Applying the Fundamentals

PSRI and Process Conceptualization

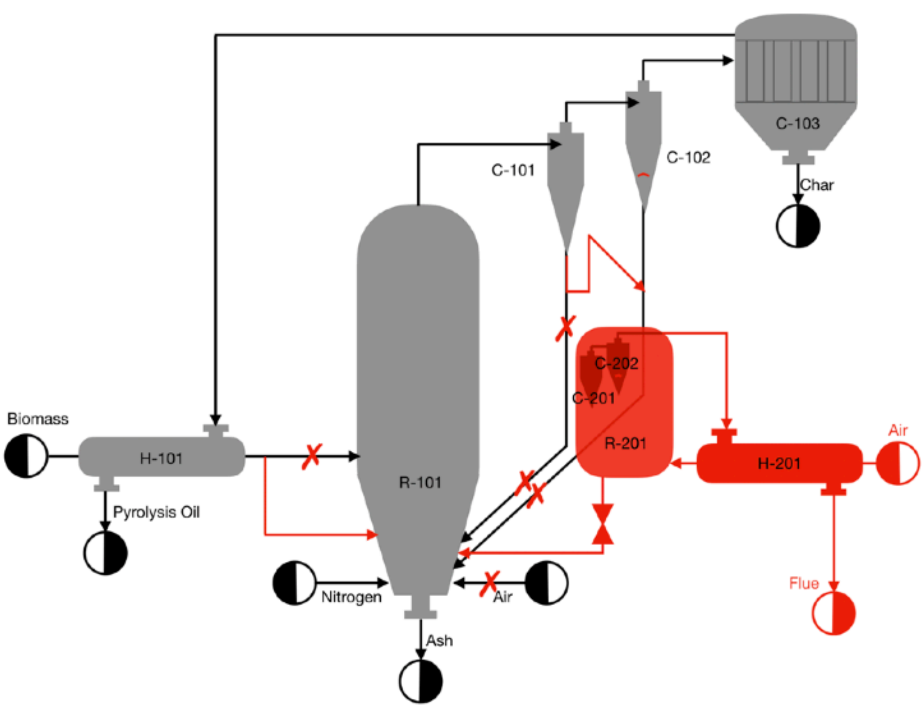
Success scale-up and commercialization of multi-phase flow processes require much more than viable technical diagrams. At PSRI, we believe this should be an evolutionary process to ensure success. Beyond the equipment specification, block flow, process flow, process and instrumentation diagrams, process commercialization needs to include tracing each phase and its impact both up- and down-stream of other unit operations. Scale-up must include particle properties and relevant distributions as it moves and changes through the process. Understanding the process allows for better improvements to the process that maximizing asset utilization and reliability while minimizing risks.

PSRI Particulate Solid Research, Inc.

PSRI Process Conceptualizations for Granular Fluid Operations

Step 1: Boxing the Concept - The fundamental part of process conceptualization is the idealization of process flow, but such an exercise is better when based on feedback from world-class experts that can serve as a sounding board or cold-eye view of the concept. PSRI has the depth and breadth of experts to provide specific details on your process while being able to leverage experience from other similar ventures. In the end, your path forward will be more detailed and distinct, including the R&D and scale-up costs.

Step 2: The Structure and Synthesis of Process Flow - Once a block flow diagram has been conceived, the process flow diagram follows. The flow of gas and liquid streams is straight forward, but the particulate phase adds an extra degree of difficulty. Although the particle density, shape, and size distributions including fines levels need to be managed, other properties such as deformability, microstructures, and adsorption levels all can have a significant impact on fluidization, filtration, classification, and final product specifications. Indeed, miss-management of fines levels or ignoring surface roughness could result in defluidization, expanded beds, high solids losses, and poor reactivity for some fluidized bed operations.



Step 3: Tracing All Phases - The first process flow diagram should not be the last one. This is the first step to PSRI's evolutionary approach. As a team, each unit operation and the streams to and from that

operation needs to be scrutinized. Are our particle properties optimum, how can we better manage solids losses, is agglomeration an issue, do we need to manage slurries downstream, and how does the chemistry change particle properties? These are just some of the questions that should be asked. Afterwards, the process flow diagram may be revised and how the integration of each operation affects other operations needs to be addressed.

Step 4: Identifying and Addressing the Weak Points in the Process Flow - The next step of PSRI's evolutionary approach is an objective analysis of weak points in the process flow diagram. This is a formal, everybody in the same room, process that requires the whole team and experts in the field. PSRI has these experts, and they have decades of experience in process design, process optimization and troubleshooting particle/powder operations. If a recycle stream has had historical issues with other processes or a particular flow is known for erosion or plugging, they will know it. Once weak points have been identified, solutions to mitigating those weak points become the second exercise of Step 4.

Step 5: Equipment Design and Operations - Once a process flow diagram has been optimized, the design of the equipment, instrumentation, and operational procedures need to be developed. PSRI has a multidimensional approach to equipment specifications. Basically, if we don't know the answers, we have the tools to find the answers. PSRI's $6MM research facility, computational capability, and a pool of experts allow us to explore what has not been done before to develop breakthrough technologies. We do this by a combination of expertise, modeling, and large-scale experiments. At PSRI, the equipment is sized for the experiment, and not the experiment squeezed into the equipment. Even simple cold-flow testing of distinct behaviors can be beneficial with testing constraints and mitigating risk.

Step 6: Identifying and Addressing the Weak Points with Equipment Designs and Operations - As with Step 4, the equipment specifications are reviewed, and weak points are addressed. How are we going to start up the units, will there be solids feeding issues, how does bed behavior change with operational conditions, are there issues with classification, are the transfer lines sized for stated and improved capacities, is aeration sufficient and positioned correctly, are the diplegs sized and positioned correctly even for start up, where are the erosion points, where are the attrition generators and how can we mitigate them? These are just a few questions that needs to be addressed. Once weak points have been identified, solutions to mitigating those weak points become the second exercise of Step 6.

Step 7: Process Risk Assessment - This assessment addresses the reliability of the proposed process. Again, this is a formal, everybody in the

same room, process that requires the whole team and experts in the field. Step by step, each unit is evaluated for reliability and sensitivity to other unit failures. What happens to downstream equipment with high fines/dust generation, how long are the cyclones going to last, where are the erosion points on the sparger, what happens if a coil breaks? These are even more questions that need to be addressed with a process risk assessment for many processes. Basically, the process risk assessment provides detailed knowledge of estimated uptime, frequency, and length of downtimes, and the costs associated with expected failures. PSRI has the experts have at least 25 years of experience in the field and are well suited to provide these estimates.

Step 8: Process Safety Assessment - A significant amount of health and safety issues in the manufacturing and agricultural community is linked to an inadequate assessment of the risks particle have in a production environment. Small particles can oxidize or heat up more readily and trigger autocatalytic reactions resulting in dust explosions. Lost of containment issues are often due to erosion or expansion in processing equipment from particles. Exposure to particles needs to be minimized even for those particles considered innocuous. Static discharges can result in fires despite having explosion-proof equipment and utilities. At PSRI, we are aware of the risk particles can have during synthesis, processing, and post-processing. These issues need to be addressed early on, so hazards are eliminated, passivated, or protected with proper safeguards.

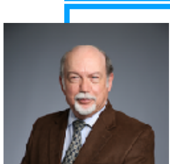
Step 9: Presentation of the Design Package - The design package needs to be more than a set of block flow, process flow, process and instrumentation, and equipment drawings. The evolution of how these drawings were obtained needs to be disclosed. In other words, disclosing the key learnings and why or why not a unit or stream were or were not used is paramount in ensuring less than optimum designs make it back to the design package.

Step 10: Provide Training - Training is how PSRI maintains the gain. Research teams often are not the design team, and design teams are not the operators. This disconnect often results in miss opportunities and rework with the R&D and scale-up process. PSRI provides a wide range of training for the engineer, design team, run plant engineers, and the operators to ensure everyone is on the same page. We have a four-day PSRI Fluidization Seminar and Workshop available all over the world and a three-day PSRI Fluidization Operators Training in Chicago. For members, PSRI provides continuing training with tutorials, research reports, and webinars.

Applying the Fundamentals

Dr. S.B. Reddy Karri, Consulting Director: Reddy has 28 years experience in particle technology and fluidization. He has worked on FCC technology, cokers, polyolefins, methanol to olefins, maleic anhydride, acrylonitrile, TiO_2, polycrystalline silica, gasification, pyrolysis, sulfur capture, CO2 capture, biomass and radioactive

Dr. Ted Knowlton, Fellow: Ted has 46 years experience in particle technology. He has worked on FCC technology, cokers, polyolefin, MTO, maleic anhydride, acrylonitrile, TiO_2, polycrystalline silica, gasification, pyrolysis, sulfur capture, CO2 capture, and mining. He has developed well-known processes such as HYGAS, U-GAS, PEATGAS, RENUGAS, HYTORT, PFH and is the developer of the L-valve.

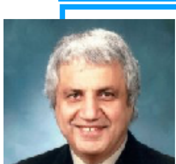


Mr. John Findlay, Technical Consultant: John has 34 years of experience in particle technology and fluidization. He has worked on FCC technology, cokers, polyolefin, TiO2, coal gasification, pyrolysis, sulfur capture, CO_2 capture, and biomass.

Dr. Ray Cocco, President and CEO: Ray has 27 years experience in reactor engineering, modeling, fluidization, and particle technology. He has worked on ceramic processing, oxydehydrogenation, pharmaceutical hydrogenation, catalytic oxidation, hydrogenation, hydrodesulfurization, composite materials, biomass, chemical looping, polyolefin, chlorination and oxychlorination.

Mr. C.J. Farley, Technical Consultant: CJ has 28 years of FCC experience. He has worked for operating companies, FCC design groups, FCC catalyst providers, and has been an independent consultant. He has extensive troubleshooting experience and skill. He has assisted more than 200 FCC units in troubleshooting, optimization, and design issues.

Dr. Ben Freireich, Technical Director: Ben has 8 years of experience in particle technology and has recently been listed as one of AIChE's 35 under 35. He as worked on a wide range of reactor engineering and solids processing problems including catalyst deactivation and attrition, bin design, fluidized beds, pneumatic conveying, mixing and blending, segregating systems, size reduction, etc.



Dr. Manuk Colakyan, Technical Consultant: Manuk has 30 years experience in reactor engineering and solids processing. Notably, he was instrumental in the R&D efforts for the commercialization of the Unipol process. He also has experience with multiphase flow systems, heat and mass transfer and super critical fluids.

Dr. Ulrich Muschelknautz, Technical Consultant: Ulrich has 27 years experience in particle technology with emphasis on cyclone design and optimization as applied to the energy and chemical sectors. Of late, he has been involved in the R&D efforts for the next generation of axial separators.

Dr. Greg Mehos, Technical Consultant: Greg has 20 years of experience in hopper and feeder design, design of gravity reclaim systems, spray dryers, and analysis of purge columns.. He has worked with pharmaceutical formulations, wet granulation, fumed metal oxides, biomass gasification, pigments, and