Field-Performance Verification of Carbon Dioxide, Water, and Nitrous Oxide Closed-Path Eddy Covariance Systems with Vortex Intakes

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Introduction

Closed-path eddy covariance systems measure the flux of greenhouse gases such as carbon dioxide, water vapor, and nitrous oxide. The challenge is to make accurate field measurements at sites around the world, even in extreme environmental conditions. Sites with dirty air present a particular challenge. Gas concentration measurements may be degraded as dust or debris is deposited on the optical windows in the sample cell. Dirty sample air can also contaminate other system components such as membrane dryers.

Objective

This work presents a new eddy-covariance system with a vortex air cleaner and demonstrates field performance from several sites around the world. Design objectives include:

- Reduce system maintenance
- Reduce downtime due to plugged filters
- Maintain high frequency response
- Maintain low-power requirements

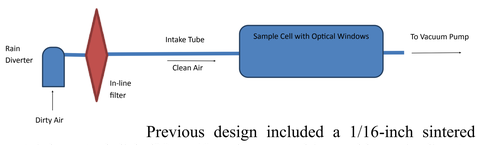
Traditional Solutions

Calibration:

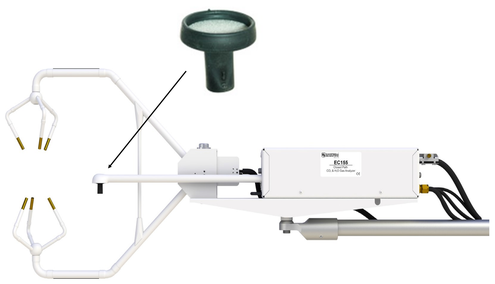
The EC155 calibration procedure includes mitigation to account for diminished optical signal strength due to dirty windows. Cleaning windows is recommended when signal strength diminishes to 80%.

In-line Filter:

- Keeps analyzer windows clean
- Must be replaced when pressure drop becomes too large
- Must be sized properly
  - ◊ Small filters require **frequent changes**
  - ◊ Large filters behave like a mixing volume and can **degrade frequency response**
  - ◊ Large filter surface area may further degrade frequency response for H_2O
  - ◊ A fine pore filter plugs quickly
  - ◊ A coarse pore filter allows windows to get dirty too quickly

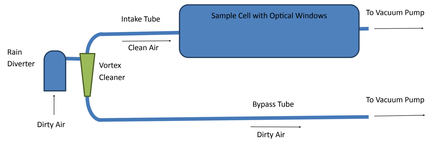


Previous design included a 1/16-inch sintered stainless steel disk (20 or 40 µm) mounted in a rubber rain diverter (volume = 1.7 mL).

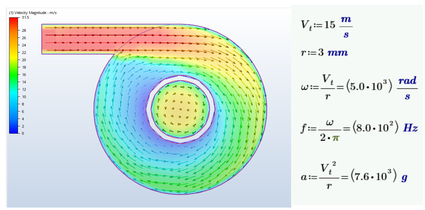


Vortex Cleaner

A novel eddy-covariance system that includes a vortex air cleaner (United States Patent No. 9,217,692) has been developed and field tested. It keeps the analyzer windows clean and eliminates the requirement for an in-line filter upstream of the gas analyzer.

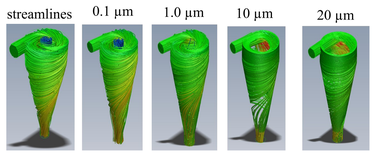


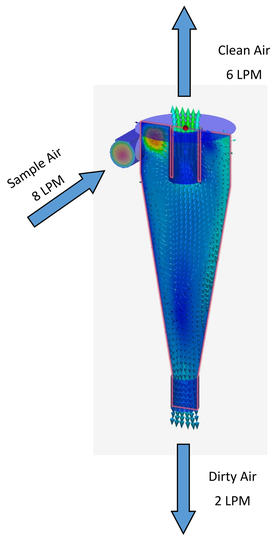
Vortex Flow, Separator

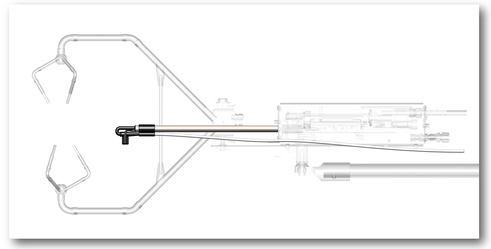


Dirty air enters the vortex chamber through a tangent port inducing vortex flow. Momentum keeps larger heavier dirt particles away from center of vortex flow. Air in the center of the vortex is clean.

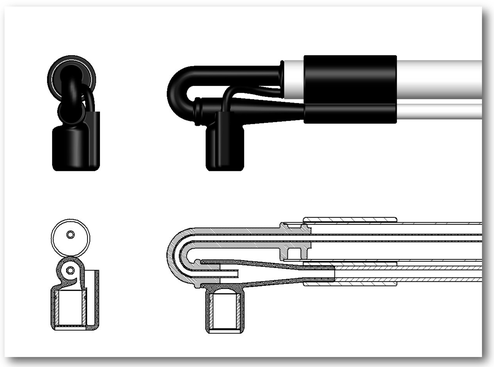
Assuming dust particles are spherical, their mass is proportional to the diameter cubed. Drag force is proportional to square of diameter. Momentum dominates particle trajectory, in this design, for particles larger than 1 µm according to the Computational Fluid Dynamics model results shown below.







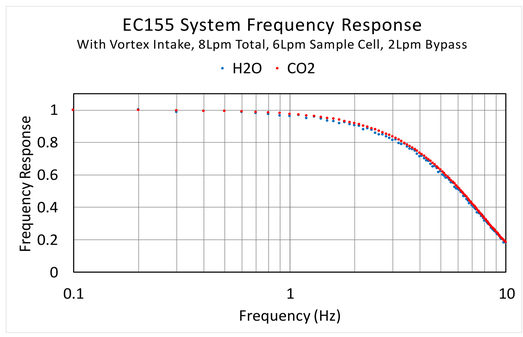
CPEC200/EC155 System with Vortex Intake



Details of Vortex Intake for CPEC200/EC155 and TGA Eddy Covariance Systems

Specifications

- Rain diverter volume: 1.3 mL
- Vortex chamber volume: 0.9 mL
- Heater power (typical): 0.7 W (prevents frost and dew on intake)
- Flow (typical): 8 LPM total, 6 LPM clean sample, 2 LPM dirty bypass
- Worst case perfect mixing volume time constants for typical flow
  - ◊ Rain diverter: 9.8 ms
  - ◊ Vortex chamber: 6.8 ms
- CPEC200/EC155 system frequency response (see graph below)
  - ◊ Half power bandwidth: 4.3 Hz for CO_2 and 4.2 Hz for H_2O
  - ◊ Including the analyzer, intake tubing, vortex chamber, and rain diverter
  - ◊ Typical flow as specified above
  - ◊ Measured using the laboratory method as described in the white paper Quantifying Frequency Response of a Low-power, Closed-path CO_2 and H_2O Eddy-covariance System (Sargent, 2012).



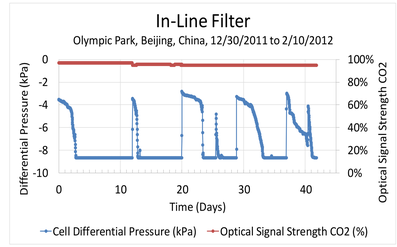
Field Studies

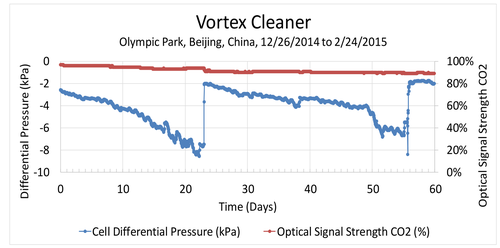
Olympic Park, Beijing, China

A CPEC200 was used to measure CO_2 and H_2O fluxes as part of an environmental study (Xie, et al., 2015). Olympic Park is an urban forest surrounded by the city of Beijing. Air quality at this site is extremely poor and is typically worst during winter months. This CPEC200 was originally equipped with a traditional in-line filter. In 2014, it was fitted with a vortex intake. The sample cell pressure and optical signal strength are useful for indicating when it's time to change filters and clean windows.

Field Maintenance Summary for plugged filters or dirty windows at Olympic Park

Begin Date	End Date	Intake	Time Range (days)	Number of Maintenance Services	Down-time due to plugged intake (days)	Downtime Fraction	Minimum Required (days)	Average Required (days)
12/30/2011	2/10/2012	Inline filter	42	6	25	60%	**1**	**3**
12/26/2014	7/18/2015	Vortex	204	4	12	6%	**23**	**48**



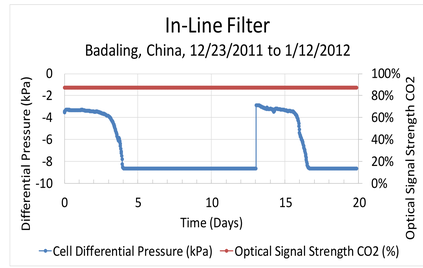


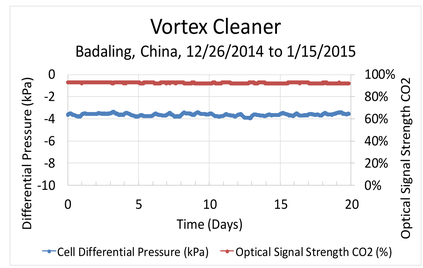
Badaling, China

A CPEC200 measured CO_2 and H_2O fluxes as part of an environmental study at Badaling, China (Tang, et al., 2013). This rural site is in the mountains north of the city of Beijing and is near a popular section of the Great Wall of China. The air quality is typically better than at the Olympic Park site, but degrades during the winter months. This CPEC200 was also originally equipped with an in-line filter, but replaced with a vortex intake in 2014.

Field Maintenance Summary for plugged filters or dirty windows at Badaling

Begin Date	End Date	Intake	Time Range (days)	Number of Maintenance Services	Down-time due to plugged intake (days)	Downtime Fraction	Minimum Required (days)	Average Required (days)
12/23/2011	1/12/2012	Inline filter	20	2	13	65%	**3**	**4**
12/26/2014	6/5/2015	Vortex	161	0	0	0%	**> 161**	**> 161**





Logan, Utah, USA

An outdoor test using a CPEC200 with a vortex intake was performed in a field north of Campbell Scientific, Inc. in Logan, Utah, USA where the air quality is generally good. This test began 12/17/2013. It ran for **307 days with no maintenance** on the intake or sample cell windows.

Another long-term outdoor test with the final production design CPEC200/EC155 with heated vortex intake began on 10/21/2015 and is ongoing.

Elora, Ontario, Canada

A low-power N_2O eddy covariance system with a TGA200A (Somers, et al., 2015) has been running with a vortex intake in an agricultural site near the University of Guelph since the 06/22/2015 (Brown, et al., 2015).

Conclusions

Results show that the closed-path eddy covariance systems with a vortex intake, perform very well and require lower maintenance compared to similar systems with in-line filters. These systems maintain excellent frequency response with low power consumption.

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Acknowledgements

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