbulent fluidization (TFB)[26] and the fast fluidization (operating in circulating fluidized bed, CFB).[27] Both the TFB and CFB have fluidization behaviours "away" from the bubbling fluidized bed (BFB), reducing or eliminating the bubbles, and providing better gas-solid contact efficiency. One interesting point worth noting was that both the TFB and CFB were not actually new and have been in practice in the industry in the 1950s-1960s. The TFB concept was already adopted by Shell[25] and Exxon[28] in the earlier 1960s and perhaps even earlier when it was considered a high-efficiency BFB. The CFB was adopted in the FCC process in 1958 by Mobile, termed the transport riser reactor,[29] and even earlier in the Sasol Synthol reactor.[30] Those were typical examples of research lagging behind industrial development.

Both TFB and CFB are pushing for higher gas-solid contact efficiency and thus higher productivity, and both doing so by reducing the two-phase behaviour and driving more uniform gas-solid fluidized suspension. TFB does so by reducing the bubble size and having more frequent break-up and formation of the bubbles (voids), and CFB does so by converting the gas phase into the continuous phase and dispersing particles into the gas phase albeit a significant fraction of particles still have a strong tendency to form particle clusters and thus localized two-phase phenomena.

Coming with the TFB and CFB were several new fluidization regimes maps, such as those by Matsen,[31] Grace[32] and Horio [33] for gas-solid system in the 1980s - 1990s, plus those for LS and GLS fluidization systems[34] in 2000 that show, for the first time, how the newly developed circulating L-S and G-L-S circulating fluidized beds coming out of as expansions of their corresponding conventional systems. My group also proposed a consolidated flow regime map for upward gas fluidization:[35]

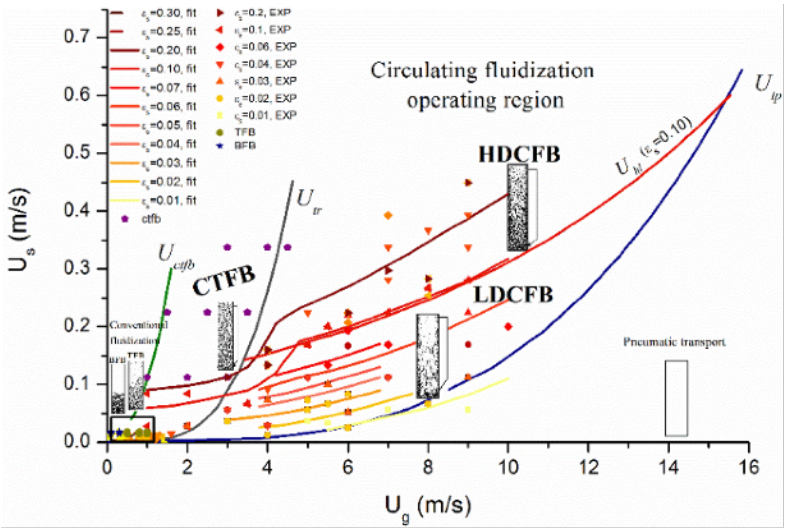


Fig 7. A consolidated flow regime map of the upward gas-solid fluidization (for FCC particles) [35]

Studying those regime maps can sometimes lead to the discovery of new fluidization regime, such as that from the above map, a new Circulating Turbulent Fluidized Bed (CTFB) was identified. The CTFB combines the benefits of both TFB (higher solid holdup and more extensive G-S contact) and CFB (reduced axial dispersions of both gas and particles), and, as a new fluidization regime, bridges the BFB with CFB.[36]

Following the same string of thoughts in the L-S system, we also developed the new Circulating Conventional Fluidized Bed (CCFB) in liquid-solid system.[37] The CCFB is shown in Figure 8 to "smoothly" connect the conventional L-S fluidization to the circulating L-S fluidization.

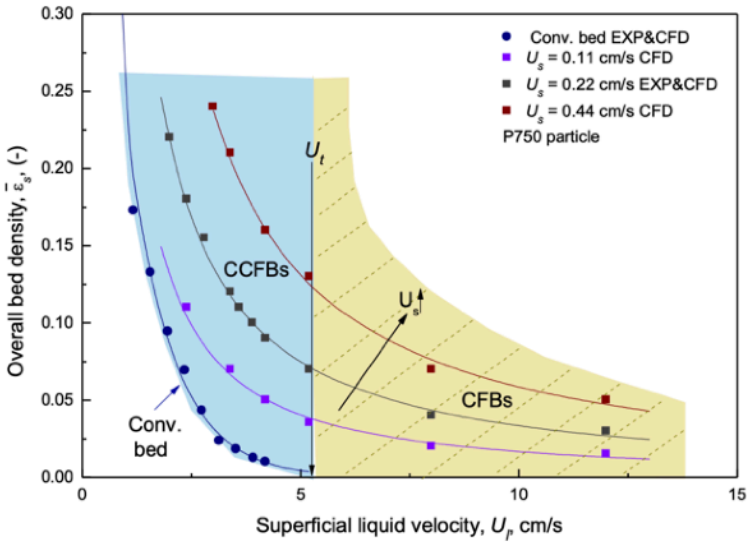


Fig 8. A flow regime map (overall bed density vs. Ul) for upward liquid-solids fluidization systems [37]

Mirroring Figure 8 to the "negative liquid velocity" range would lead to the inverse L-S fluidization regimes as shown in Figure 9[37] where lighter particles are "inversed fluidized" by downing liquid flow from the top of the bed.[38] Both CCFB[39] and CFB[40] can be identified, using the fluidization regimes shown in Figure 9.

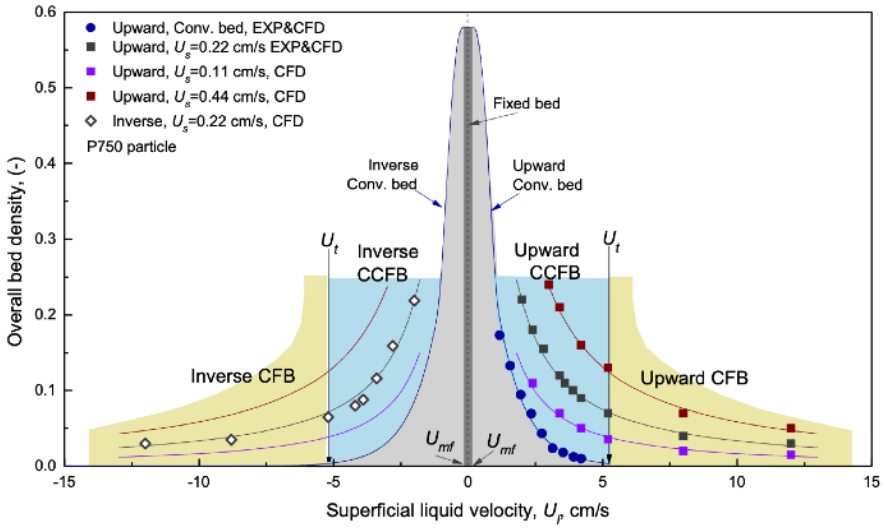


Fig 9. A completed flow regime map (overall bed density vs. Ul) for both upwards and inverse liquid-solids fluidization systems [37]

The complete regime maps (solids velocity vs liquid velocity) for all possible liquid-solid systems can be further represented in Figure 10 below, proposed as a complete four-quadrant regime map.[41] Such map can also be used to identify potential new operating areas of fluidization. Similar four-quadrant flow regime maps can also be developed for gas-solid systems.

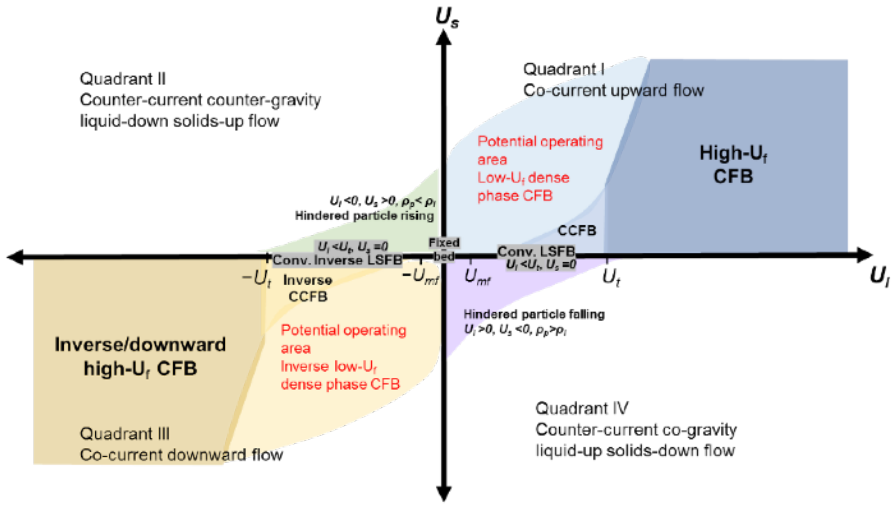


Fig 10 . A schematic representation of the flow regimes in the complete four-quadrant regime map for LSFBs, including potential new operating areas of fluidization.

The regime map shown in Figure 3 can also be expanded to include inverse fluidization, as shown in Figure 11.

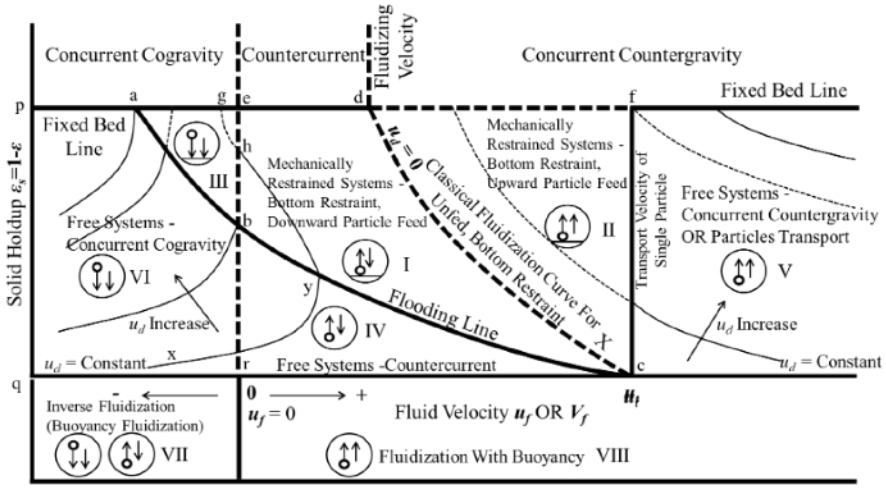


Fig 11. Fluidization operation modes and systems generalized via single phase flow system to include inverse fluidization

More recent developments have been pointing to intensifying and integrating fluidization processes, instituting new processes in other "non-conventional" process industries, comprehensive process modelling, and more in-depth fundamental studies to reveal the underlining principles by fully utilizing the rapid developments of powerful measurement tools and computational capabilities. Utilizing fine group C particles[42] and establishing micro flow fluidized bed reactors shall also come to play. For example, using a novel nano-modulation technique, the so-called Geldart Group C+ particles (Group C + Nano Additives) are shown to have significantly higher bed expansion (>200%)[43] and ozone conversation performance[44]. New fluidization theories, especially those related to the above-mentioned developments are anticipated to come.

Symbols

Epsilon	bed voidage
V_f	superficial fluid velocity
Delta$P_{1\text{-}4}$	pressure drop across a section of the fluidized bed

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Preventing Particle Segregation in Dense Granular Flows

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Dense granular flows in which particles undergo multiple enduring contacts are common in industry and nature, but an understanding of the flow behavior of powders, pellets, or grains is often gained only after years of laborious trial and error experimentation. In particular, ***segregation (de-mixing) and mixing*** of polydisperse granular materials (differing in size, density, or other particle properties) is critical in many situations. The basics of segregation are quite simple, as shown in Fig. 1.[1] In a flowing mixture of particles with two different sizes, smaller particles fall between larger particles, a segregation process known as ***percolation***. For particles of the same size but different densities, heavier particles sink and lighter particles rise, a process known as ***buoyancy-driven segregation***. The result is similar in both cases: segregation of the two species of particles. Similar behaviors occur in polydisperse systems composed of particles of several different sizes and the same density or several different densities and the same size, as well as in systems of particles varying in shape, e.g., a mixture of rods and spheres. The challenge lies in going beyond the simple explanation of segregation in Fig. 1 to a predictive framework for segregation. It is this challenge that we have addressed in our research over the last decade.[2]

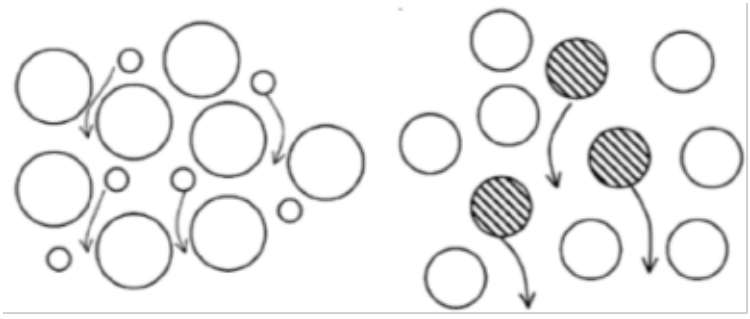

Fig. 1. Segregation in flowing mixtures differing in size (left) and density (right).

Modeling Granular Segregation

The most successful approach to modeling particle segregation in dense granular flows is the advection-diffusion-segregation continuum transport model for gravitationally driven free surface flows,[2,3] in which the spatial and temporal evolution of the concentration field for a particular species c_i takes the general form:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (\boldsymbol{u} c_i) + \frac{\partial (w_{seg,i} c_i)}{\partial z} = \nabla \cdot (D \nabla c_i) \quad (1)$$

where $\boldsymbol{u}$ is the velocity field, z is normal to the free surface of the flow, D is the collisional diffusion coefficient, and $w_{seg,i}$ is the segregation velocity of species i.[4] To solve Eq. 1, $w_{seg,i}$, D, $\boldsymbol{u}$, and appropriate boundary conditions must be known. The velocity field can be determined from analytic expressions for the relevant flow, discrete element method (DEM) simulations, theory, or experimental measurements.

Diffusion coefficient can be determined using the relation, $D \propto d^2 \dot{\gamma}$ where d is local mean particle size and local shear rate, *gamma*, is computed from the velocity field.[5,6]

Although this general approach was conceived nearly forty years ago,[7] it is only in the last decade that the form for the key ingredient in the continuum framework, the segregation term, has been explored. Many approaches have been suggested for the third term on the lefthand side of Eq. 1,[2,3] but one of the most successful is based on a "segregation velocity," $w_{seg,i}$, in Eq. 1. For size bidisperse mixtures, a relationship for the vertical segregation flux based on "kinetic sieving" of small particles though a bed of flowing large particles[8] provides a species-specific segregation velocity of the form

$$w_{seg,i} = S \dot{\gamma} (1 - c_i), \quad (2)$$

where $(1-c_i)$ is the concentration of the other species and S is a segregation length scale whose sign is positive for larger (less dense) particles and negative for smaller (denser) particles in size (density) bidisperse mixtures.[2,4] The parameter S is specific to any particular pair of particle species and depends on the ratio of the sizes (densities) of the two species in addition to other particle properties. Equation 2 makes intuitive sense in that for a particle to segregate it must differ in size or density (reflected in the parameter S) and be surrounded by particles of the other species $(1-c_i)$ that are moving to open voids for segregation to occur (*gamma*.). The segregation length scale, S, is key here. It depends on particle properties such as the size or density ratio.[9,10] S is not a fitting parameter but rather a physical characteristic of the particle mixture, much like the diffusion coefficient or solubility of a species for a liquid mixture is a characteristic of the mixture components.

The segregation parameter S for specific pairs of non-cohesive spherical particle species can be found from DEM simulations[9,10] or experiments.[11,12] Typically, we have done this by considering heap flow of spherical particles, where it is possible to measure $w_{seg,i}$ over a wide range of shear rates and concentrations in a single DEM simulation. Repeating this for a wide range of particle size

ratios provides a relationship for the dependence of S on diameter ratio R_d. The value of S for density bidisperse mixtures can be found in the same way using particles of the same size with different densities. In this case, S depends on the density ratio R_{rho}.[10] Experimentally, it is possible to determine S for an arbitrary bidisperse mixture by measuring the concentration in a heap flow and finding the value for S that minimizes the difference between that predicted by Eq. 1 and the measured concentration.[11,12]

Of course, particles encountered in many applications are not spherical, so we consider cylindrical particles as a proxy for non-spherical particles. By using super-ellipsoids to model cylindrical particles, both rods and disks,[13] in DEM simulations of bidisperse heap flow it has been possible to measure S for these non-spherical particles. The result is remarkable. Regardless of the shape of the particles, the value for S depends primarily on the particle volume ratio, R_v, as shown in Fig. 2.[14,15] The relationship is surprisingly robust, noting that it applies to disk-rod, disk-disk, rod-rod, rod-sphere, disk-sphere, and sphere-sphere particle mixtures with a very wide range of shapes (flat disks to long rods), as shown in the upper left of Fig. 2. Note that S, which is a length scale, is nondimensionalized by the diameter of the smaller volume-equivalent spherical particle, $d_{s,eq}$. Thus, regardless of particle shape, the value for S can be estimated from Fig. 2 based on only the volume ratio of the particles, provided that the particles have the same density.

A remarkable consequence of the results in Fig. 2 is that *it is possible to minimize, perhaps even eliminate, segregation of particles having different shapes by simply assuring that their volumes are similar*. This corresponds to a value of $S/d_{s,eq} = 0$ at $R_v = 1$ in Fig. 2 for which $w_{seg,i}$ in Eq. 2 is zero, indicating no propensity for either particle species to rise or sink.

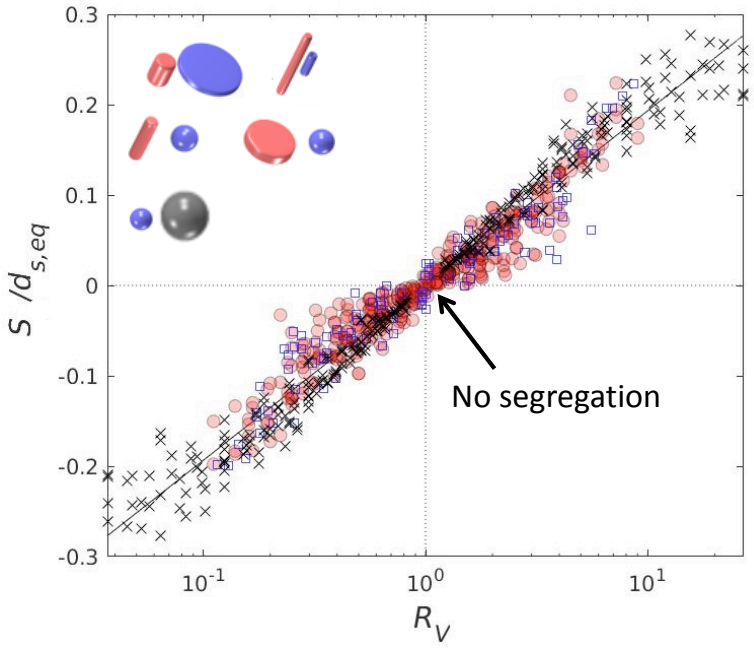

Fig 2. Dependence of the segregation length scale, S, on the particle volume ratio, R_v.

An important aspect of this approach is that for both spherical and non-spherical particles, *S* is independent of the nature of the flow, whether it be chute flow, heap flow, rotating tumbler flow, or hopper flow. It is also important to note that although Eqs. 1 and 2 were developed for bidisperse mixtures of particles, they can be applied to mixtures of several different species and even polydisperse mixtures with slight modification.[16-18] The success of the segregation modeling approach of Eqs. 1 and 2 is evident in Fig. 3, which shows a visual comparison of 2D hopper flow of a polydisperse mixture of spherical particles for an experiment, a DEM simulation, and the continuum model of Eqs. 1 and 2.[19,20] Not only is the qualitative correspondence between the continuum model and both the experiment and DEM simulation clear, but the three cases also match quantitatively.

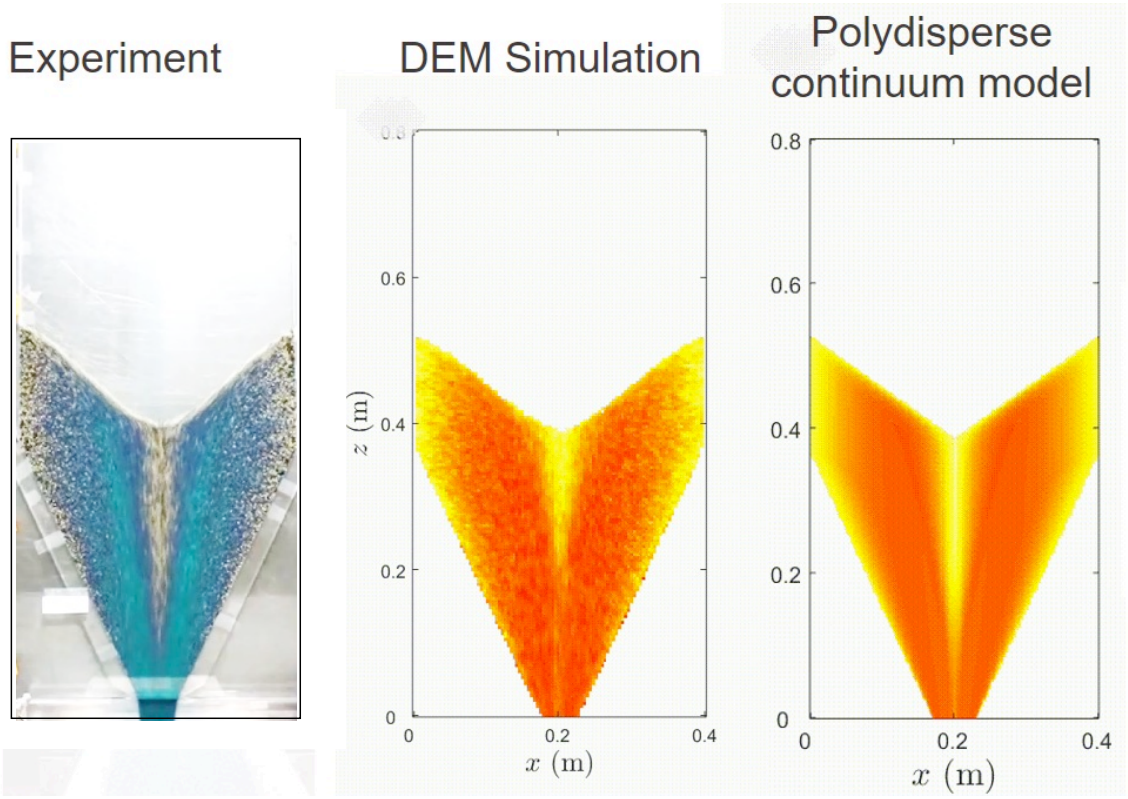

Fig 3. Comparison of experiment, DEM simulation, and polydisperse continuum model for 2D hopper flow. Light colors correspond to larger particles.

The continuum model produces accurate results over a wide range of particle mixtures (size-bidisperse, density bidisperse, multidisperse, polydisperse, and with overlapping particle size distributions)[10,16,18,19,21] as well as many flow geometries (heap, chute, rotating tumbler, pure shear, and hopper flow),[16,17,19,20,22,23] but one of its limitations is that it is necessary to specify the velocity field, ***u***, in Eq. 1. Fortunately, the continuum model is fairly insensitive to the details of the velocity field, so it can be based on theory, experiments, or DEM simulations. For instance, for Fig. 3, the velocity field in the thin flowing layers at the V-shaped top surface is based on experimental results for heap flow,[24] while the velocity field in the rest of the hopper is based on the standard kinematic model of Nedderman and Tüzün.[25] It is also fortunate that, at least to a first approximation, the flow

is largely uncoupled from the segregation based on our experience for free surface flows like heaps, chutes, and tumblers where the flow occurs in a relatively thin surface layer. Nevertheless, a fruitful area for future research will be to devise approaches that couple the flow to the segregation, perhaps via a granular rheology model such as the *mu*(*I*)-rheology.[26] Finally, although the simple linear dependence of $w_{seg,i}$ on concentration c_i in Eq. 2 is convenient to use and accurate in many situations, a more accurate quadratic expression for size-bidisperse mixtures may be more appropriate in some cases, particularly situations where the concentration of one particle species dominates over the other.[27]

Although the continuum model of Eqs. 1 and 2 works well for both size-disperse and density-disperse particle mixtures, the combined effects of both size and density make its application more challenging. Through a large number of meticulous DEM simulations (well over 200) for a range of size ratios ($1 \le R_d \le 3$) and density ratios ($1 \le R_{?} \le 4$) a quadratic expression for the dependence of $w_{seg,i}$ on c_i can be used in place of Eq. 2 to handle combined size and density variations.[28]

Preventing Segregation

An exciting practical by-product of this research with broad potential impact is the ability to intentionally "design" non-segregating particle mixtures by the appropriate combination of mixture concentration, density ratio, and size ratio.[29] In most practical cases, the concentration of each species is fixed based on the product requirements. Furthermore, the density of either species is usually difficult to alter, resulting in a fixed density ratio. However, the size ratio of the particles can be varied by one of several standard processes such as agglomeration or grinding. *Thus, it is possible to specify a size ratio for a given density ratio and relative concentration of species that minimizes segregation.* For example, in a rotating tumbler (Fig. 4) a 60:40 mixture of steel (blue) and glass (red) particles, corresponding to a density ratio of $R_r = 3$, would quickly segregate for particles of the same size. However, using a size ratio of $R_d = d_{steel}/d_{glass} \approx 1.3$ actually mixes initially segregated particles in DEM simulations in a rotating tumbler (Fig. 4 at $t = 50$ s). Recent experimental results confirm that non-segregating mixtures can be "designed" using this approach.

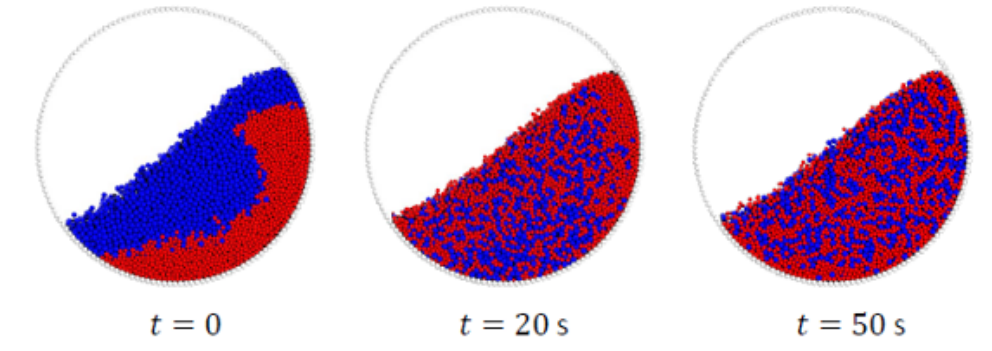

Fig 4. Steel (blue, $c_{steel} = 0.6$) and glass (red, $c_{glass} = 0.4$) particles with $R_{rho} = Rho_{steel}/Rho_{glass} = 3$ would normally remain segregated in rotating tumbler except for the specific size ratio $R = d_{steel}/d_{glass} \approx 1.3$ ($d_{steel} = 3$ mm) used here, where the particles mix in less than 50 s (15 cm quasi-2D tumbler rotating at 25 rpm).

Ongoing Work on Segregation

The continuum model approach outlined above is quite successful in addressing the problem of predicting granular segregation from a practical phenomenological viewpoint, but the underlying physics of the interaction of small particles with large particles at the particle scale is also important — after all, it is the balance between gravitational and interparticle forces that determines segregation. The ultimate goal is to connect forces on a particle that drive segregation to its segregation velocity, $w_{seg,i}$, much like the drag force on a particle is connected to its velocity through the Stokes drag law in a fluid. The forces on intruder particles in DEM simulations of shear flow can be measured using a virtual spring, as shown in Fig. 5.[30,31] Recent results provide a prediction of whether a single intruder particle rises or sinks in a sheared bed of particles, depending on the size and density ratios of the intruder particle to the bed particles,[30] as well as the shear and pressure gradients in the flow.[31] Even more interesting are the results for multiple intruders (*i.e.*, mixtures) using the same virtual spring approach. These measurements not only provide the segregation force on particles of different sizes over the full range of relative concentrations, they provide an accurate description of pressure partitioning between species (useful in continuum models) and the concentration below which the single-intruder assumption applies.[32] The associated phase plot is shown in Fig. 6 as a function of the particle size ratio and large particle concentration. It is evident that even at relatively large concentrations particles in mixtures feel the same segregation force as intruder particles, particularly for large particles.

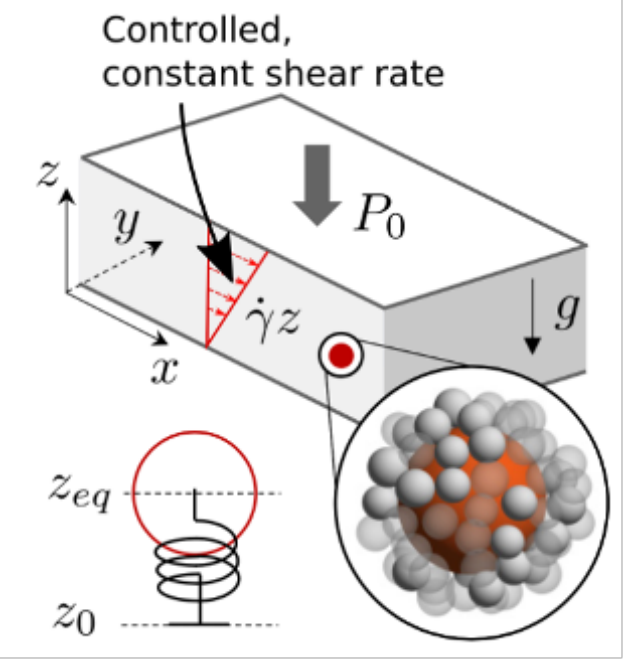

Fig 5. Plane shear flow for a large red intruder particle attached to a virtual spring, which restricts z-axis motion, to measure the forces on the intruder.

Over the past decade we have made substantial progress on predicting segregation/de-mixing of particles of different sizes, different densities, and even different combinations of size and density.

However, there are many avenues that remain to be pursued. First is the connection between drag forces on a particle and its segregation velocity. Preliminary results indicate that the drag force is connected to the velocity through a Stokes-like drag law. While others have suggested this for a very limited range of particle size ratios, our data indicates that the Stokes-like drag law dependence of the drag coefficient on Reynolds number for a spherical particle holds over a wide range of size and density ratios and for effective Reynolds numbers spanning several orders of magnitude; the granular drag coefficient has a value that lies approximately between that for form drag (8/Re) and the total drag (24/Re).

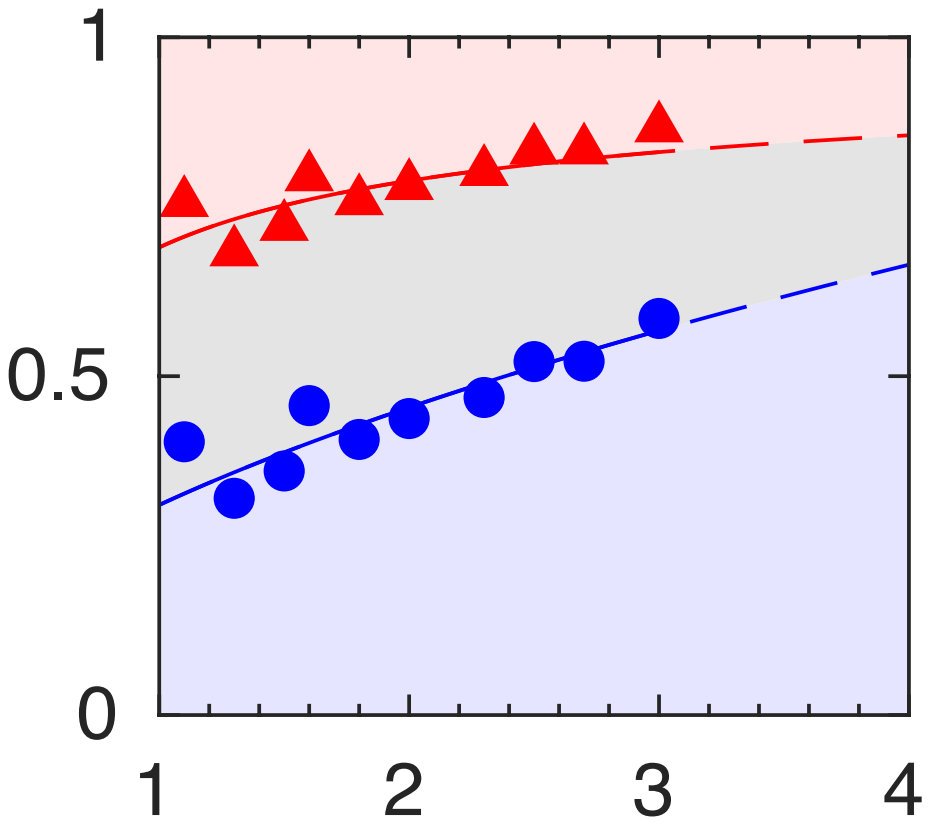

Fig 6. The phase space for the segregation force in a mixture being similar to that for a single intruder (blue for large, red for small) depends on the concentration of large particles, c_l, and size ratio, d_l/d_s. The right side is a visual representation of the concentration.

Second, all of the results for the continuum model of Eqs. 1 and 2 are for size ratios $R_d < 3$. Above this size ratio, free sifting (the ability of fine particles to segregate in the absence of shear) plays a role. In fact, preliminary simulations of heap flow for $R_d = 6$ in Fig. 7 indicate that fine particles immediately percolate through the flowing layer and static large particles to build up on the sloped surface below the feed zone as the large particles flow down the slope, Fig. 7(a). This layer of fine particles gets thicker and eventually starts to flow down the slope, but at a lower velocity than the large particles, Fig. 7(b). As the process continues, a "front" of fine particles that is distinct from the

large particles propagates separately down the slope, Fig. 7(c). This two-layer propagation is completely different from what happens for $R_d < 3$ where only a single layer flows down the slope.

Third, we are considering segregation under conditions where particles have attractive forces, both close-range forces like adhesion and long-range forces like electrostatic attraction. In these cases, particles tend to agglomerate into clusters and these clusters rise in the flow, much like large particles. At the same time, shear forces due to the flow act to break up the agglomerates. As a result, there is a very interesting coupling between the flow, segregation, and attractive forces.

Gratitude and Thanks

Before concluding, I have to make clear that our work on segregation/de-mixing that led to the Dow Particle Processing Award is based on the effort, skill, and insight of many of my collaborators. Karl Jacob, formerly at Dow, provided the initial impetus for this line of research. Prior to Karl prodding us to shift to study mixing and segregation, Julio Ottino and I had pursued research on pattern formation in granular systems. Although this was an interesting academic pursuit and the phenomena depend on size- or density-segregation, it did little to directly address the practical problem of predicting segregation in granular flows. Our initial work, funded by Dow as a result of Karl's effort, was focused on experiments for segregation on heaps.[33] But the breakthrough came as a result of a brilliant post-doc, Yi Fan, who now works at Dow. Yi proposed the simple model for the dependence of the segregation velocity on the shear rate and concentration in Eq. 2.[4] The key here is the simplicity. Other researchers proposed complicated constitutive relations that were hard to apply because of the difficulty in connecting the parameters in the constitutive relations to real granular systems. Yi's approach allowed us to determine a single variable (S) from DEM simulations that reflects the propensity for segregation based on only the size ratio.

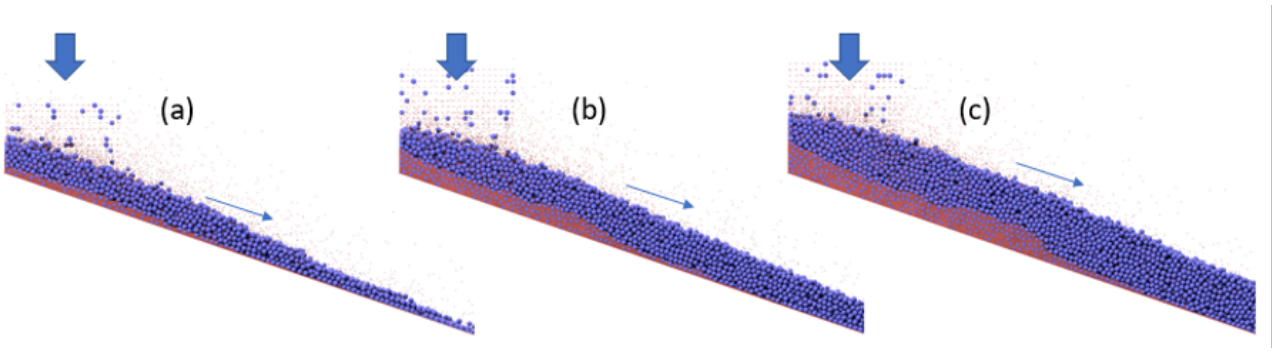

Fig 7. Large particles (d_l = 4 mm) with fine particles (R = 6) fed on the left side flow down the 50 d_l long heap; (a) t=12 s; (b) t=24 s; (c) t=36 s. Simulations by PhD candidate Song Gao.

Conor Schlick worked with Yi to extend the approach from heap flows to rotating tumblers and from size-bidisperse mixtures to polydisperse mixtures.[4,9,18,23] Hongyi Xiao showed that the approach could be applied to density-bidisperse mixtures,[10] and Austin Isner applied it to fully 3D heap flows.[34] Zhekai Deng and Hongyi Xiao showed that the approach could be applied to transient and

periodic flows in heaps,[35] hoppers,[19,20] and chutes,[17] while Yongzhi Zhao (visiting from Zhejiang University) and Ryan Jones showed the approach can be applied to mixtures of non-spherical particles.[13-15] Alex Frey demonstrated how the segregation parameter from our model can be extracted from careful experiments.[11,12] Song Gao considered overlapping particle size distributions[21] and is currently considering large size ratios where free sifting occurs. Most recently, Yifei Duan extended the approach to combined size- and density-bidisperse systems.[28] As described above, this allows the prediction of the conditions (size ratio, density ratio, and relative concentration) that prevent segregation altogether, a result that will surely have a direct impact on preventing segregation in industrial granular flows. Finally, Lu Jing is working on connecting particle level forces with the segregation velocity to provide a fundamental basis for its dependence on the size and density ratios.[30,31] I also mention former graduate students and post-docs Ivan Christov, Vidushi Dwivedi, Gabriel Juarez, Thomas Lynn, Paul Park, Florent Pignatel, Lauren Smith, Mengqi Yu, and Zafir Zaman, as well as French collaborators Umberto D'Ortona and Nathalie Thomas, with whom I have worked on other aspects of granular flow and segregation in the past decade.

Over the past decade, my collaborators Paul Umbanhowar and Julio Ottino have provided insight and vision as we have guided this remarkable set of PhD students and post-docs through their work. I have also enjoyed working with collaborators/co-authors at The Dow Chemical Company, Yi Fan, Ben Freireich, Karl Jacob, James Koch, Madhusudhan Kodam, and Jörg Theuerkauf, and at the Procter & Gamble Company, John Hecht and Vidya Vidyapati. Both companies and the National Science Foundation (NSF grants CMMI-1000469, CBET-1511450, CBET-1929265) have provided generous funding for this research.

I owe a debt of gratitude to all of these colleagues and many more who touched this research in one way or another. It is to them that I dedicate this award.

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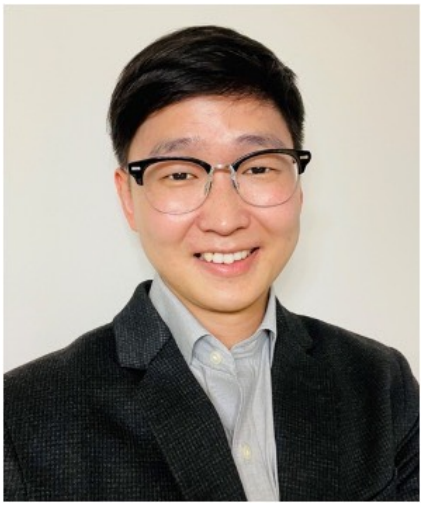
George Klinzing Best Ph.D. Award

Coupled Kinetic and Mechanistic Study of Carbonation of Silicate Materials with Tailored Transport Behaviors for CO_2 Utilization

Gaunhe Rim

Postdoctoral Fellow

Georgia Institute of Technology, Georgia, USA



Since the industrial revolution, atmospheric CO_2 concentration has steadily increased due to the combustion of fossil fuels, reaching 410 ppm. According to the IPCC report, it was recognized that the anthropogenic greenhouse gas emissions caused by human activities are major drivers for global warming of 1.5 °C above the pre-industrial level. Due to the unprecedented scale of human driven CO_2 emission and its environmental impact, the mitigation of climate change requires a wide range of multifaceted solutions. Thus, enormous global efforts have been placed on the development of Carbon Capture, Utilization, and Storage (CCUS) to mitigate CO_2 emissions in the immediate future.

Carbon Mineralization via CO_2 Partial Pressure Swing

Most recent reports by the U.S. National Academies and the Mission Innovation presented that *ex-situ* carbon mineralization is a CO_2 utilization technology with a great carbon storage potential and a large market size. Also, fixing CO_2 into a solid matrix of carbonate minerals is one of the most permanent methods for carbon storage. Although the *ex-situ* carbon mineralization presents many advantages and great potential as CCUS technology, its commercialization has been limited due to the mammoth scale of the process, slow reaction kinetic between CO_2 and silicate minerals, and high energy and operating cost. To minimize energy and chemical (acid and base) consumption of this technology, recent research has been focused on a two-step carbon mineralization via Pco_2 swing using highly reactive heat-treated serpentine mineral (**Figure 1**). In the mineral dissolution step, protons from carbonic acid are used to leach Mg and Si from heat-treated serpentine. The carbonic acid is formed by bubbling of the CO_2-rich gas stream ($Pco_2 \leq 1$ atm, e.g., flue gas) into the HTS slurry leading to the lowered pH of 6 – 7. After the leaching step, the Mg-rich solution saturated with CO_2 is proceeded to the precipitation step, where an increase in the solution pH is necessary for the sufficient formation of CO_3^{2-} ions to induce the precipitation of carbonate particles. The pH can be raised via the Pco_2 swing method, in which a gas stream with a relatively lower Pco_2, such as air (about 410 ppm CO_2), is bubbled into the solution to remove excess carbonic acid from the solution and increase the pH. Finally, magnesium carbonate is precipitated at the elevated pH conditions (8.5 – 9.5). In this scheme, the mineral dissolution and carbonate

formation reactions can be independently optimized and the need for strong acid and base can be eliminated while producing high quality final products, such as magnesium carbonate and high surface area silica. However, the elemental (Mg and Si) extractions from the complex silicate structures of heat-treated serpentine are still poorly understood and a more fundamental understanding of the Pco_2 swing process is required to develop a commercial-scale plant.

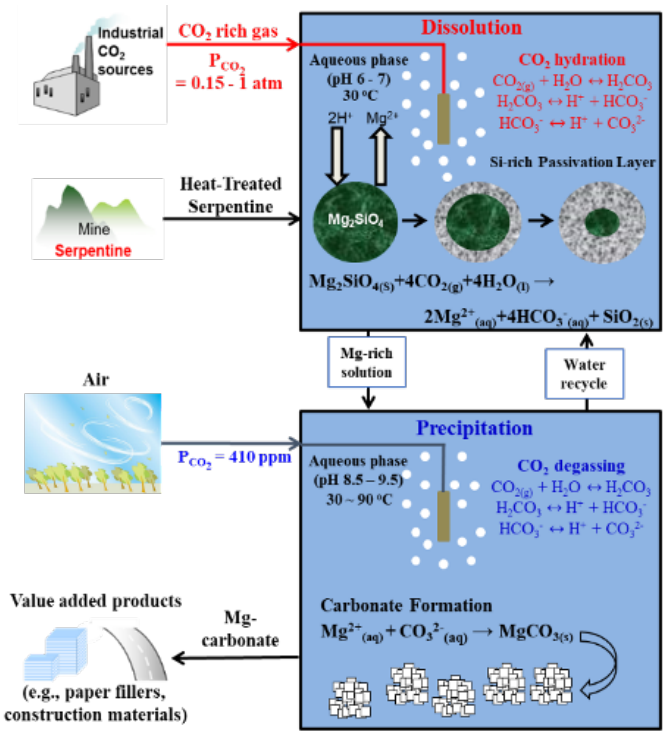


Fig 1. Schematic diagram of the two-step carbon mineralization technology via Pco_2 swing developed for combined CO_2 capture, utilization, and storage.

Thus, the objectives of this study are directed toward addressing these technical challenges. The effect of operating conditions, such as temperature, slurry density, and CO_2 partial pressure, on the dissolution of heat-treated serpentine and subsequent Mg-carbonate precipitation behaviors, were studied to provide a fundamental understanding of the Pco_2 swing carbon mineralization with highly reactive silicate materials.[1] The heat-treated serpentine was reacted in an aqueous solvent saturated with 1 atm CO_2, while varying temperature, slurry density, and the concentration of Mg-targeting ligand (i.e., citrate). Non-stoichiometric dissolution behaviors between Mg and Si were confirmed under far-from-equilibrium conditions (0.1 wt% slurry density) and the re-precipitation of the extracted Si was observed at near-equilibrium condition (1 wt% slurry density). These experiments with a wide range of slurry densities provided valuable insights into Si re-precipitation phenomena and its role in the mass transfer limitation during mineral dissolution. As the slurry density was increased beyond 1 wt% (as high as 10 wt%), the rapid supersaturation of Si was achieved due to the low solubility limit of amorphous silica, and thus, resulted in limited Mg extraction behaviors (**Figure 2**).

Investigation on Abrasion versus Fragmentation of the Si-rich Passivation Layer for Enhanced Carbon Mineralization

While the mineral carbonation reaction is thermodynamically favored, its kinetics has been considered to be too slow without engineered enhancements. Particularly, the formation of the Si-rich passivation layer on mineral particles limits the overall reaction rate by creating a significant diffusion barrier (**Figure 2**). In this study, a unique internal grinding system was designed by directly incorporating grinding media into the carbon mineralization reactor based on Pco_2 (partial pressure of CO_2) swing.[2] The effect of physical properties (e.g., sizes and densities) of grinding media on the dissolution behaviors of heat-treated Mg-silicate minerals (i.e., serpentine, $Mg_3Si_2O_5(OH)_4$) was investigated. The stress intensity (**Equation (1)**), which is proportional to the energy transferred from grinding media to the heat-treated serpentine particles during a stress event, was used to describe the effect of the reaction parameters on the extent of the physical activation and the enhancements in mineral dissolution.

$$SI = d_{GM}^3(\rho_{GM} - \rho)V_t E_{P,rel} \quad (1)$$

where d_{GM} is the grinding media diameter, rho_{GM} is the density of the grinding media, *rho* is slurry density, V_t is tip speed of a rotating impeller, and $E_{P,rel}$ is the fraction of kinetic energy transferred from the grinding media to mineral particles during the collision event.

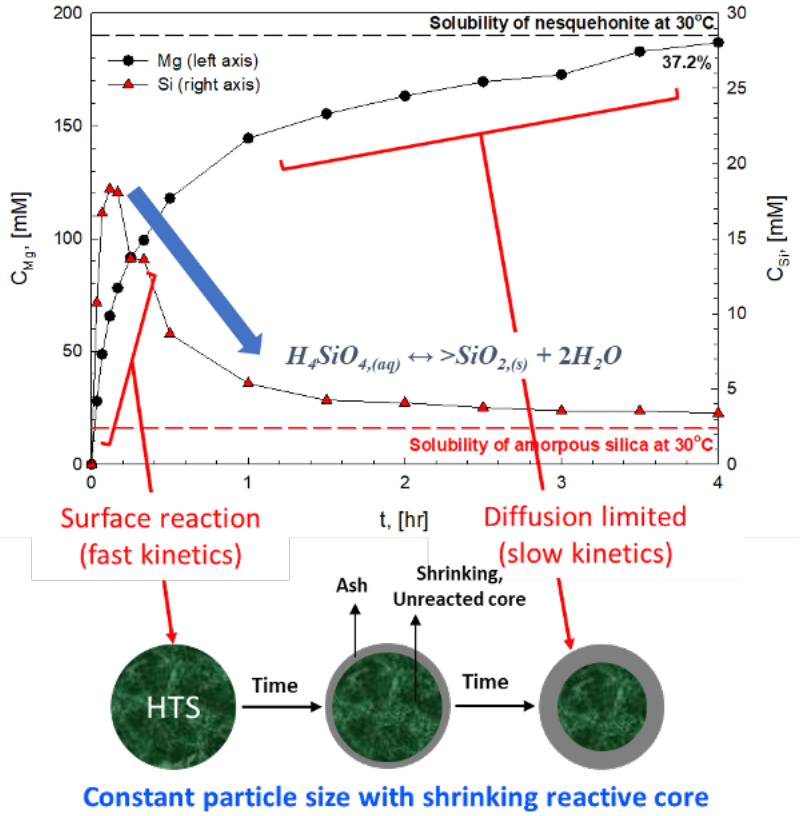


Fig 2. Re-precipitation of extracted Si and its effect on the formation of the Si-rich passivation layer and mass transfer limited mineral dissolution behaviors.

The existence of the optimum stress intensity was identified where the minimum particle size was obtained. As shown in **Figure 3**, it was found that two attrition modes, abrasion and fragmentation/ pulverization, were dominant depending on the stress intensity and that the fragmentation/ pulverization mode was more effective in removing the Si-rich passivation layer and promoting Mg extraction during the dissolution step. The internal grinding system resulted in greater Mg leaching compared to the conventional *ex-situ* grinding because the *in-situ* approach allowed the synergistic effect of continuous removal of the Si-rich layer and surface dissolution reaction leading to the improved overall energy efficiency of the developed CO_2 utilization and storage technology.

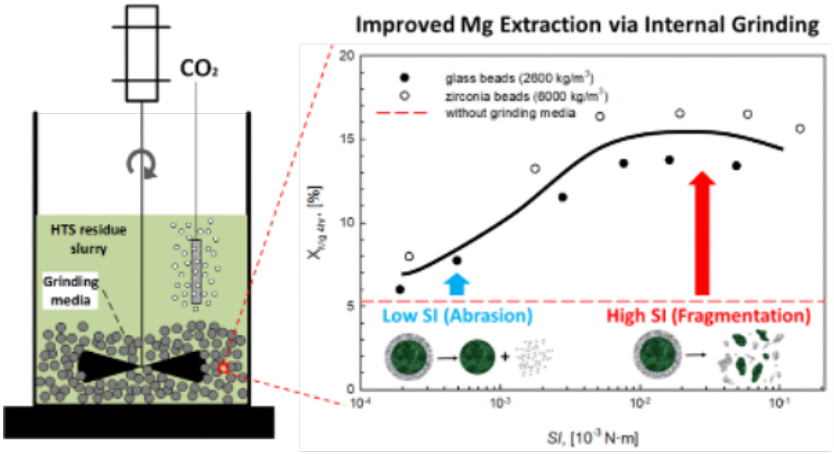


Fig 3. Enhanced elemental (Mg) extraction behaviors of heat-treated serpentine in the internal grinding system.

^{29}Si Solid-state MAS NMR Study on Leaching Behaviors and Chemical Stability of Different Mg-Silicate Structures

For the fundamental understanding of the complex dissolution behaviors of heat-treated serpentine, the changes in the silicate structures (Q^0 – Q^4) of heat-treated Mg-bearing mineral (serpentine) exposed to a CO_2-water system (carbonic acid) was investigated using ^{29}Si MAS NMR and XRPD.[3] The identified silicate structures were employed to provide insight into how Mg and Si are liberated from the different silicate structures during the dissolution process(**Figure 4**). The results indicated that the heat-treated serpentine is a mixture of amorphous (Q^1: dehydroxylate I, Q^2: enstatite, Q^4: silica) and crystalline (Q^0: forsterite, Q^3: dehydroxylate II, and serpentine) phase, while natural serpentine mineral has a single crystalline Q^3 silicate structure. The leaching experiments showed that both Mg and Si in the amorphous silicate structures (Q^1: dehydroxylate I, Q^2: enstatite) are more soluble than those in the crystalline phase (Q^0: forsterite, Q^3: dehydroxylate II and serpentine). Therefore, tuning the silicate structure towards Q^1 and Q^2 would significantly improve the carbon sequestration potential of silicate minerals, whereas silicate materials with a Q^3 structure would provide great chemical stability in acidic conditions. The solubilities of silicate structures were in the order of Q^1 (dehydroxylate I) > Q^2 (enstatite) >> Q^0 (forsterite) > Q^3 (dehydroxylate II) > Q^3 (serpentine) and this finding can be used to better design a wide range of energy and environmental materials and reaction systems.

Precipitation of Mg-carbonate Phase via Pco_2 swing for CO_2 Utilization and Storage

The Pco_2 swing Mg-carbonate precipitation behaviors were investigated in the semi-batch CO_2 desorption system. The CO_2 desorption kinetics and subsequent alkalization by Pco_2 swing were investigated with thermodynamic calculation and kinetic modeling. The modeling study indicated that the CO_2 gas-liquid mass transfer is the rate-limiting step of the overall CO_2 desorption process. The bubbling of air (400 ppm CO_2) into the CO_2 saturated Mg-rich (Mg-bicarbonate) solution led to CO_2 degassing, resulting in alkalization of the solution. Consequently, the precipitation of Mg-carbonate was achieved at elevated pH conditions where CO_3^{2-} ions prevail (**Figure 5**). The experimental results demonstrated that the overall Mg-carbonate precipitation is controlled kinetically by the CO_2 desorption rate. Thus, the overall precipitation kinetics were accelerated by carbonic anhydrase (CA). In the presence of seed particles (synthesized magnesite), the induction time, which is the time required for forming stable Mg-carbonate nuclei, was reduced, resulting in improved precipitation behaviors. Besides, the kinetics and yields of Mg-carbonate precipitation were enhanced at elevated temperature conditions (60 – 90 °C) due to decreased solubilities of $CO_{2(g)}$ and Mg-carbonate solid phase in water. The formation of hydrous Mg-carbonate phases, nesquehonite (at 30 °C) and hydromagnesite (at 60 – 90 °C), were confirmed.

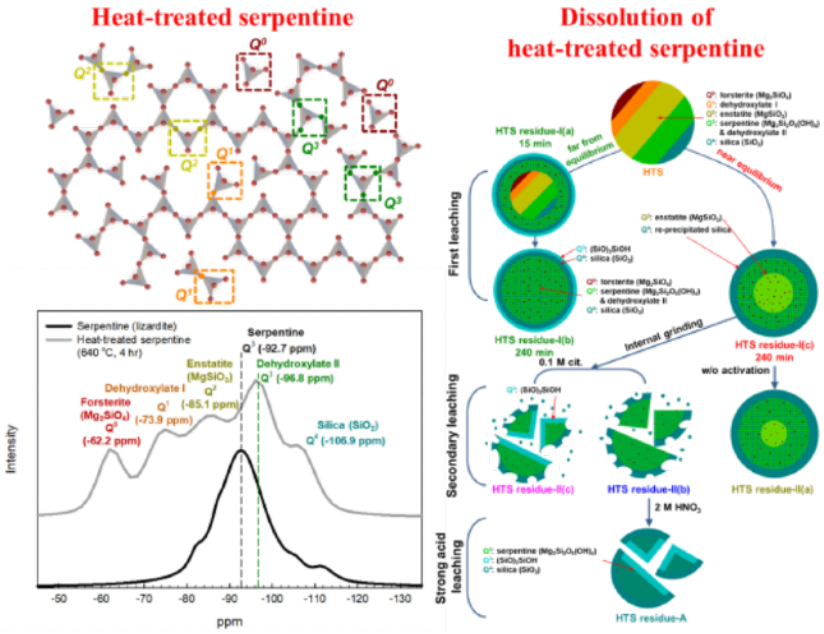


Fig 4. Identified heat-treated serpentine silicate structure by ^{29}Si MAS NMR and proposed dissolution mechanism of heat-treated serpentine particle.

Summary

In this study, physically enhanced elemental (Mg and Si) extractions from heat-treated serpentine (HTS) and subsequent Mg-carbonate precipitation via Pco_2 swing were investigated for the development of effective Carbon Capture, Utilization, and Storage (CCUS) technology. This approach will bring a great paradigm shift in the energy and environmental field since the less

energy-intensive and low-cost *ex-situ* carbon mineralization process via Pco_2 swing will be able to allow long-term and sustainable carbon utilization.

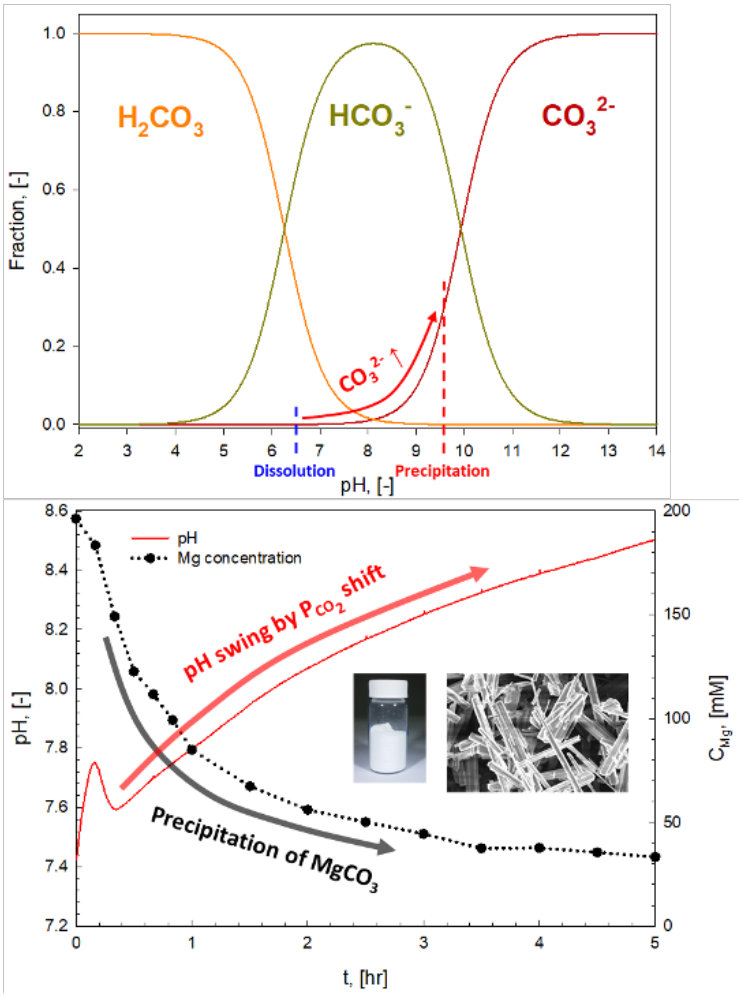


Fig 5. Mg-carbonate precipitation via Pco_2 swing.

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2022 PTF Award Nominations – Open Since March, 2022

Dear PTF Members:

The deadline for nominations is approaching fast. The full package (a single PDF document) is due by Tuesday, May 31st, 2022

The nomination information, award criteria, and previous winners for each of these awards are found in the links below:

https://www.aiche.org/community/sites/divisions-forums/ptf/awards

PSRI Fluidization and Fluid-Particle Systems

https://www.aiche.org/community/awards/psri-fluidization-and-fluid-particle-systems

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Elsevier Particle Technology Forum Award for Lifetime Achievements:

https://www.aiche.org/community/awards/elsevier-particle-technology-forum-award-lifetime-achievements

SABIC Young Professional Award

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George Klinzing Best PhD Award

https://www.aiche.org/community/awards/george-klinzing-best-phd-award

ANSYS Particle Technology Forum Service Award

https://www.aiche.org/community/awards/ansys-particle-technology-forum-service-award

The PTF Executive Committee strongly encourages nominations from all qualified applicants for each award, especially nominees who are women and/or otherwise underrepresented backgrounds in our Forum, the Institute, and in STEM fields.

Key information for this year is below.

The Nomination process is a single step. The full package (a single PDF document) is due by **Tuesday, May 31st, 2022**, containing items specific to each award.

- If the nominee has previously received any award from PTF, an explicit statement of new accomplishments or work over and above those cited for the earlier award(s) must be included (maximum of 1 double spaced page).
- Selected bibliography (including major papers published, books, and patents)
- In a given year, the same person cannot win more than one PTF award
- Wait period for nomination after previous award

- A former PTF award winner cannot be nominated for another award for at least three years after receiving any previous PTF award
- **It is required that the nominators are current PTF members**
- **Nominees are not required to be PTF members**
- For the PTF Lifetime Achievement Award, one of the support letters must be from a former PTF Lifetime Achievement Award winner.
- Except for the PTF Service Award, the Executive Committee has released the nominee PTF membership requirement. PTF membership is still expected for the PTF Service Award.

All questions and concerns should be addressed to me by email to reddy.karri@psri.org with the subject line including the name of the award. The Executive Committee is actively developing processes to ensure equity, diversity, and inclusion in the forum and its awards.

We encourage the PTF members to nominate those well deserving candidates for various awards.

S.B. Reddy Karri

PTF Vice Chair 2021-2023

James Gilchrist

PTF Chair 2021-2023

PTF Membership

To continue receiving the PTF newsletters (3 issues per year) and stay current with particle technology events and news, please make sure to renew/ start your membership by either:

- Checking Particle Technology Forum when renewing your AIChE membership annually,
- Becoming a PTF lifetime member so that you don't have to renew membership every year

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- PTF Membership Committee

WORLD CONGRESS ON PARTICLE TECHNOLOGY (WCPT9)

The 9th World Congress on Particle Technology (WCPT9) will be held in September **18-22, 2022**, in **Madrid** (Spain) as a face-to-face event. **WCPT9** is the **world's most influential event for the particle and bulk technology community** under the auspices of the **World Assembly of Particle Technology**, **representing main societies and federations around the world**. It's where world-leading researchers and companies share the latest thought leadership about the progression and future of particle technology. And it's the best place for networking opportunities with your colleagues to share mutual professional goals.

It happens every time. You arrive in **WCPT** and think **"What a great atmosphere!"** there's something in the air, an energy that invigorates you and fills you with positive emotions sharing your knowledge with your colleagues. Together, **face-to-face**, we will shape the future of particle technology. It's time to reconnect, meet again, enjoy networking with your colleagues **in a safe environment** discovering a unique way of living in Madrid.

The **scientific program** outlined **covers** the most relevant topics nowadays for industry and our society. WCPT9 **main topics** are:

- Particulate solids handling
- Particle and particulate systems characterization
- Particle processing
- Particle-fluid systems: fluidization and multi-phase flow
- Particle formation and design
- Particle separation
- Aerosol particles
- Nanoparticles: production, characterization, and applications
- Modelling and simulation
- Science, Technology, Engineering and Design in particle-based materials and products.

Beyond these main topics, **Joint Events (JE)** will be also organized in engineering, scientific or technically related fields, where particle technology is present. Three WCPT9-JE have been already confirmed:

- Challenges of microplastics: analysis and control.
- III ANQUE-DECHEMA Leading edge conference "Particle Technology. Shaping the future".
- Multidimensional particle properties: characterization, separation, and application.
- Thermomechanical behaviour of granular materials (MATHEGRAM).

Two memorial sessions are being also organized in honor of Prof. Rolf K. Eckhoff and Prof. Ugur Tuzun to remember them and celebrate their work.

WCPT9 has received over 570 contributions from all around the world until now, counts with the confirmation of 8 plenary speakers, around 40 keynotes, over 450 oral and flash presentations, and over 80 poster communications covering a wide range of areas related to particle technology. Under the theme **"Exploring beyond limits"**, WCPT9 aims to engage the whole community on particle technology in the different continents and their countries through an outreach and promotion program specifically designed for this purpose.

The deadline for abstract submission was 2 May 2022 but it will be possible to send us your research work as a poster (5 min orally presentation) until **18 September 2022, do not miss the opportunity to participate!** You will find all the details to prepare your abstract and the information related to the evaluation in the following link:
CALL FOR ABSTRACTS

Poster presentations are very welcome until 18 September 2022!!.

We **welcome sponsors and exhibitors** to be part of this great event with world-wide impact that continues regularly being celebrated every four years for over a quarter of a century. A **guide with different opportunities for sponsorship and exhibitors** can be found here.

The **website** will be updated constantly with information provided from organizers and participants, so please be aware of the notifications regarding WCPT9 at: https://wcpt9.org/

If life were a city, it would be Madrid. If your interest is particle technology WCPT9 is the conference to participate in, **what else?**

The organizers of WCPT9 look forward to welcoming you in Madrid 2022 with renewed optimism and ambition, in September 18-22, 2022. **JOIN US!!**

Carlos Negro, *Congress Chair*
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Álvaro Ramírez-Gómez, *Scientific Committee Chair*
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Job Postings

Engineer at Particulate Solid Research, Inc. (PSRI), Chicago, Illinois

PSRI is looking for an independent engineer / researcher who can carry out experiments and / or simulations to understand processes involving particulates. Please apply here, if you are interested: https://psri.org/about/careers

- **Key responsibilities:**
  - Design and perform experiments and/or simulations to qualify/quantify various fluidization phenomena
  - Design custom test rigs to support experimental work.
  - Collaborate with and communicate results to clients
  - Share research outputs in the form of presentations and reports
  - Contribute to the technology advancement and expansion
- **Competencies and Qualifications:**
  - Bachelor's or Ph.D. in Chemical or Mechanical Engineering or related
  - Background in particle technology and multiphase-flow preferred
  - Meticulous with data
  - Self-motivated and takes initiative
  - Independent and can work well with a team
  - Organized and detail oriented

PSRI is an international consortium of companies focused on advancing technology in multiphase flows with granular and granular-fluid systems. PSRI focuses on large-scale experiments, mathematical models, and the design and optimization of granular-fluid unit operations such as cyclones, pneumatic conveying, fluidized beds, ebullated beds, slurry beds, and circulating fluidized beds. We are the conduit from using new technology developed in the lab to applications in the field for many companies, including Ascend Performance Materials, BASF, BP, Chevron, Chevron Phillips, Dow Chemical, ExxonMobil, Flour, SABIC, IFPEN, Phillips 66, Siemens, Technip Energies, UOP Honeywell, etc. Our company has amassed a prolific amount of design data, technology, know-how, design criteria and models on all aspects of slurries, liquid injection, fluidization, entrainment, pneumatic conveying, attrition, erosion, distributors, standpipes, solids transfer, and circulating fluidized beds. In short, we are globally recognized as being the premiere leader in the research and development of granular fluid operations.

If you have any questions, please contact ***Dr. Jia Chew*** (jia.chew@psri.org)

Solids Processing Research Scientist at Dow Chemical, Texas

Dow's Plastics & Hydrocarbons R&D organization has an exciting opportunity for a talented & motivated ***Research Scientist*** with expertise in Solids Processing and Handling (particle technology) in our New Process Technology Development organization. This organization is responsible for process research & development, technology implementation, and troubleshooting across all technology platforms and global assets aligned to our Plastics & Hydrocarbons businesses. As a member of this team, you will work closely with capital project & engineering teams as well as our technology centers to conceptualize, innovate, and design new processes. While the group has a global presence, the current position will be located in Lake Jackson, TX at our Texas Innovation Center – a premier work environment with modern offices & laboratories equipped with the latest technology.

The key responsibilities for this role will be to provide technical expertise in the areas of solid particle conveying (pneumatic and mechanical), silo storage, fluidization & fluidized bed processes, drying, coating, feeding/dosing, classification, separation technologies (solid-solid, gas-solid, solid-liquid), mixing/blending and particle engineering. The ideal candidate will bring in-depth expertise and practical knowledge across a breadth of these solids processing technology areas, and apply scientific principles for innovation, troubleshooting and problem solving.

Required Qualifications:

- A minimum of a Master's degree in Chemical or Mechanical Engineering is required; emphasis on solids processing & handling (particle technology) preferred
- Minimum of 7 years of relevant experience preferably in the field of solids processing after graduation with the highest degree

Preferred Qualifications:

- PhD with emphasis in solids processing / particle technology
- Prior industrial experience in pilot plant or manufacturing plant operations, ideally involving troubleshooting real world problems and developing innovative & practical solutions
- Proven track record of high performance and ability to convert complex technical issues into straight-forward value propositions
- Ability to generate and interpret data to make statistically relevant conclusions that will be used for process development and design

For additional details and to apply for this position please contact *Dr. Shrikant Dhodapkar* (sdhodapkar@dow.com)

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