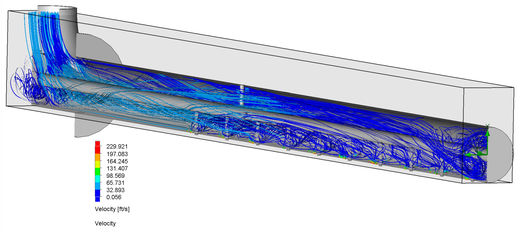

Importance of Gassing Slot Sizing on Carbonation Gas Absorption: A Computational Approach

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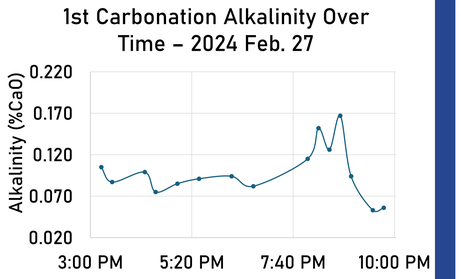
Introduction

- During Campaign 2023-24, significant swings in 1st carb. alkalinity were noticed in Bay City Factory. Alkalinity swings led to seemingly "random" instances of poor filtration.
- Gassing tubes were replaced in ~2020, but drawings could not be located when the changes were made. Could the slot sizes be inappropriate? Modelling was needed to determine.



Calculation Methods

- Carbonation gas properties were calculated using NIST's REFPROP software. Carbonation gas was assumed to have the following composition:
  - CO_2: 28.5% v/v
  - O_2: 14% v/v
  - N_2: 52.5% v/v
  - H_2O: 5% v/v

Washed Kiln Gas - 5% H_2O							
Pressure (psia)	Density (lb/ft^3)	Cp (BTU/lb-F)	Cp/ Cv	Phase	Molar Mass (g/mol)	Viscosity (mPa-s)	Adiabatic Bulk Modulus (psia)
15	0.078	0.42	1.35	Gas	32.6	0.0184	20.3
20	0.105	0.42	1.35	Gas	32.6	0.0184	27.0
25	0.131	0.42	1.36	Gas	32.6	0.0184	33.8
30	0.157	0.43	1.36	Gas	32.6	0.0185	40.6

- Distribution calculations were performed using three methods:
  - Hand calculations using equation 14-206 from Perry's Chemical Engineers' Handbook 9th edition

$$\frac{V_h}{V_0} = \sqrt{\frac{C_o V_h}{\frac{\Delta V_h}{V_h}}}$$

    - Where V_h is hole velocity; V_0 is pipe velocity; ΔV_h is difference between maximum and minimum hole velocity; and C_0 is the orifice coefficient
  - PIPE-FLO software model
  - Computational Fluid Dynamics (CFD) software
- Percent absorption was calculated by measuring CO_2 with a handheld analyzer and calculated using the following equation:

$$\%Abs = 1 - \left[\frac{1 - \%CO_{2,Header}}{1 - \%CO_{2,Stack}} \frac{\%CO_{2,Stack}}{\%CO_{2,Header}}\right]$$

Analysis Results

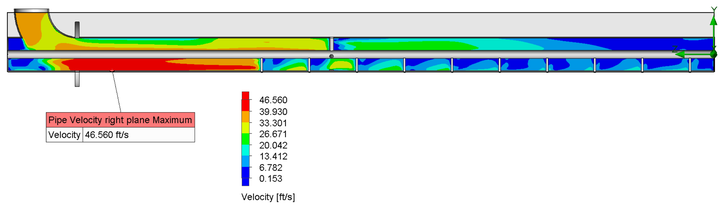
- Calculations were performed on Bay City's 1st carbonation which has five gassing tubes with 40 total slots.
- A PIPE-FLO model was set up treating each slot as an orifice to calculate the flow distribution. At first, the slots were believed to be 5" x 1"; 3" x 0.5" was arbitrarily chosen as a more realistic comparison:

Inlet Flow	20,000	lb/hr
Slot Size	Max Slot Flow (lb/hr)	Min Slot Flow (lb/hr)
3"x0.5"	509	496
5"x1"	684	422

- After the factory shut down for the year, the slots were remeasured at approx. 8.5" x 1". Calculations were re-performed using the hand calculations at 8.5" x 1" and 4.5" x 0.5". Documentation found at the factory suggested 4.5" x 0.5" may be more appropriate:

Slot Size	Flow Variation
8.5"x1"	153%
5"x1"	89%
4.5"x0.5"	41%

- Due to the poor agreement between PIPE-FLO models and hand calculations, CFD was employed to get a more accurate calculation. A single gassing tube was modelled as pictured:



- Results of the CFD are below:

Slot Size	Average Gassing Variability	Coefficient of Variation
4.5" x 0.5"	4.83%	5.66%
8.5" x 1"	29.9%	28.9%

- Based on the analytical results, slot sizes of 4.5" x 0.5" were chosen for the tubes in Pre-carbonation, 1st carbonation, and 2nd carbonation.

Process Modifications

- Since rebuilding the entire tubes was impractical, covers were fashioned to bring the open area to 4.5" x 0.5".

Conclusion

- Modifying the slot sizes had significant impact on absorption in carbonation. Results below:

	Before Change	After Change	Target Absorption
Pre-Carb. Absorption	31.1%	63.6%	>60%
1st Carb. Absorption	78.7%	92.3%	>80%

- The pressure at the distribution headers rose according to both the hand calculations and the CFD, suggesting the results were reasonable.
- Additionally, during stable operating conditions, the alkalinity control was improved in the months of September and October:

Campaign	Alkalinity Standard Deviation	Alkalinity Coefficient of Variation
2023	0.0072	0.087
2024	0.0061	0.072

- These results suggest that proper gas distribution requires an open slot area of less than half the open area of the tube. Further investigation is required to validate the true "rule of thumb" ratio.

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Accelerated Filtration

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