

REINHOLD ENVIRONMENTAL Ltd.



**2018 NO_x-Combustion Round Table
& Expo Presentation**

February 19-20, 2018, in St. Louis, MO / Hosted by Dynegy

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TRAINING CLASS 8

DSI 101

A SYSTEM PERSPECTIVE

2018 NOX-COMBUSTION-CCR
ROUND TABLE

FEBRUARY 20, 2018

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Lhoist North America

DSI 101

- › Part 1. Overview
 - › What is DSI – it's a system and a process
 - › How does DSI work
 - › Design considerations and challenges
- › Part 2. Implementation
 - › System design and configuration
 - › Operating Issues & best practices
 - › System Performance & Assessment
 - › Mixing/Contact
 - › Enhanced Sorbents & Improved Utilization
- › Questions



PART 1. OVERVIEW



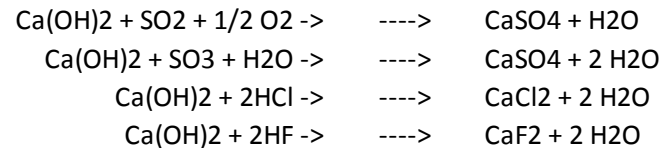
What is DSI

- › Injection of dry alkaline mineral into a flue/exhaust gas to reduce acid gas emissions
- › Control of multiple pollutants
 - › Acidic components - $\text{SO}_3/\text{H}_2\text{SO}_4$, HCl, SO_2 , HF
 - › Micro pollutants – Hg, dioxins
- › Low CapEx air pollution control solution
 - › Non-complex systems engineering
 - › Short construction timeline
 - › Small footprint
 - › Minor duct modifications
- › Flexible operation
 - › Well suited for load following
 - › Quickly reacts to changes in emissions profile (feedback control)
 - › Intermittent use and dispatch
- › Unit customizable
 - › Supports multiple injection points
 - › Supports various balance of plant configurations (BHF, ESP, SDA, WFGD)

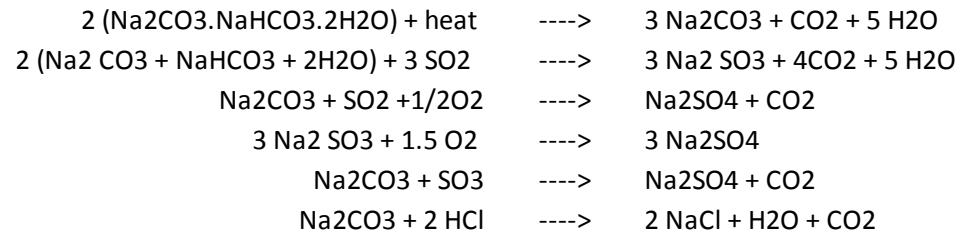
An inexpensive and easy to implement emissions control approach

How does it work

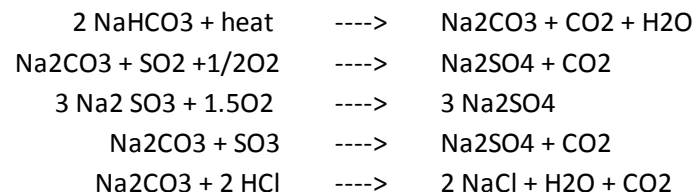
- › Relative simple and straight-forward acid-base reaction chemistry
 - › Calcium-based approach
 - › Hydrated Lime



- › Sodium-based approach
 - › Trona (sodium sesquicarbonate)

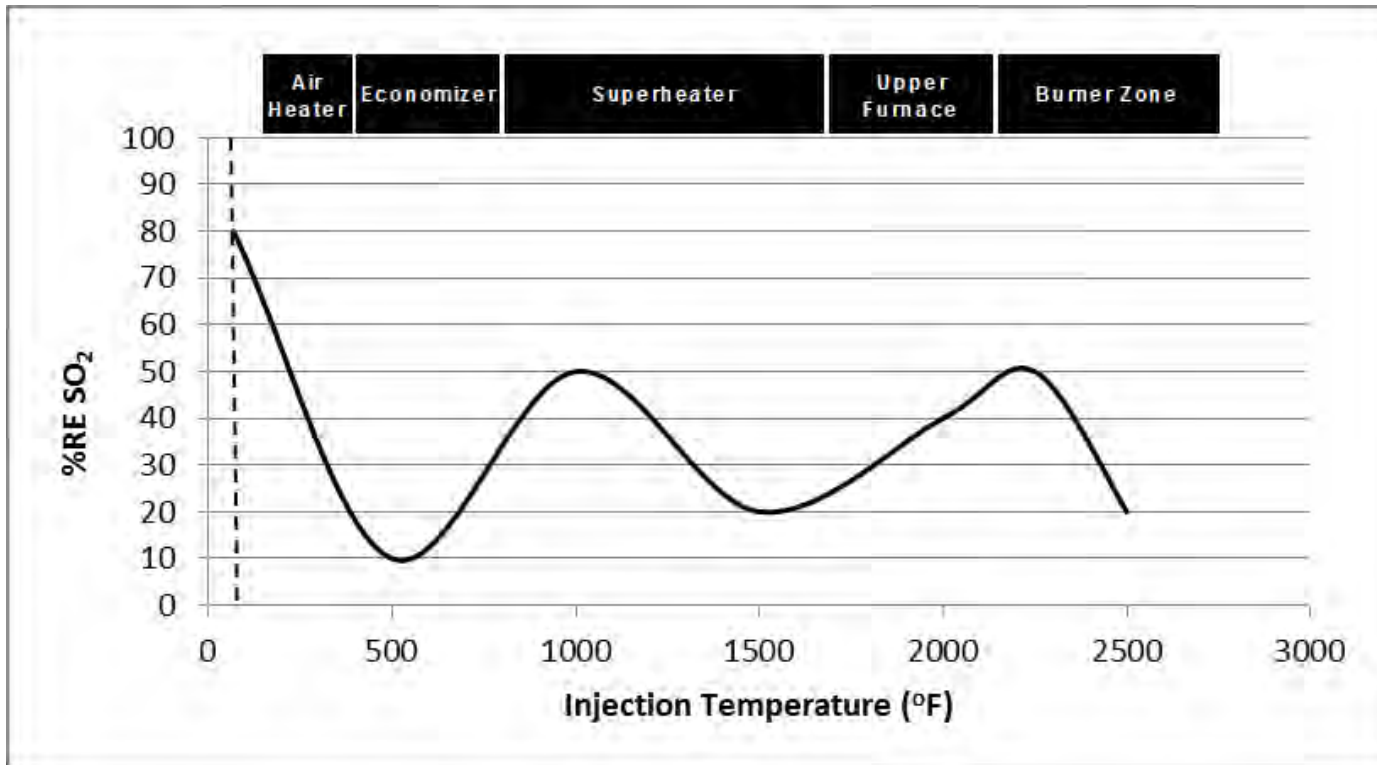


- › Sodium bicarbonate



How does it work

- › Impact of flue gas properties
 - › Temperature
 - › Significant impact on alkaline sorbent performance
 - › Injection location targeted to capture goals

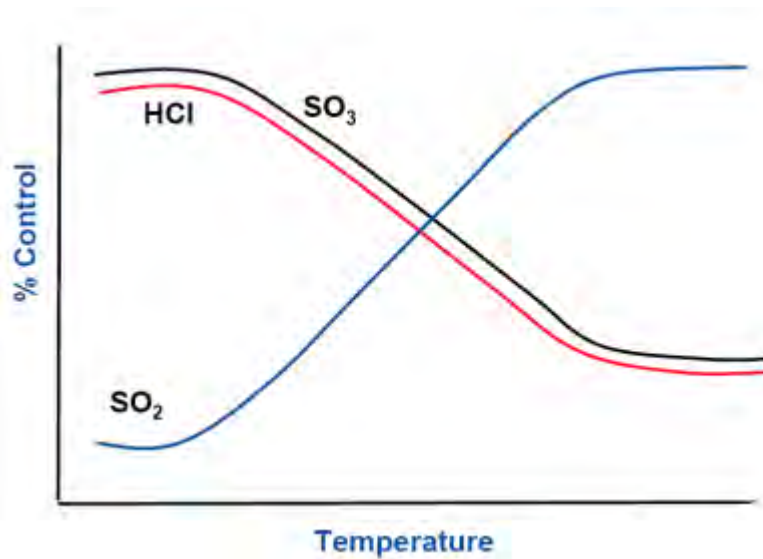
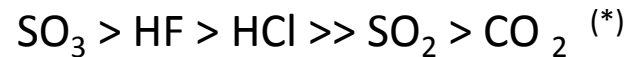


Adapted from: Helfritch, D.; Bortz, S.; Beittel, R.; Bergman, P.; Neil, B. T. Combined SO₂ and NO_x Removal by Means of Dry Sorbent Injection. *Environ. Prog.* **1992**, *11* (1), 7–10.

How does it work

Hydrate DSI can be applied across a full range of operating temperatures

The reactivity sequence between hydrated lime and select pollutants:

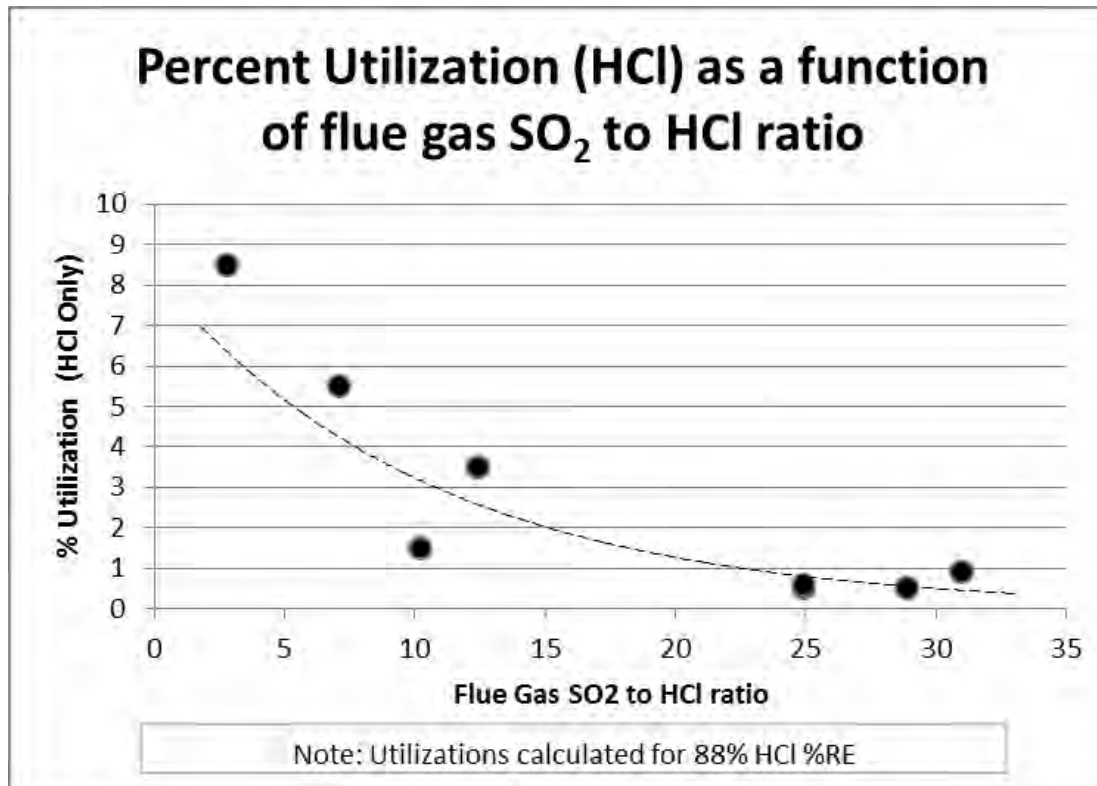


The impact of temperature on the relative control efficiency of hydrate for specific pollutants

(*) Source: Karpf, Rudi H., Basic Features of the Dry Absorption Process, Paper, Germany, 2015

How does it work

- › Impact of flue gas properties
 - › Acid Gas Concentrations



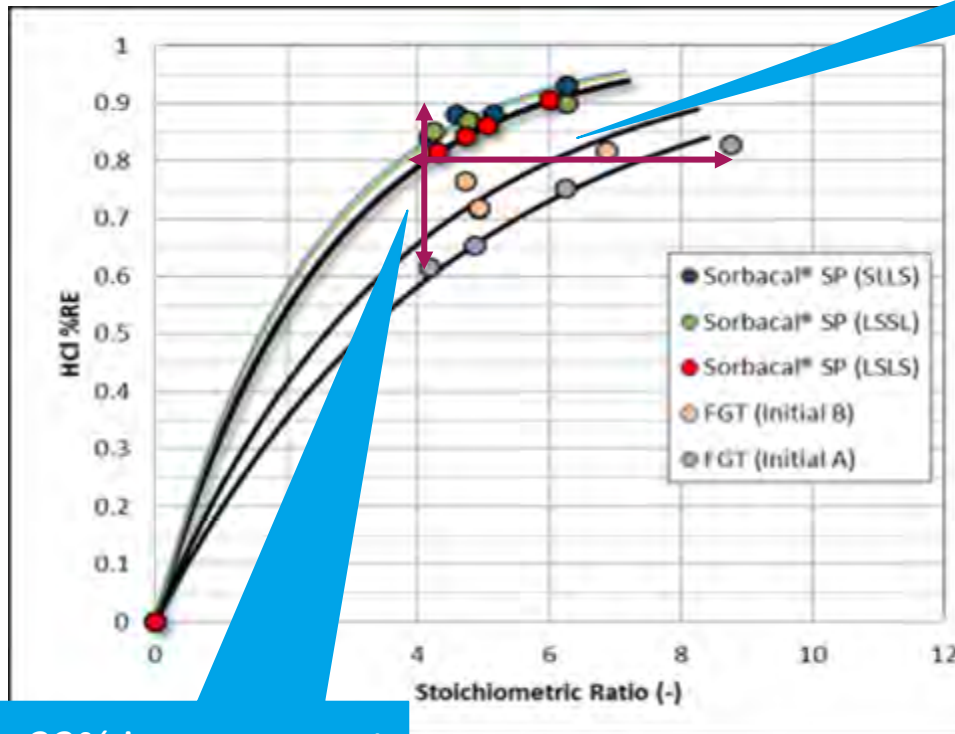
Percent Utilization is calculated as the percent HCl removal divided by the quantity, molar quantity of sorbent injected divided by molar quantity of HCl in the flue gas.

$$\%Utl (HCl\ Only) = \frac{\% RE\ HCl}{(mol\ of\ sorbent\ injected)/(mol\ of\ HCl\ in\ the\ flue\ gas)}$$

How does it work

- › Impact of flue gas properties
 - › Impact of sorbent distribution
 - › Good mixing makes good chemistry
 - › Small improvements in sorbent distribution significantly impacts relative performance

Nearly 50% reduction in required sorbent to achieve 80% RE HCl



Over 33% improvement in HCl %RE (@ SR of 4)

How does it work

› First Generation Systems

- › North American consideration in the late 1980's and early 1990s
- › DOE National Energy Technology Laboratory (NETL) began studying "DSI with calcium sorbents"
- › Response to the compliance challenge from CAAA of 1990
- › Duct injection of hydrated lime for SO₂ control
- › First systems were unsophisticated, material-handling approaches to a chemical application problem

› Second-Gen Systems

- › Early 2000's – Hydrated lime for SO₃ control
 - › e.g., TVA Widows Creek
 - › Corrosion control, plume mitigation, acid deposition, enhanced PM control Dilute-phase conveyance with a more sophisticated destitution

› Current State of the Art

Air Island

Optimized dilute-phase conveyance
Inlet Chiller- Dehumidifiers - Aftercoolers

Material Storage Island

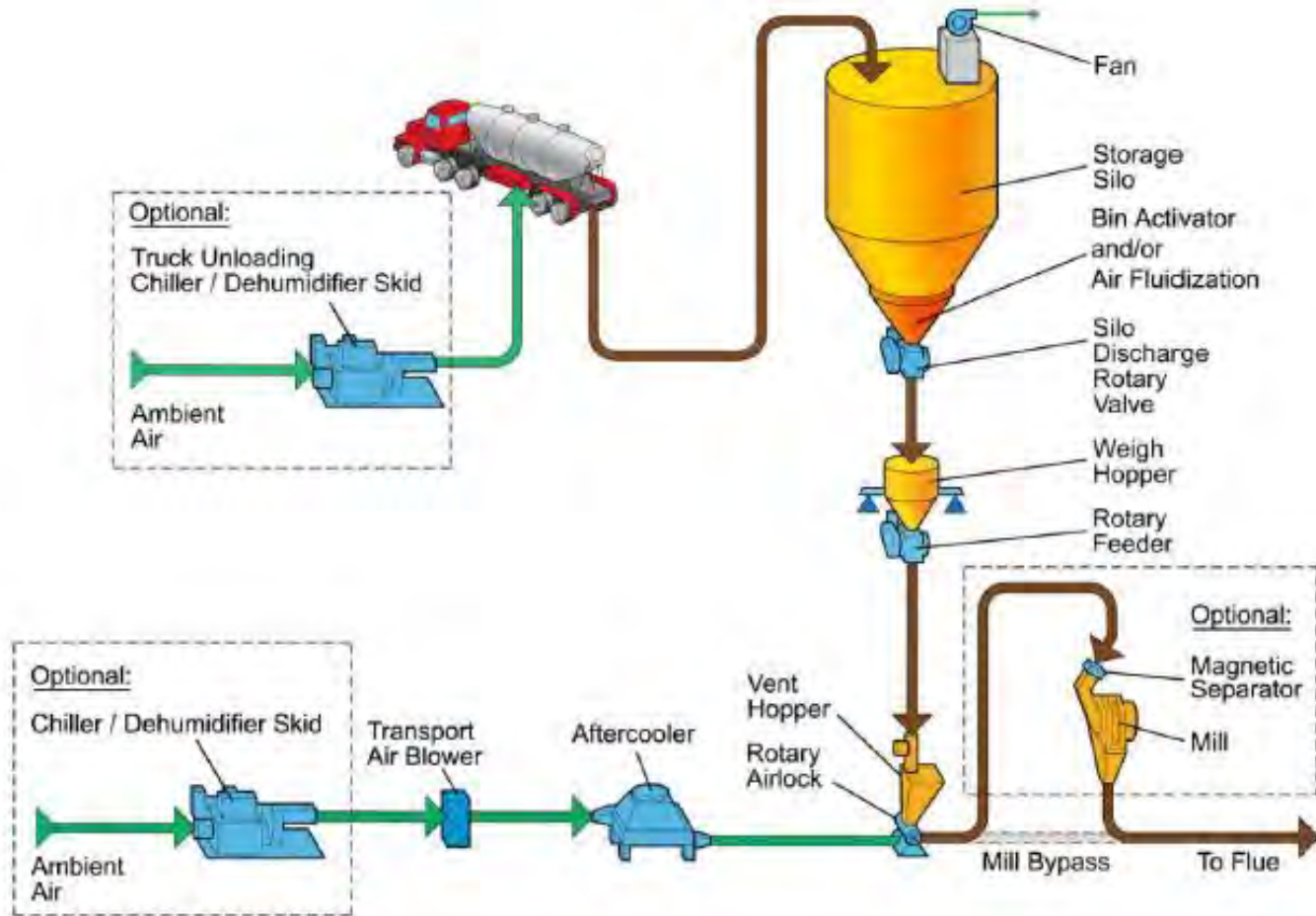
Advanced multi-stage LIW
Precise feeds
Feed forward-feed back logic
Flow enhancing technologies

Delivery and Distribution

Engineered distribution manifolds
Modelled lance placement
Installed diagnostics
Advanced terminal injection

How does it work

Dry sorbent Injection System – typical configuration



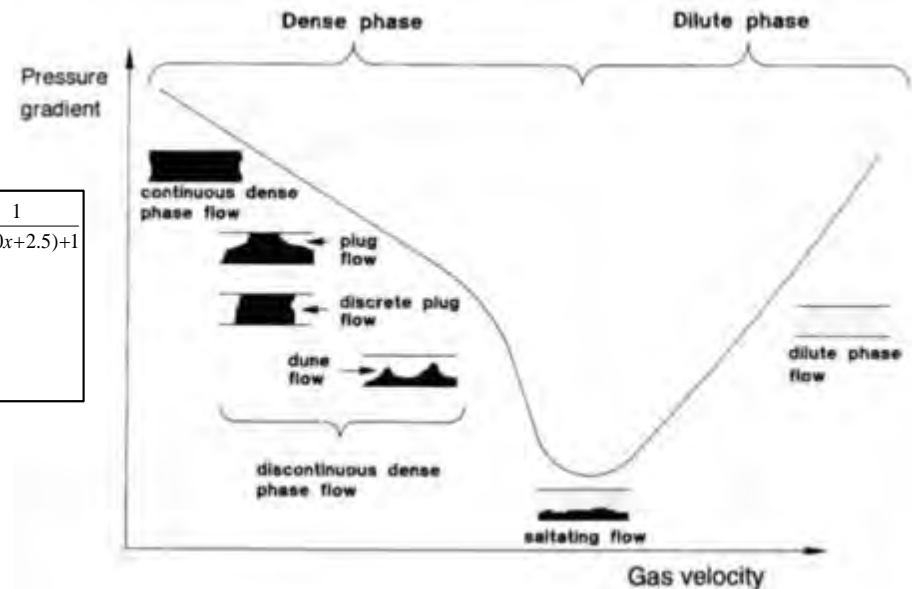
Source: Institute of Clean Air Companies, July 2016

Design considerations and challenges

- › Pneumatic design – mechanical
 - › Basic design parameters
 - › Mass rate – maximum solids transfer rate using existing gas supply and conveying line.
 - › Gas flow rate - volumetric flow needed for a specific solids transfer rate.
 - › System capacity – sizing of the conveying line for a specific solids transfer rate using existing gas supply.
 - › Saltation Velocity
 - › The solids conveying velocity where the moving fluid cannot continue to suspend and convey the solids (*)

$$U_{Salt} = \left[\frac{4 \times M_p \times 10^{(1440x+1.96)} \times g^{(1100x+2.5)/2} \times D^{\left(\frac{1100x+2.5}{2}-2\right)}}{\pi \times \rho_f} \right]^{\frac{1}{(1100x+2.5)+1}}$$

› X



(*) Source: Rizk, F., Pneumatic conveying at optimal operation conditions and a solution of Bath's equation. Proc Pneumotransport, 3, Bath, England, pp. 443-58 (1976).

Design considerations and challenges

› Solids conveying velocity

- › Superficial gas velocity is the velocity of the conveying air disregarding the presence of the solid particles
- › Solids velocity is always less than the superficial gas (*)
 - › The difference is called “slip”.
 - › Lighter/smaller materials have less slip than those of larger/heavier particles.
 - › For fine powders, solids velocity is about 90% of the superficial gas velocity

$$V_{particle} = 0.9 \times V_{gas}$$

› Solids Velocity entering/exiting Long Radius Bends (*)

- › For a 90 degree radius bend
 - › solids velocity of fine powders at the exit of the bend will be 0.9 to 0.8 times the solids velocity at the inlet of the bend .
- › After leaving a 90 degree bend
 - › 20 pipe diameters approximate the the length of the straight pipe for the solids to re-accelerate to the particle entry velocity

› Solids to Air Ratio (SAR)

- › The ratio of the mass flow rate of the material conveyed to the mass flow rate of the air used for conveying
- › Describes the nature of the gas–solid flow in a pipeline.
- › Generally low values for SAR are successful in alkaline sorbent DSI

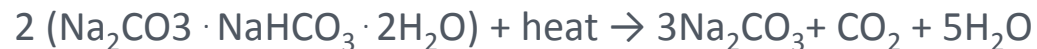
(*) Source: Agarwal, A.T., Theory and Design of Dilute Phase Pneumatic Conveying Systems. *Powder Handling and Processing*, February 2005

Design considerations and challenges

- › Pneumatic conveying in alkaline sorbent DSI a chemical process
 - › Conveying air quality impacts the system

- › Alkaline sorbent DSI is a reactive chemical process
 - › Decomposition of sodium sorbents initiate at relatively low temperatures
 - › Hygroscopic - agglomeration and caking are common
 - › Dehydrate in the conveying system making water available for agglomeration and caking
 - › The feasible temperature for converting Trona to sodium bicarbonate is in the range of 135°F to 212°F.(*)
 - › At temperatures above 135°F, Trona begins to decompose and dehydrate
 - › At a temperatures above 122°F, sodium bicarbonate is believed to begin to decompose and dehydrate

Trona Decomposition



Sodium Bicarbonate Decomposition



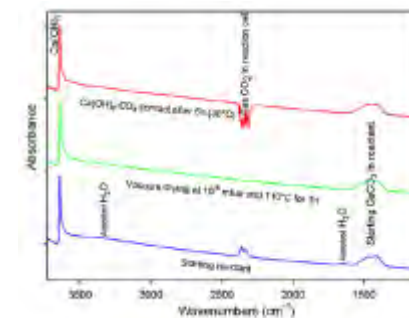
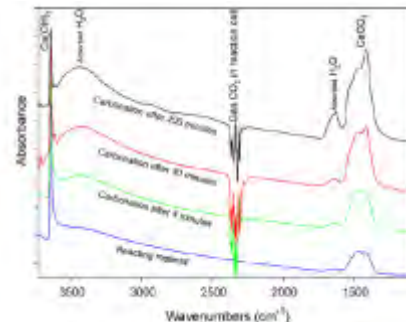
(*) Source: Kyungmin Jacob Cho, A Modeling and Experimental Study of the Conversion of Trona to Increase Its Reactivity with SO₂ in Dry Injection System, Division of Research and Advanced Studies of the University of Cincinnati, 2007

Design considerations and challenges

- › Pneumatic conveying in alkaline sorbent DSI a chemical process
 - › Conveying air quality impacts the system
 - › Alkaline sorbent DSI is a reactive chemical process
 - › Hydrated lime reacts with carbon dioxide (CO₂) to form calcium carbonate and water



- › At low temperature (below 85°F) adsorbed water is mandatory for carbonation of hydrated lime (*)
- › The formation of CaCO₃ is inevitable at temperatures above 158°F (**)
- › Water plays a catalytic role in carbonation at low Temperature(*)
- › Given a slight amount of absorbed water present on surface - both CaCO₃ and reaction water are shown to increase
- › No water on the surface of the hydrate - no evidence carbonation even after 5 hours

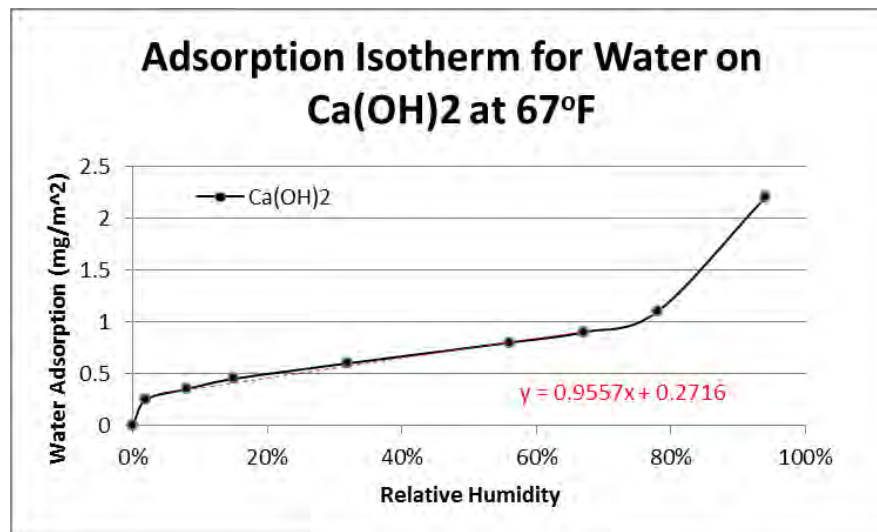


(*) Source: Montes-Hernandez, G.; Pommerol, A.; Renard, F.; Beck, P.; Quirico, E.; Brissaud, O. In Situ Kinetic Measurements of Gas–solid Carbonation of Ca(OH)₂ by Using an Infrared Microscope Coupled to a Reaction Cell. *Chem. Eng. J.* 2010, 161 (1-2), 250–256

(**) Source: Wenlong Wang,* Mingqiang Hu, Yong Dong, and Chunyuan Ma, Study on the Effect of CO₂ on the Consumption of Desulfurizing Agent Ca(OH)₂ in Flue Gas Desulfurization, *Ind. Eng. Chem. Res.* 2010, 49, 1444–1449

Design considerations and challenges

- › Carbonation of hydrated lime (i.e., scale) at low temperatures is dependent on the relative humidity of the conveying air (*)
 - › The effect of gas phase CO₂ concentration on the carbonation of Ca(OH)₂ is negligible when excess CO₂ is present for the reaction, as when using ambient air as the motive source.
 - › Critical relative humidity at about 8%,
 - › below 8% RH carbonation of Ca(OH)₂ does not proceed
 - › above 8% the final conversion of Ca(OH)₂ increases with relative humidity and temperature
- › A water monolayer layer is necessary for the reaction with CO₂(**)
 - › Water adsorption for %RH between 2% and 70% is approximately linear
 - › Increase of relative humidity catalyzes the gas–solid carbonation



(*) Source: Shin-Min Shih, Ch'un-Sung Ho, Yuen-Sheng Song, and Jyh-Ping Lin, Kinetics of the Reaction of Ca(OH)₂ with CO₂ at Low Temperature, *Ind. Eng. Chem. Res.* 1999, 38, 1316-1322

(**) Source: Dario T. Beruto*, Rodolfo Botter, Liquid-like H₂O adsorption layers to catalyze the Ca(OH)₂/CO₂ solid-gas reaction and to form a non-protective solid product layer at 20C, *J. of the European Ceramic Society* 20 (2000) 497±503

Design considerations and challenges

- › Avoiding the formation of calcium carbonate scale in the hydrate DSI system
 - › At %RH above 8% carbonate scale will form
 - › At %RH below 0.5%, triboelectric effects play apart in material “clinging” to the conveying system

Values are calculated using the August-Roche-Magnus approximation

		Conveying Air Temperature ("T")												
		(°F)	50	60	70	80	90	100	110	120	130	140	150	160
Conveying Air Dew Point ("TD")	-70	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	-60	0.5%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	-50	0.9%	0.6%	0.4%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
	-40	1.5%	1.1%	0.8%	0.5%	0.4%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%
	-30	2.7%	1.9%	1.3%	1.0%	0.7%	0.5%	0.4%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%
	-20	4.6%	3.2%	2.3%	1.6%	1.2%	0.9%	0.6%	0.5%	0.4%	0.3%	0.2%	0.2%	0.2%
	-10	7.7%	5.3%	3.8%	2.7%	2.0%	1.4%	1.1%	0.8%	0.6%	0.5%	0.4%	0.3%	0.3%
	0	12.4%	8.6%	6.1%	4.4%	3.2%	2.3%	1.7%	1.3%	1.0%	0.8%	0.6%	0.5%	0.5%
	10	19.6%	13.6%	9.6%	6.9%	5.0%	3.7%	2.7%	2.1%	1.6%	1.2%	0.9%	0.7%	0.7%
	20	30.3%	21.1%	14.9%	10.6%	7.7%	5.7%	4.2%	3.2%	2.4%	1.9%	1.4%	1.1%	1.1%
	30	46.0%	31.9%	22.5%	16.1%	11.7%	8.6%	6.4%	4.8%	3.7%	2.8%	2.2%	1.7%	1.7%
	40	68.4%	47.5%	33.6%	24.0%	17.4%	12.8%	9.5%	7.2%	5.5%	4.2%	3.2%	2.5%	2.5%
	50	100.0%	69.5%	49.1%	35.1%	25.5%	18.7%	13.9%	10.5%	8.0%	6.1%	4.7%	3.7%	3.7%
60		100.0%	70.6%	50.5%	36.7%	27.0%	20.1%	15.1%	11.5%	8.8%	6.8%	5.3%	5.3%	

$$RH = 100 * (\text{EXP}((17.625 * TD) / (243.04 + TD)) / \text{EXP}((17.625 * T) / (243.04 + T)))$$

$$TD = 243.04 * (\text{LN}(RH/100) + ((17.625 * T) / (243.04 + T))) / (17.625 - \text{LN}(RH/100) - ((17.625 * T) / (243.04 + T)))$$

$$T = 243.04 * (((17.625 * TD) / (243.04 + TD)) - \text{LN}(RH/100)) / (17.625 + \text{LN}(RH/100) - ((17.625 * TD) / (243.04 + TD)))$$

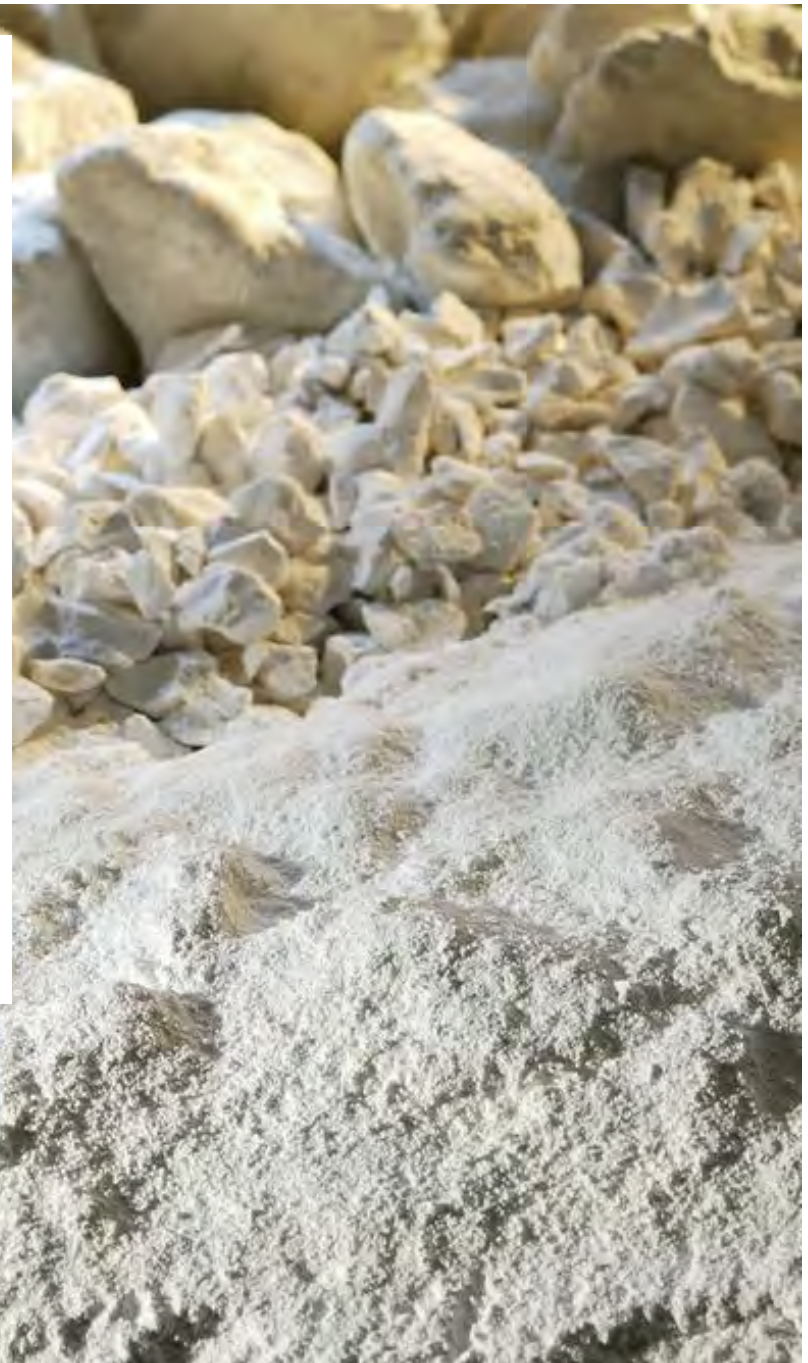
"--> T and TD inputs/outputs to the equations are in Celsius"

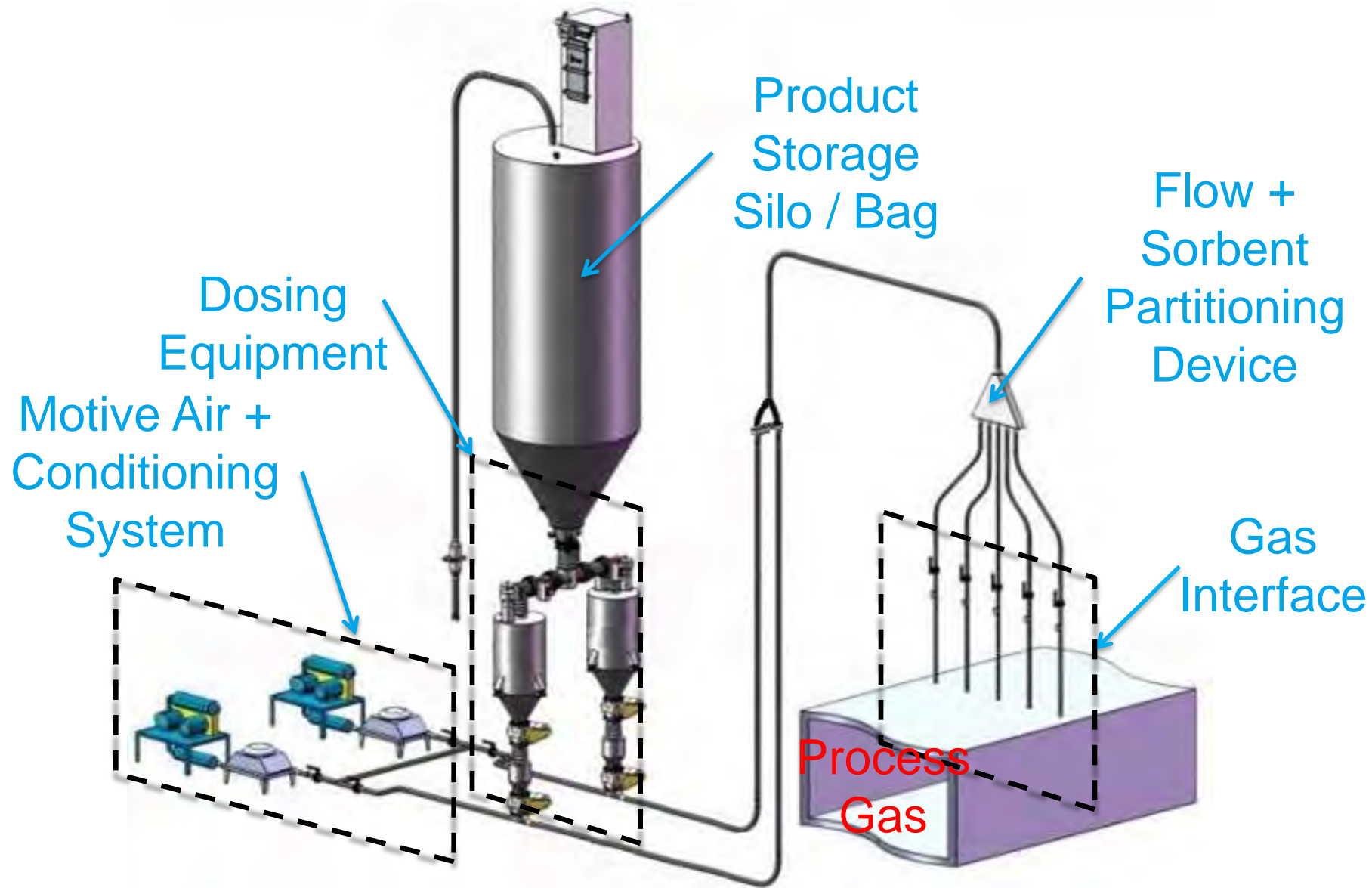
References:

- [Alduchov, O. A., and R. E. Eskridge, 1996: Improved Magnus' form approximation of saturation vapor pressure. J. Appl. Meteor., 35, 601–609.](#)
- [August, E. F., 1828: Ueber die Berechnung der Expansivkraft des Wasserdunstes. Ann. Phys. Chem., 13, 122–137.](#)
- [Magnus, G., 1844: Versuche über die Spannkkräfte des Wasserdampfs. Ann. Phys. Chem., 61, 225–247.](#)



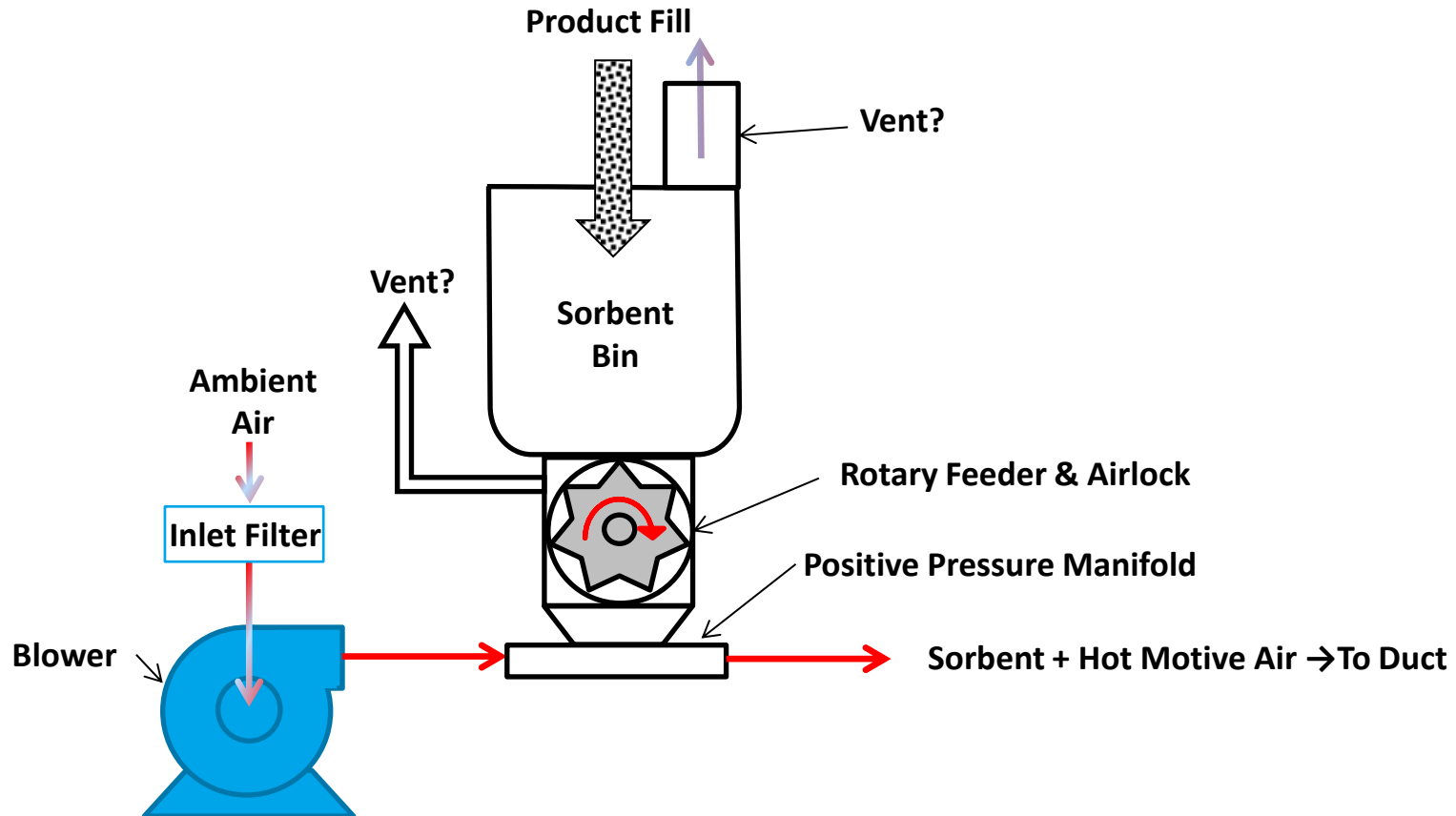
PART 2. IMPLEMENTATION





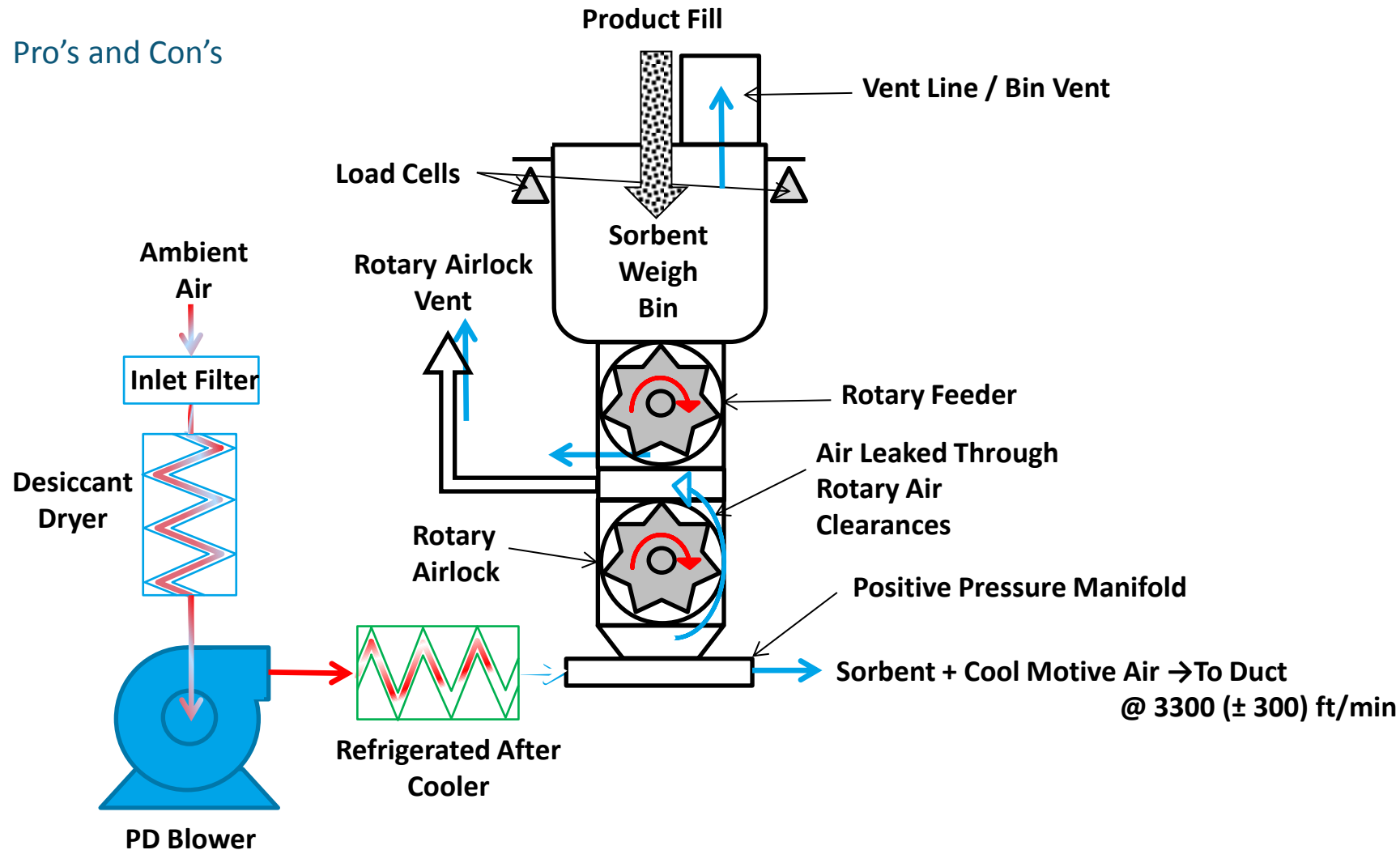
System Design and Configuration – ‘Base Model’

› Pro’s and Con’s



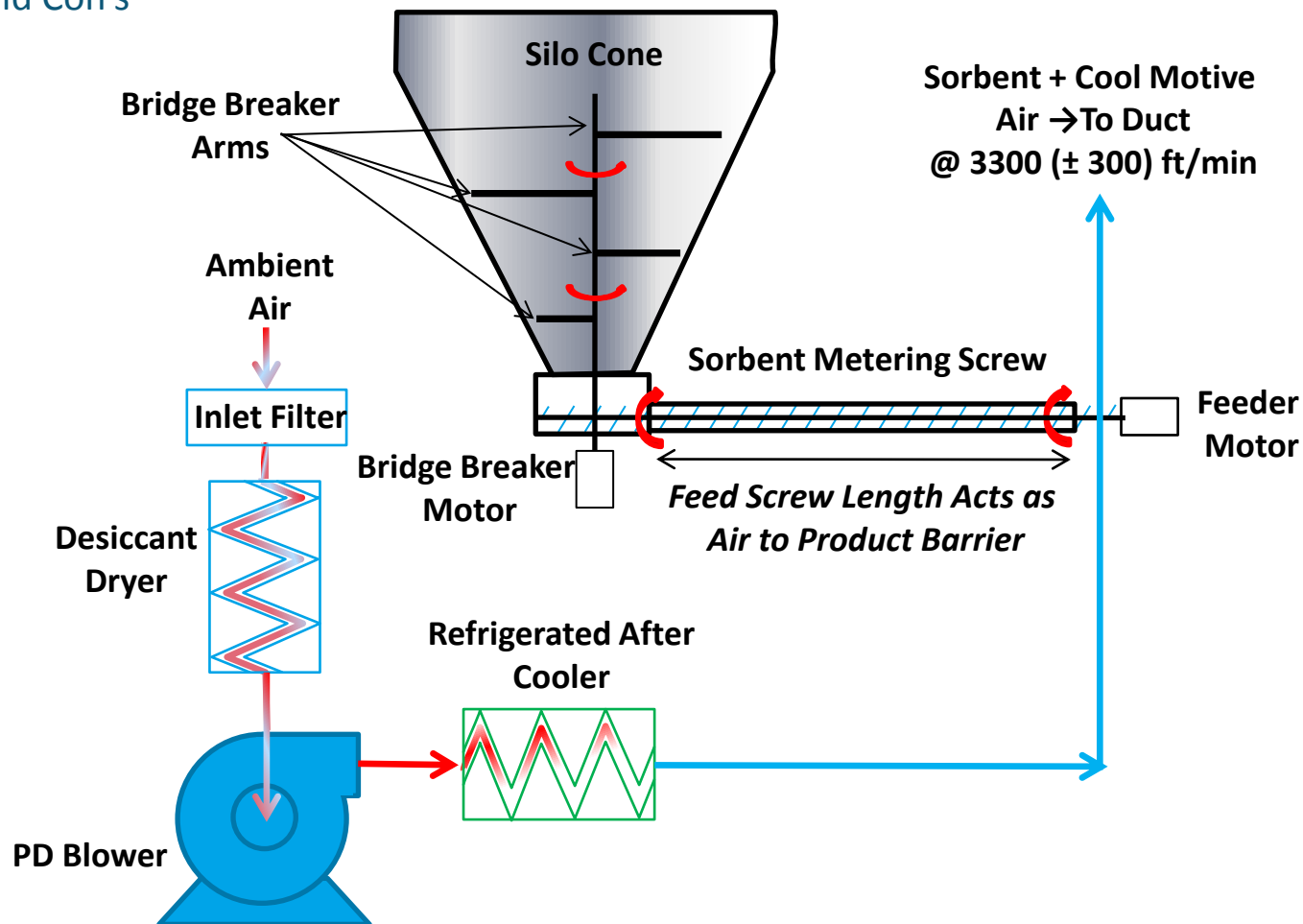
System Design and Configuration – ‘Typical’

› Pro’s and Con’s



System Design and Configuration – ‘Alternate’

› Pro’s and Con’s



Common Issues

- › Conveying Air:
 - › Temperatures
 - › *After cooler maintenance?*
 - › Relative Humidity
 - › *Desiccant dryer settings & maintenance?*
 - › Velocity (too slow/ fast)
 - › *Hard vs. Soft Plugs*
- › Rotary Air Lock
 - › Wear
 - › Loss of tolerances
 - › Carbonate accelerated wear
- › Hopper Venting
 - › Rotary Air Lock Wear
 - › Commodity grade valves
 - › Inadequate...
 - › Air to Cloth for range of permissible range of RAL wear
 - › Vent line size
 - › Feed rate Control / Load cell noise

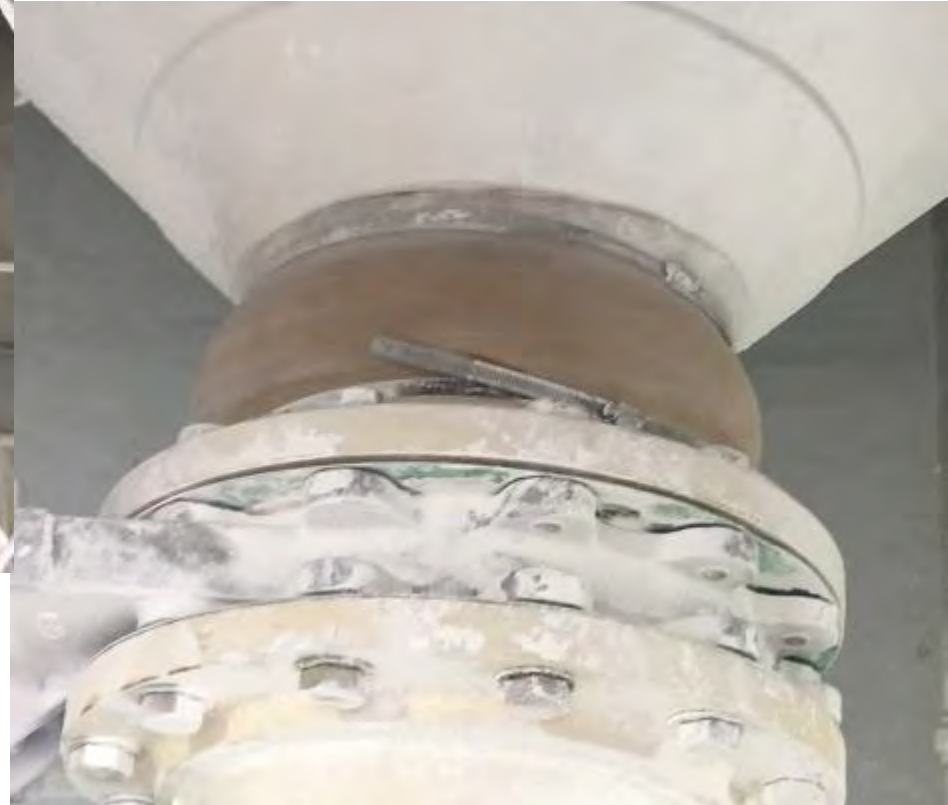


Operating Issues & Best Practices

› System Design / Best Practices



Courtesy of Dixon © 2018 Dixon Valve & Coupling



Operating Issues & Best Practices

› System Design / Best Practices



Courtesy of Lance © 2018 Lance Valves

Operating Issues & Best Practices

- › System Design / Best Practices
 - › Silo Skirt / Unloading Station & Duct



System Performance & Assessment

Mixing / Contact



System Performance & Assessment

Mixing / Contact

- › Advanced lance/lances-less Technologies
 - › Relatively easy retrofit
 - › Enhanced mixing and distribution
 - › Use of distribution plates produce low-pressure zones to increase particle dispersion
 - › Boosted-air injectors mated to lance-less penetrations enhance mixing and dispersion within the duct
 - › Broad particle dispersion optimizes sorbent contact with acid gases with the duct and leads to increased pollutant removal
- › Static Mixing Technologies
 - › Installed inside the duct work
 - › Provides aggressive gas-solid mixing zone / increase particle mean path
 - › Widely disperses sorbent particles throughout the flue gas
 - › Provides greater uniformity in flue gas temperature
 - › Provide uniform flue gas velocity in the sorbent-acid gas reaction zone

System Performance & Assessment

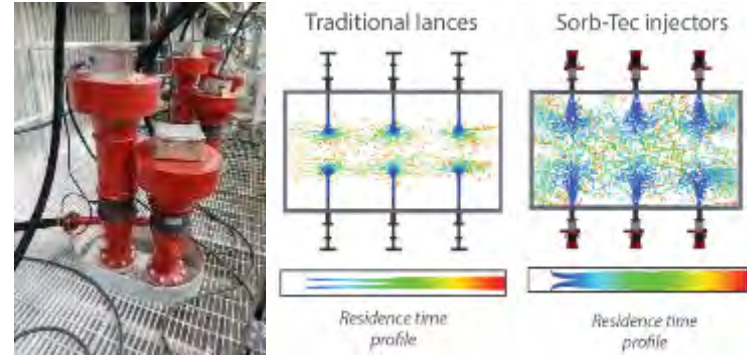
Mixing / Contact

Distribution Plate Technology



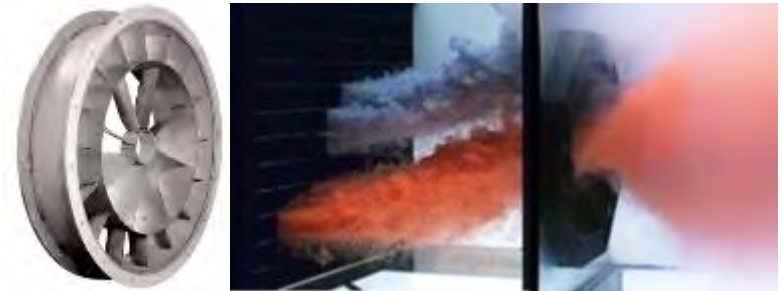
Courtesy of UCC © 2017 United Conveyor Corporation - UCC

Boosted Air, Lance-less Injector



Courtesy of Nol-Tec Systems ©2017 Nol-Tec

In-Duct Static Mixer Technology



Courtesy of BPI © 2017 Blender Products, Inc.

QUESTIONS?



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