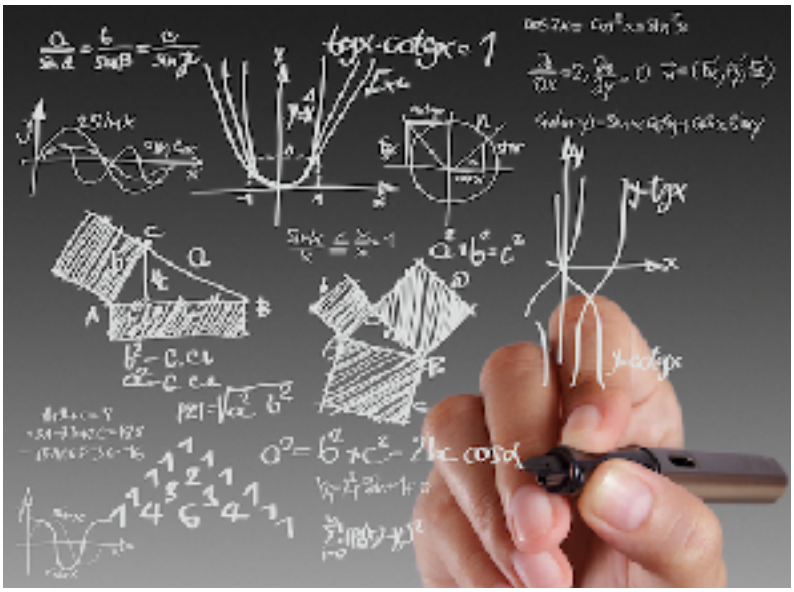
Applying the Fundamentals

PSRI Consulting Services



PSRI has over 200 years of experience in design, development, and troubleshooting with over 250 reviewed publications in granular fluid systems including gas-solid, gas-liquid and gas-liquid-solid fluidized beds and circulating fluidized beds. PSRI has been helping R&D organizations across the globe in a wide and diverse range of technologies. Chances are we have already seen your problem. If we have not, we know how to solve it, and we will provide the training to make sure that solution stays solved.

PSRI Particulate Solid Research, Inc.

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PSRI works with clients from all over the world on a wide range of processes and process. Below are just a few areas where we made a difference.

- **Acrylonitrile**: Troubleshooted the hydrocarbon gas distributors and provided the modified design for acrylonitrile reactor. Conducted cold-flow testing to improve the three-stage cyclone system performances and their reliability. Developed technical specifications for aerating diplegs. Performed cold-flow testing to understand the role of fines content on fluidization characteristics. Developed ultra-sonic probes for determining the loading and particle velocity in internal cyclones. Developed an acrylonitrile reactor CFD model for the optimization of sparger and coil placement.
- **Biomass Catalytic Pyrolysis and Gasification**: Develop feedstock preparation, handling, conveying, feeding, etc. Developed technology specifications to fluidize binary Group A and Group D solids. Conducted cold-flow testing to characterize the biomass feed zone in the fluidized bed, and determined the RTD curves for biochar in the fluidized beds. Performed testing to develop technical specifications of cyclones for capturing binary solids containing biochar. Developed technological specifications for granular bed filter for removing biochar fines. Designed non-mechanical valves for precision feed control.
- **Chemical Looping**: Helped develop moving bed looping technology for coal gasification with emphasis on hydrogen production. Developed technical specifications to fluidize binary Group D solids in mixing pot. Conducted cold-flow testing to demonstrate the continuous operation of counter-current contacting moving packed bed oxidizer, reducer, and stripper. Designed non-mechanical valves for precision solids flow control. Assisted in feeding coal reliably into a moving packed bed of sorbent. Developed a technique to remove attrited fines from a moving packed bed Pilot Scale Testing of Carbon-Negative, Product-Flexible Syngas Chemical Loop[1].
- **Chlorination (TiO_2)**: Developed new reactor designs and new conical reactor distributors for a client. Designed and developed L-valve feeding systems for TiO2 ores and coke for two PSRI member companies. Designed a Restricted Pipe Discharge System (RPDS) to continuously discharge solids from a chlorinator bed to prevent excessive buildup of impurities. Determined minimum gas velocities to limit segregation of ore and char for plant turndowns. Conceived and demonstrated a distributor design that minimized refractory erosion.
- **Fluid Cokers**: Conducted cold-flow testing to improve the hydrodynamics of fluid coker operation. Performed cold-flow modeling of the Cold Coke Transfer Line (CCTL) and Scouring Coke Transfer Line (SCTL) to improve the understanding the operation of the standpipes in these lines. Investigated an improved standpipe inlet configuration (call a sore thumb) for the CCTL. Designed a horizontal cold coke transfer line to eliminate saltation and its associated vibration in the line. Investigated solids maldistribution in parallel cyclones to help understand uneven coking of coker parallel cyclones. Examined the loading and variability of solids loading to the cyclones. Demonstrated the mechanism of cyclone fouling and improved the designs. Demonstrated the mechanics for stripper

[1] https://arpa-e.energy.gov/?q=slick-sheet-project/syngas-fuel

fouling as related to agglomerate formation in fluidized bed due to nozzle hydrodynamics[2].

- **Fluidized Catalytic Cracking (FCC):** Developed an efficient third-stage separator (TSS) for a member company that led to the successful implementation of the TSS into several commercial plants. Conducted extensive testing on gas bypassing to determine why it occurs, what parameters influence it and how it can be mitigated. Demonstrated how gas bypassing in a fluidized bed could result in the reduced performance of the primary cyclone dipleg leading to flooding. PSRI has been a leader in studying and optimizing standpipe operation/standpipe entrance configurations and aeration amount and location. PSRI has developed correlations to determine the optimum amount of aeration to add to a standpipe. Developed a bypass line (called a burp tube) for hybrid-angled standpipes to allow gas collecting at an elbow to be bypassed from the elbow into the freeboard of the fluidized bed above it. Studied different riser exit configurations with respect to erosion, pressure drop, and particle attrition. Developed design procedures for gas distributors. Analyzed and evaluated several close-coupled cyclone designs
- **Maleic Anhydride**: Assisted in producing a more attrition resistant catalyst for the production of maleic anhydride in a looping CFB units to minimize catalyst attrition. Assisted in the further development of looping technology for oxydehydrogenation.
- **Oxychlorination (EDC & RCIs):** Designed spargers, grid plates, and heat transfer tubes for ethylene chlorination. Minimized catalyst attrition with a redesign of nozzles, spargers, and cyclones. Reduced cyclone and dipleg erosion with a new cyclone design. Assisted in the design of a novel, direct ethane chlorination process. Developed an in-situ probe for quantification of bed hydrodynamics in chlorination units. Troubleshooted refractory issues in oxychlorination units.
- **Coal Combustion and Gasification:** Pioneered the development of non-mechanical devices for solids flow (L-valves and loop seals). Investigated the effects of high pressure and high temperature on bed hydrodynamics for these processes. Developed a novel dipleg configuration to prevent blockage of secondary cyclone diplegs by discharging the second stage cyclone dipleg into the first stage cyclone dipleg. Demonstrated the world's tallest fluidized bed operation for catalytic coal gasification at high pressures. Helped develop moving bed looping technology for coal gasification with emphasis on hydrogen production.
- **Methanol to Olefins (MTO):** Optimized catalyst hydrodynamics for the MTO process. Conducted cold-flow testing to develop technology specifications to design both dense fluidized bed and riser reactors. Developed technology to minimize gas bypassing in dense fluidized bed reactors. Performed testing to develop an attrition resistant catalyst. Assisted

[2] J. McMillan, F. Shaffer, B. Gopalan, J.W. Chew, C. Hrenya, R. Hays, et al., Particle Cluster Dynamics During Fluidization, Chemical Engineering Science. 100 (2013) 39–51. C.B. Solnordal, K.J. Reid, L.P. Hackman, R. Cocco, J. Findlay, Modeling Coke Distribution above the Freeboard of a FLUID COKING Reactor, Ind. Eng. Chem. Res. 51 (2012) 15337–15350.

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in operating both pilot and commercial reactors in a reliable fashion.

- **Polycrystalline Silicon**: Developed technology specifications to design gas distributors, expanded bulb, etc. for the reactor. Conducted cold-flow testing at high pressures to identify the parameters that affect the fluidization characteristics and entrainment issues. Determined optimum particle size distribution for the FBR designed cyclone-dipleg system for this application. Demonstrated a technology to continuously purge out solids from the dipleg to prevent build up of impurities in the reactor. Assisted in developing a reliable angled eductor to feed the collected fines back to the reactor. Selected the particle feed size distribution to achieve optimal reactant conversion, particle gas contacting, stable hydrodynamics, limited unreacted solids losses. Managed of solids entrainment in high pressure, high temperature, corrosive environments with a dynamically evolving particle size distribution. Provided a conceptual understanding of the link between feed impurities, particle cohesion, and the resulting reactor hydrodynamics and operability. Assisted in operating both pilot and commercial reactors in a reliable fashion
- **Polyolefins**: Developed technology specifications to design gas distributors, catalyst injection system, expanded bulb, etc. Conducted cold-flow testing at high pressures to identify the parameters that affect the electrostatics in the fluidized bed reactor leading to sheeting. Developed instrumentation to measure the levels of static electricity. Designed a cyclone system for gas-phase and condensed-phase polyolefin reactors. Assisted in developing a reliable angled eductor to feed the collected fines back to the reactor. Designed a dense-phase conveying system for product transfer, and at the same time depressurize the polyethylene. Designed and assessed in the proper designed of polymer purge bins to ensure limited volatile organic compound content and target polymer residence time distribution during various modes of operation. Identified the source for producing angel hair during the conveying of resin. Developed catalyst process that provides optimum particle size distribution. Developed a catalyst injection system that minimizes catalyst attrition
- **Sulfur Capture**: Assisted with the development of a circulating fluidized absorber to capture sulfur from syngas or other sulfur-containing gases. Assisted with the design of cold models as well as pilot, demonstration, and commercial desulfurization plants. Improved the capability to circulate absorber catalyst around the desulfurization units.

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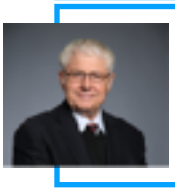
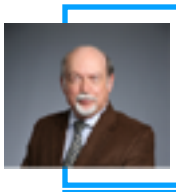
Dr. S.B. Reddy Karri, Consulting Director: Reddy has 28 years experience in particle technology and fluidization. He has worked on FCC technology, cokers, polyolefins, methanol to olefins, maleic anhydride, acrylonitrile, TiO_2, polycrystalline silica, gasification, pyrolysis, sulfur capture, CO2 capture,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



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, catalytic oxidation, hydrogenation, hydrodesulfurization, composite materials, biomass, chemical looping, polyolefin, chlorination and oxychlorination.

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 emulsification.

Dr. Ben Freireich, Technical Director: Ben has 8 years of experience in particle technology and has recently been listed as the 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.

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.

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Dr. Stephen Sutcliffe: Steve has 31 years of experience in the TiO2 pigment and additives business with Huntsman, now Venator, where lead and developed global technology development programs and strategies. He is an expert with all the key unit operations associated with TiO2 manufacture, feedstock preparations and waste handling technologies via the Chloride Process.


PSRI