

Simulation and Experimental Study to Predict the Gas Emission from Porous Media

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Problem Description

- The rationale for this study is to interpret and quantify for a specific location how soil produced carbon dioxide contributes to the green house effect.
- Respiration chambers can be used to quantify the soil efflux for certain locations whereby they come in different shapes and sizes depending on their use.



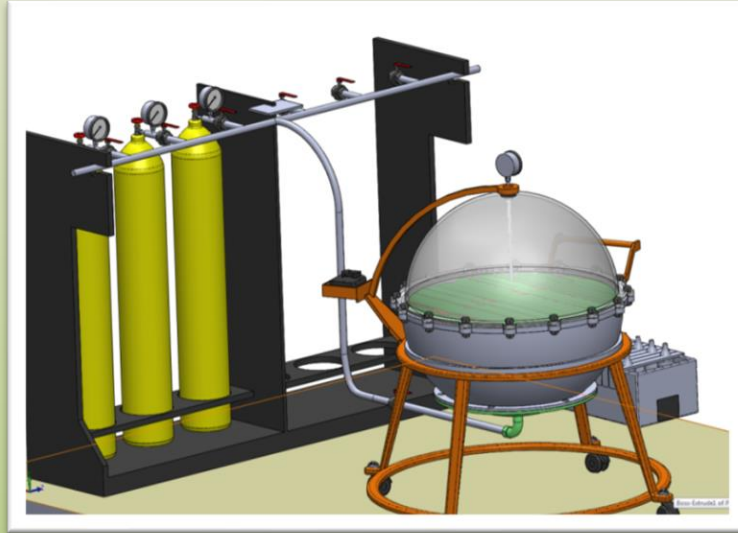
Thesis Objectives



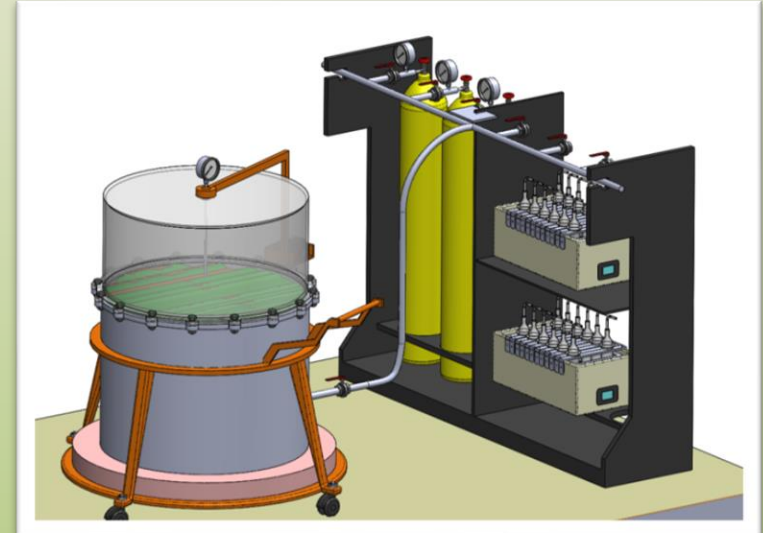
- To derive several forms of efflux equations to link soil physical mechanisms, soil biological parameters and types of soil textures that affect soil efflux respiration.
- To Develop several chamber designs that measure biologically generated carbon dioxide effluxes from soils.
- To produce an innovative portable device that measures carbon dioxide efflux.
- To develop a software code within a MATLAB environment.
- To model the mass transport using CFD (ANSYS).
- To validate the software code through the use of experiments.



Design Process Stages



Design Stage 1



Design Stage 2



Design Stage 3

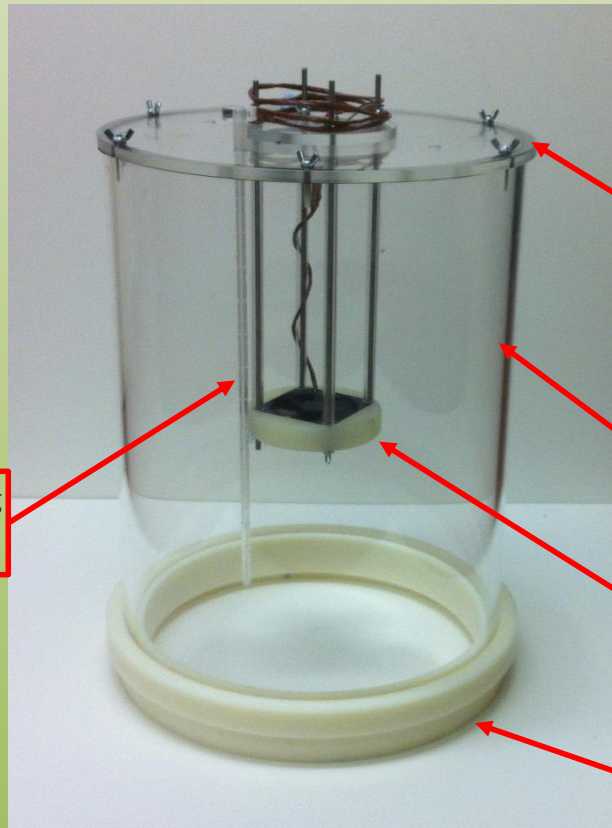


Final Design



The Experimental Setup and Part Description

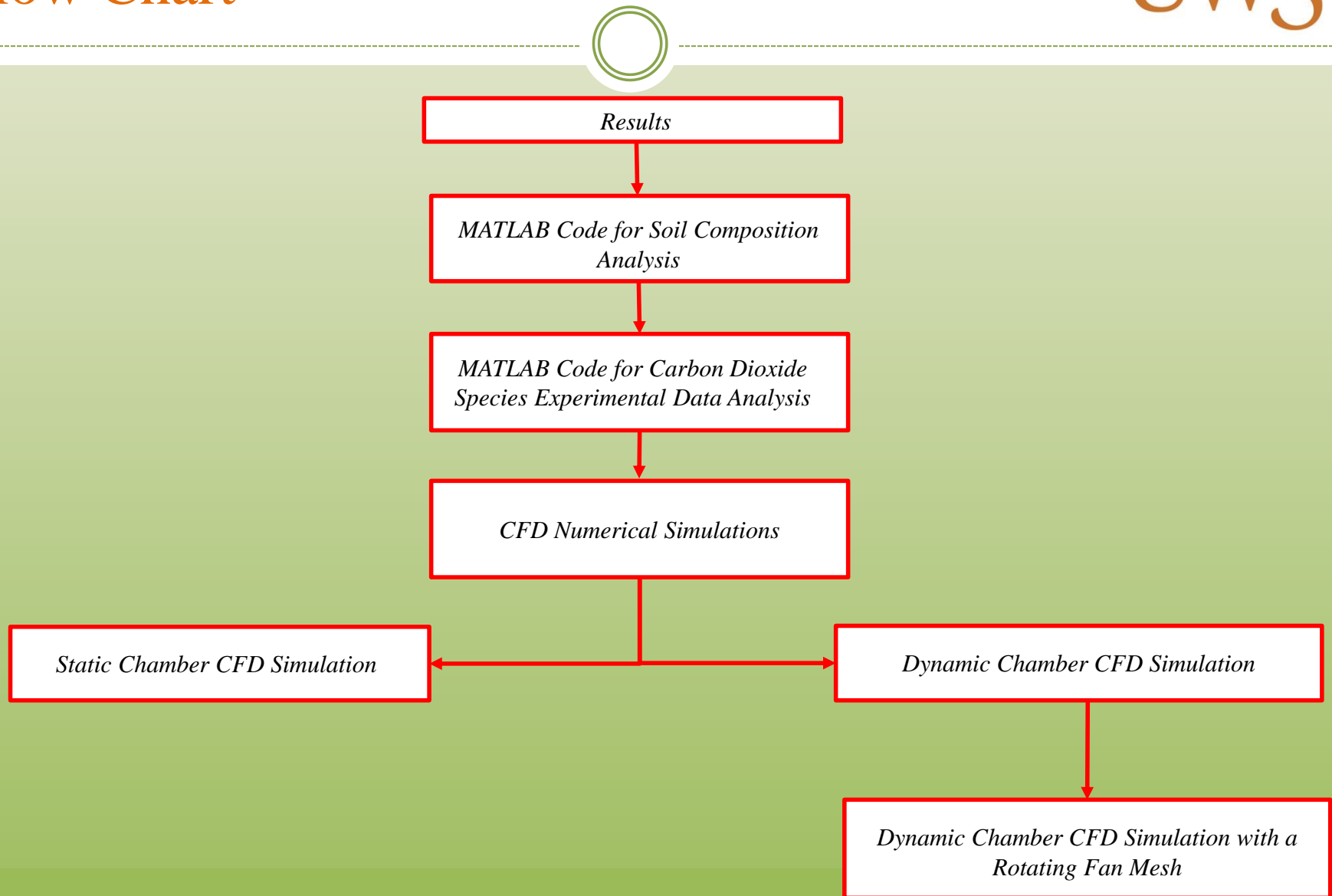
Chamber Parts Description



Chamber on Grass Land



Experimental and Numerical Results Flow Chart



MATLAB Software Interface for Soil Composition Analysis

Data Input

Standard 1 m³ Soil Mass Distribution

Standard 1 m³ Case

Mass [kg]

Volume [m³]

Soil Texture

Sand

Clay

Silt

Soil Standard Volume Fractions

Water Volume Ratio [1]

Air Volume Ratio [1]

Mineral Volume Ratio [1]

Organic volume Ratio [1]

Organism Volume Ratio [1]

Standard 1 m³ Soil Sub-volume Fractions

Alive Organic Volume Ratio [1]

Dead Organic Volume Ratio [1]

Soil Mass Fractions

Water Mass Ratio [1]

Air Mass Ratio [1]

Mineral Mass Ratio [1]

Organic Mass Ratio [1]

Organism Mass Ratio [1]

Standard 1 m³ Soil Sub-Mass Fractions

Alive Organic Mass Ratio [1]

Dead Organic Mass Ratio [1]

Data Library

Soil Constituent Density Values

Water Density [kg/m³]

Air Density [kg/m³]

Sand Density [kg/m³]

Silt Density [kg/m³]

Clay Density [kg/m³]

Organic Density [kg/m³]

Organisms Density [kg/m³]

Dead Organic Matter Density [kg/m³]

Alive Organic Matter Density [kg/m³]

Total Density [kg/m³]

Soil Standard Constituent Mass Values

Water Mass [kg]

Air Mass [kg]

Sand Mass [kg]

Silt Mass [kg]

Clay Mass [kg]

Organic Mass [kg]

Organisms Mass [kg]

Dead Organic Matter Mass [kg]

Alive Organic Matter Mass [kg]

Total Mass [kg]

Plot Mass Fractions Plot Volume Fractions Reset Default



Data Output

Soil Standard Properties

Density of Solid [1]

Dry Bulk Density [1]

Total Wet Density [1]

Dry Specific Volume [1]

Porosity [1]

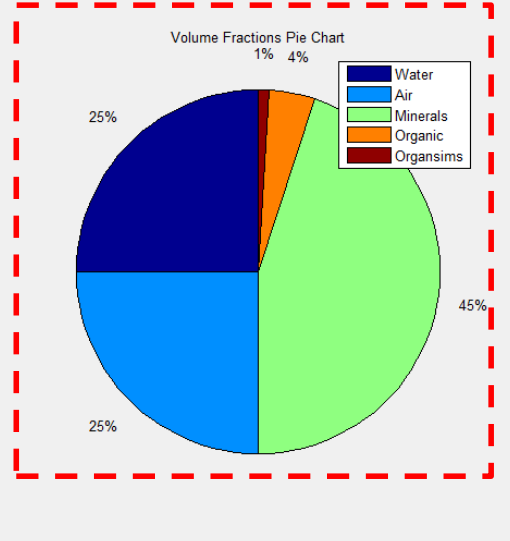
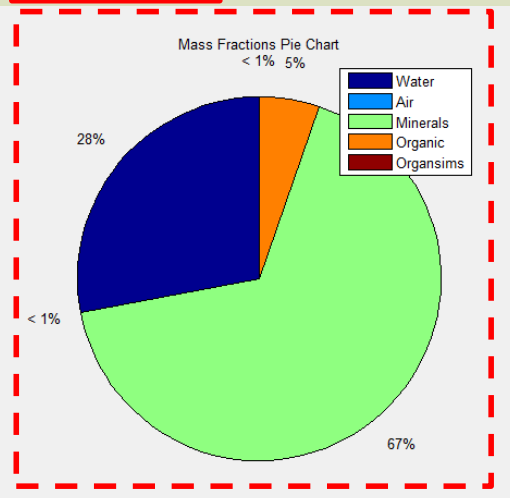
Void Ratio [1]

Mass Wetness [1]

Volume Wetness [1]

Degree of Saturation [1]

Air Filled Porosity [1]



MATLAB Software Interface for Soil Temperature Prediction in Relation to Depth and Physical Parameters



Data Input

Soil Temperature Program

Default Reset

S: 0 [1]

d: 0.133921 [m]

Lambda Sand: 8.9 [w m⁻¹ K⁻¹]

Lambda Silt: 1.67 [w m⁻¹ K⁻¹]

Lambda Clay: 2.9 [w m⁻¹ K⁻¹]

Lambda Organic: 0.25 [w m⁻¹ K⁻¹]

Lambda Water: 0.57 [w m⁻¹ K⁻¹]

Lambda Air: 0.025 [w m⁻¹ K⁻¹]

Total Lambda: 1.55388 [w m⁻¹ K⁻¹]

0.281799 [m]

Tav: 283.15 [K]

Wd: 7.27221e-05 [rad/Sec]

A0: 10 [K]

S1: 0.1 [1]

S2: 0.2 [1]

S3: 1 [1]

Ch Sand: 2e+06 [J/(m³ K)]

Ch Clay: 2e+06 [J/(m³ K)]

Ch Organic: 2.5e+06 [J/(m³ K)]

Ch Water: 4.2e+06 [J/(m³ K)]

Ch Air: 1300 [J/(m³ K)]

Initial Time: 0 [hour]

Number of Days: 1 [1]

Number of Hours: 24 [1]

End Time: 24 [hour]

Clay Ratio: 0.2 [1]

Organic Ratio: 0.04 [1]

Water Ratio: 0.45 [1]

Air Ratio: 0.25 [1]

Dead Organic Ratio: 0.02 [1]

Alive Organic Ratio: 0.02 [1]

Mineral Ratio: 0.25 [1]

Organisms Ratio: 0.01 [1]

Soil Ratio Check: 1 [1]

Volume Fraction Ratio Check: 1 [1]

Carbon Dioxide Diffusion: 1.35503e-07 [cm²/sec]

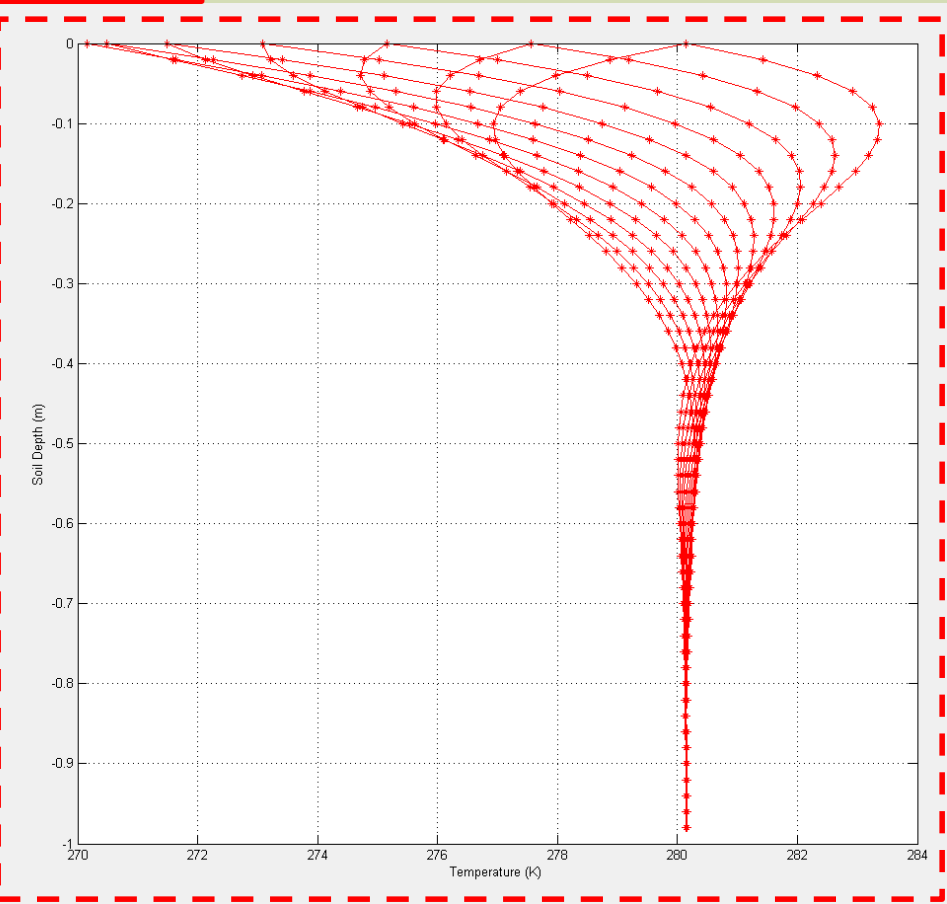
Total Ch: 2.38276e+06 [J/(m³ K)]

Average Soil Surface Temp: 280.15 [K]

Ch Silt: 0 [J/(m³ K)]

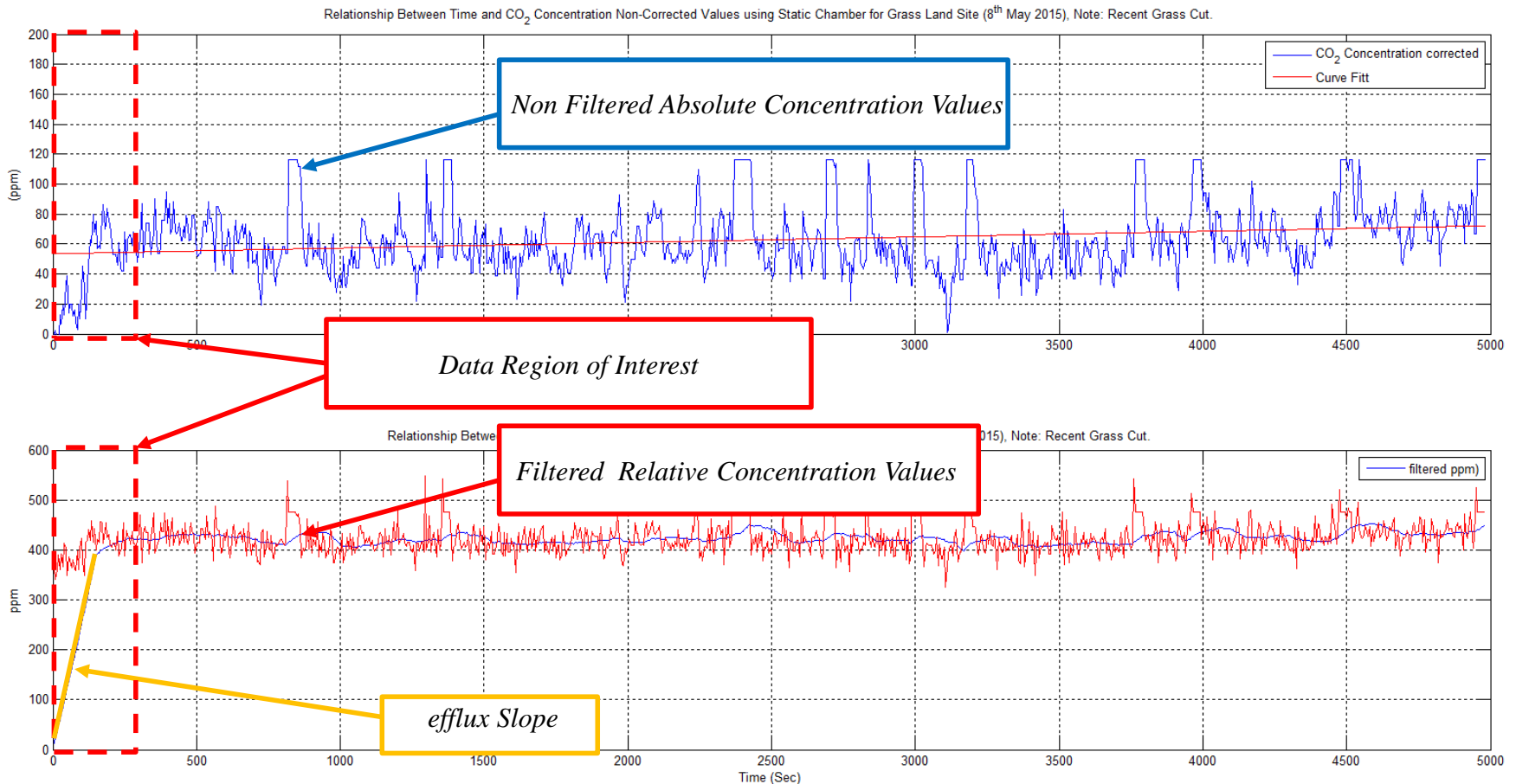
Data Library

Data Output



MATLAB Software Data Analysis

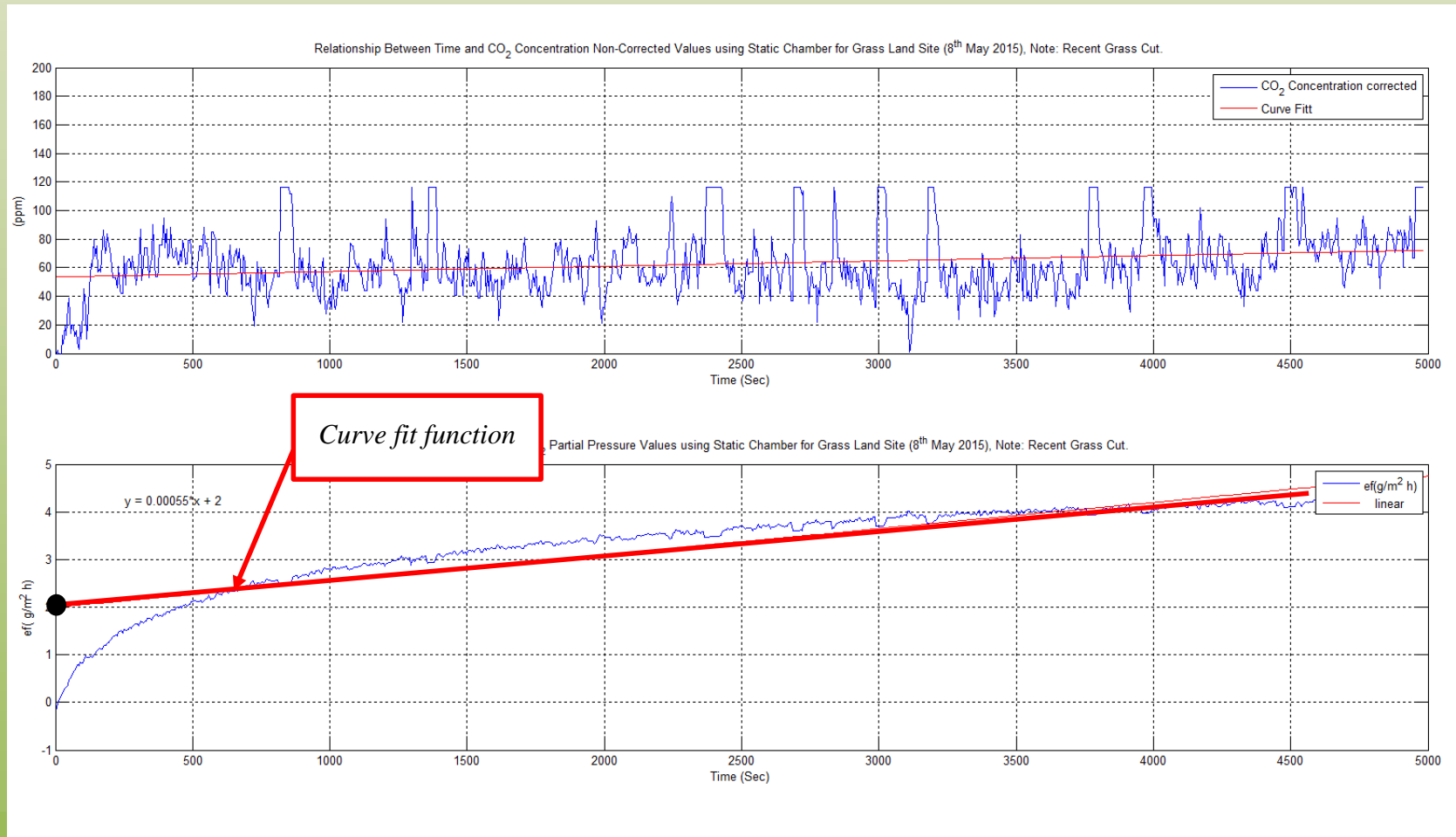
Absolute and relative species concentration values for carbon dioxide measured in experiments in relation to time.



MATLAB Software Data Analysis

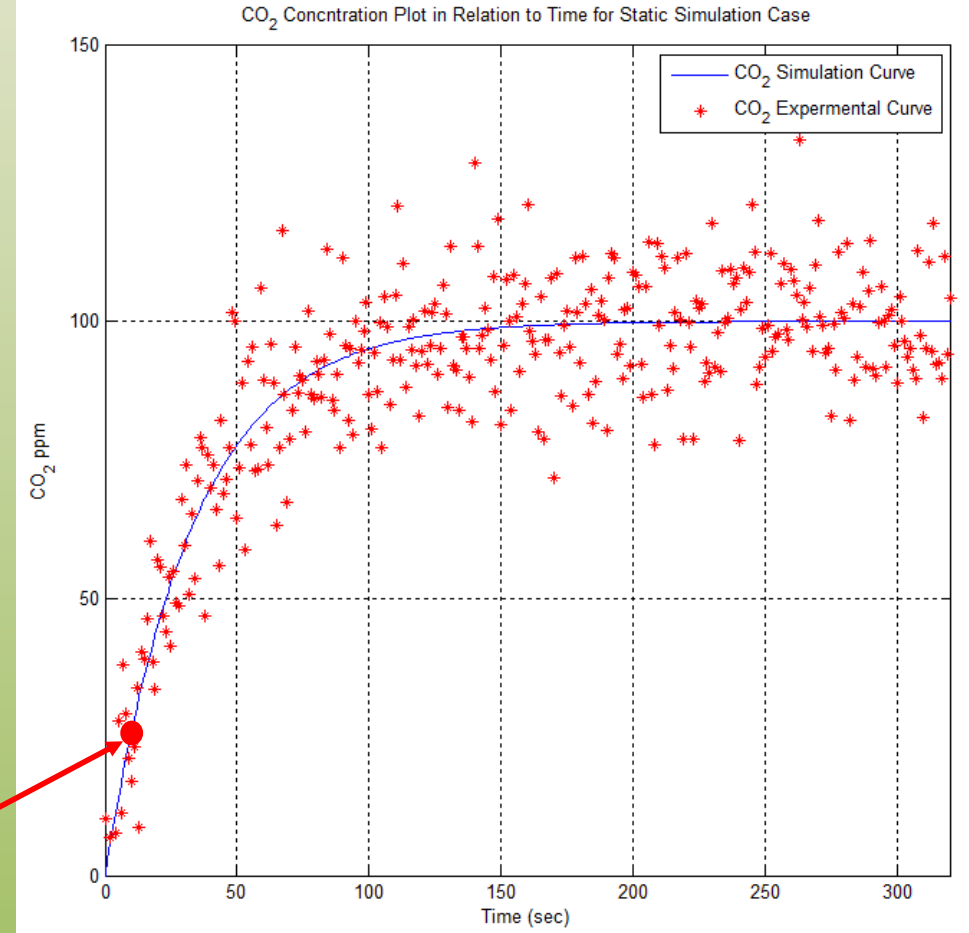
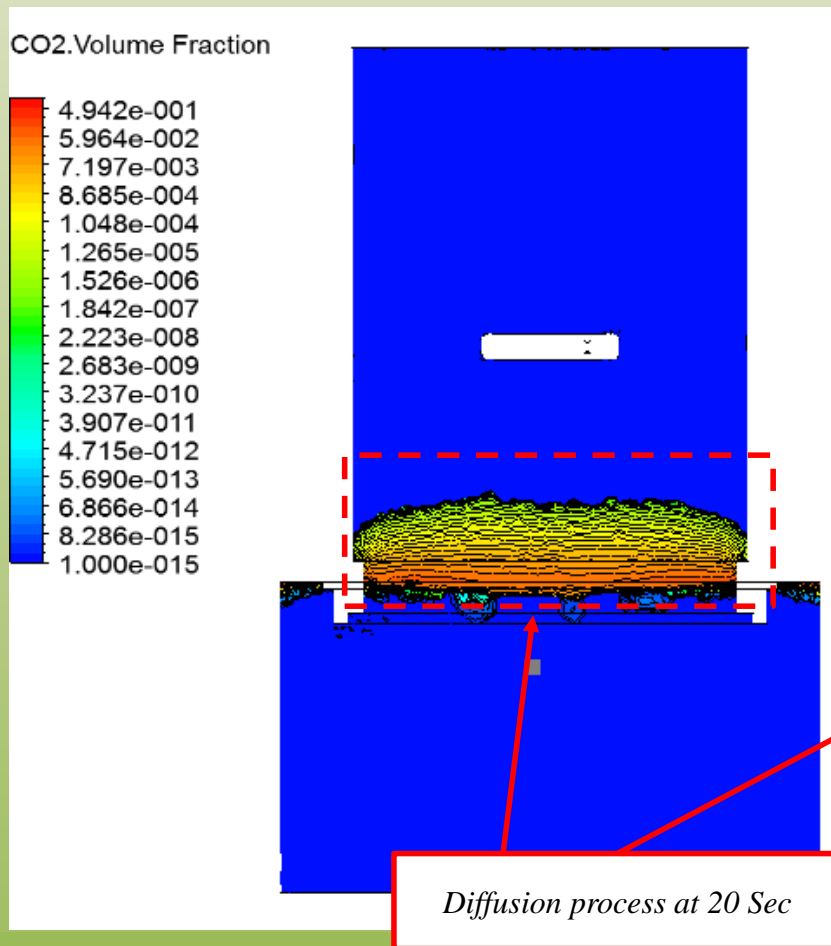


Absolute concentration values of carbon dioxide and measured efflux in relation to time



CFD Static Case Simulation

Capturing diffusion pattern within the chamber



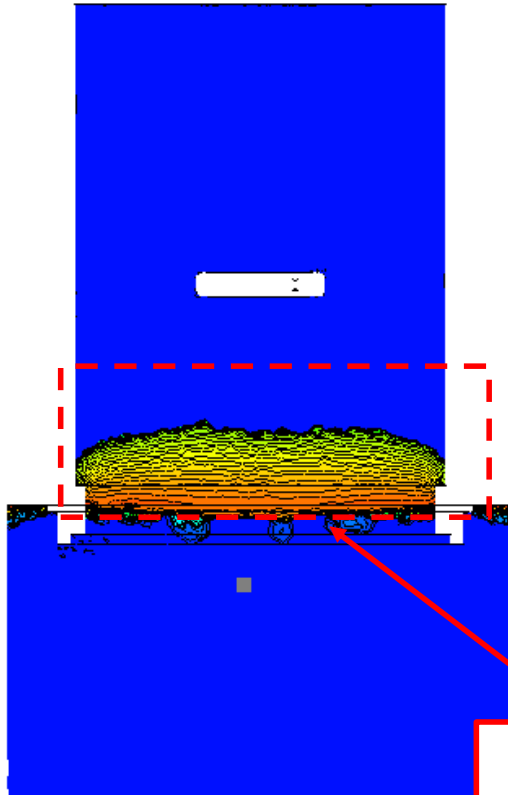
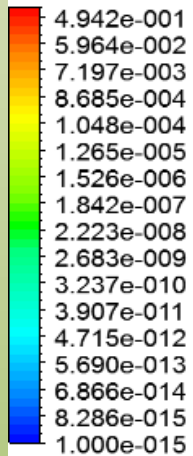
Comparison between experimental and numerical data for a static case

CFD Static Case Simulation

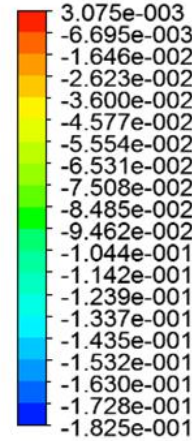
Species concentration distribution within the chamber

Temperature difference contour plot

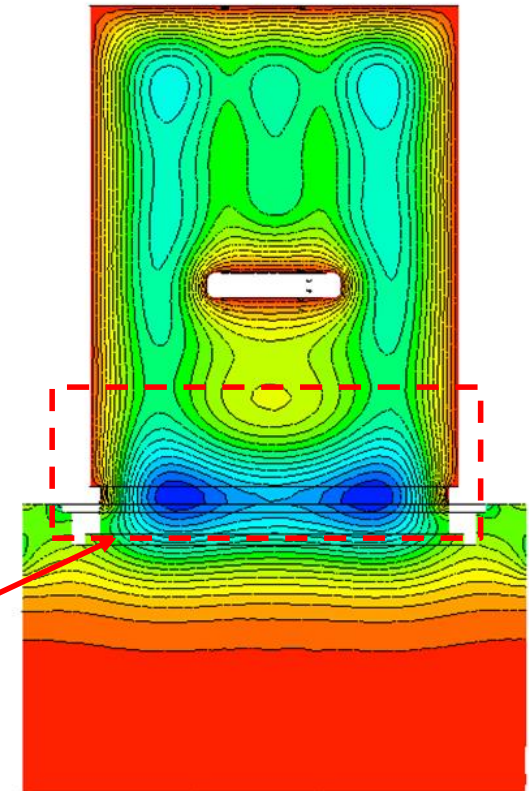
CO₂.Volume Fraction



Temperature.Difference



[K]

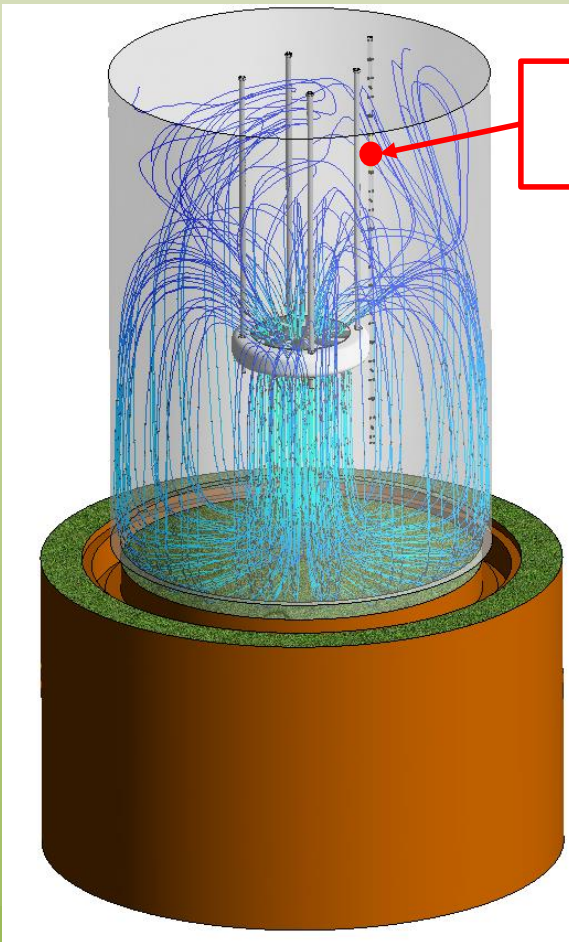


Species Suction Region

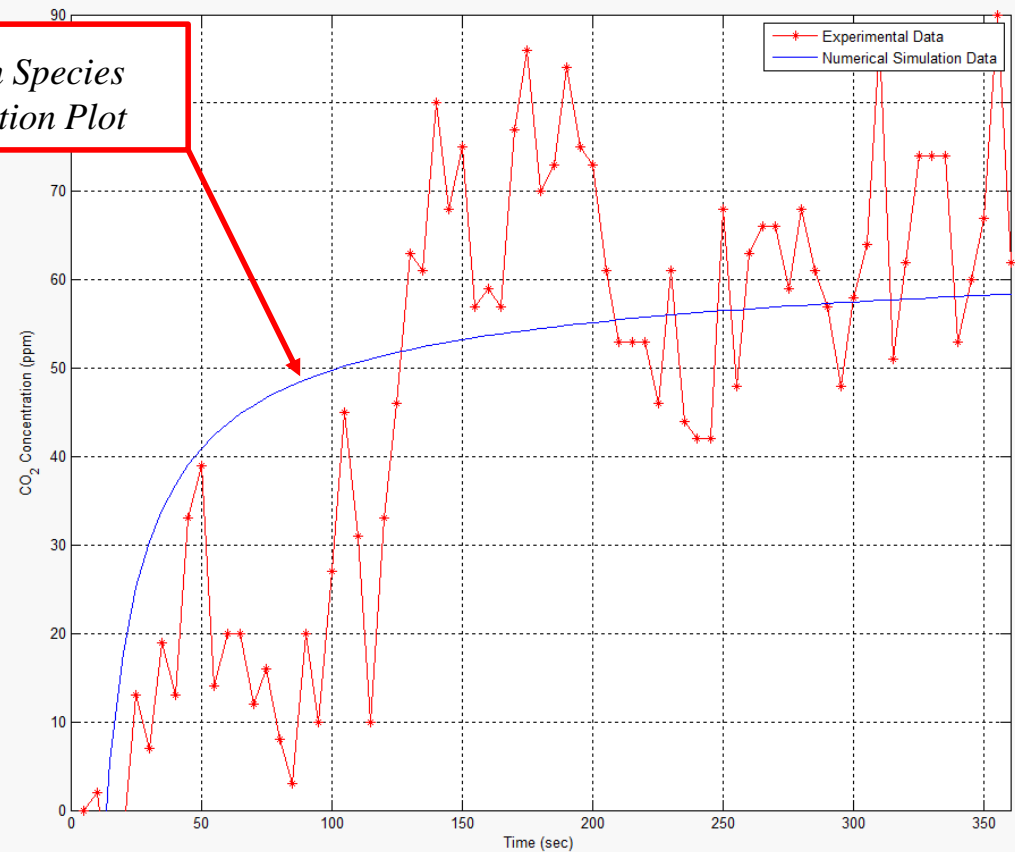
CFD Dynamic Case Simulation with a Non Rotating Mesh Simulation

Capturing the flow pattern within the chamber

Comparison between experimental and numerical data for a dynamic case

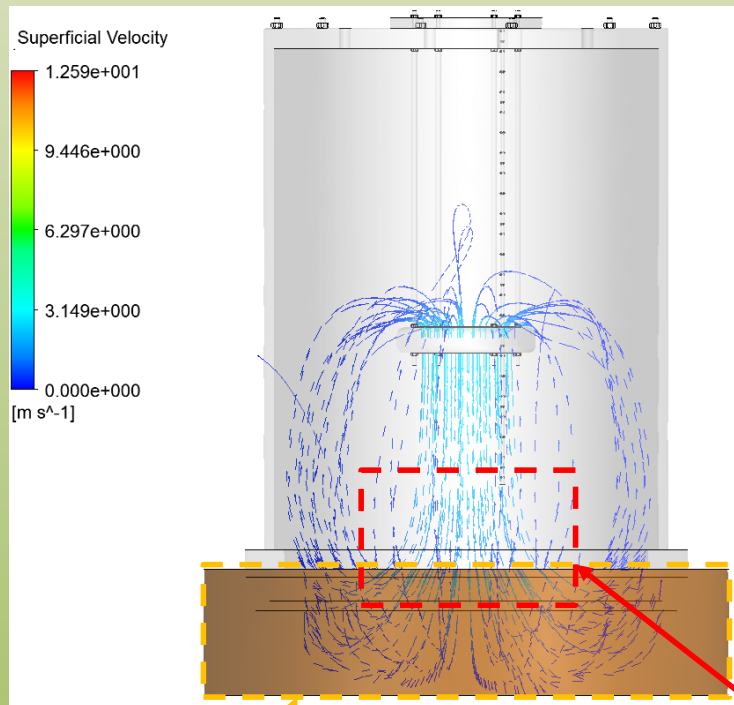


Simulation Species Concentration Plot



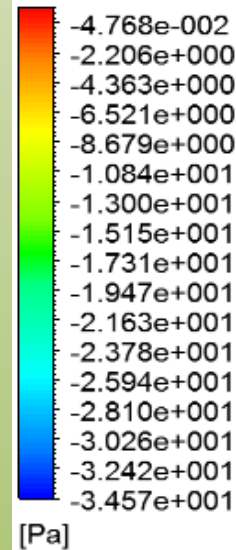
CFD Dynamic Case Simulation with a Non Rotating Mesh Simulation

Pressure effects on the active part of the soil

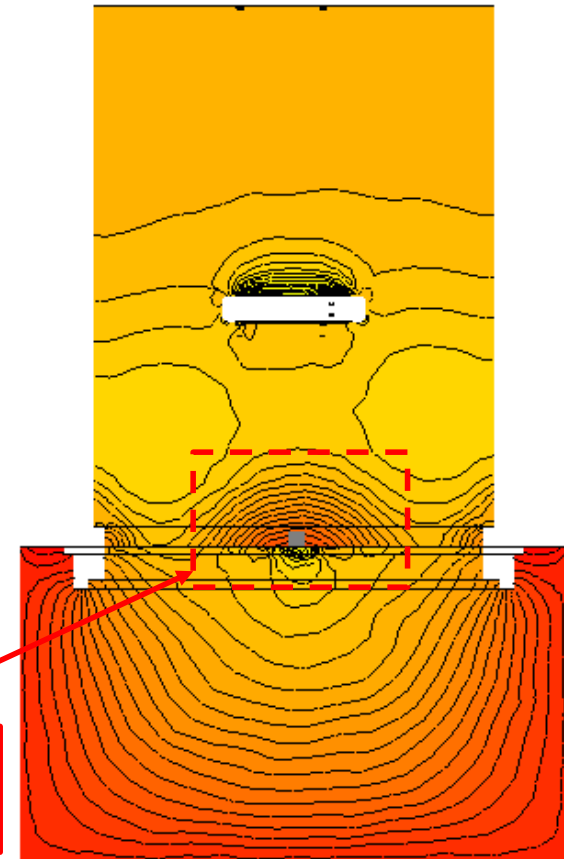


Soil Aerated Layer

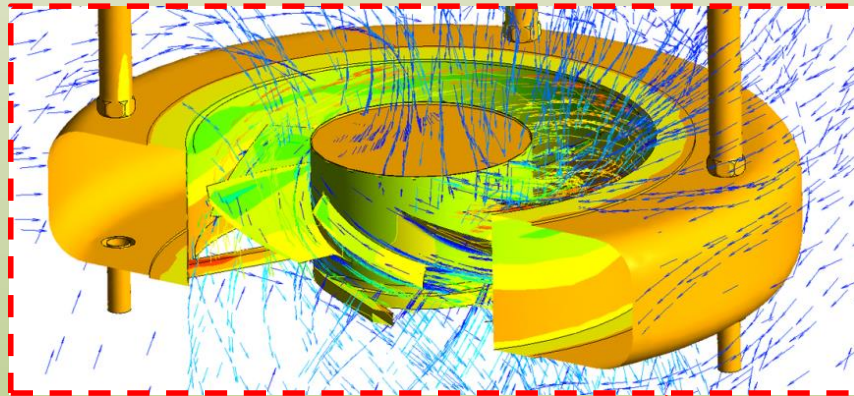
Pressure



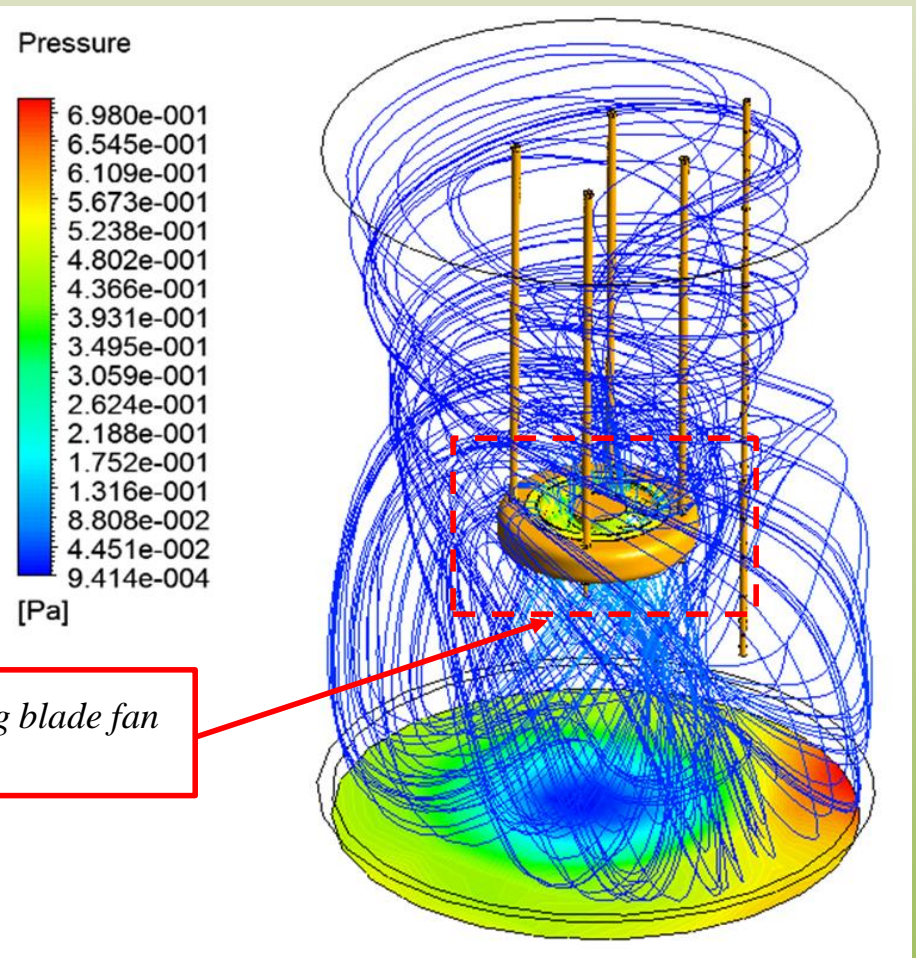
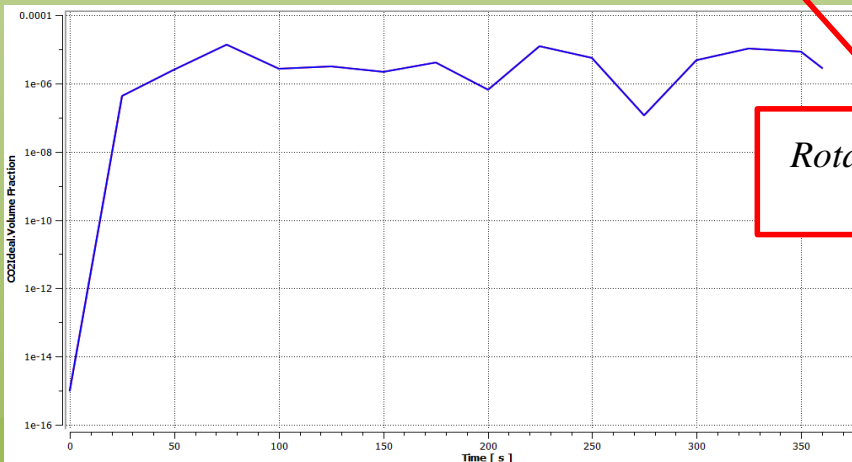
*Pressure Build Up
Region*



CFD Dynamic Case Simulation with a Rotating Mesh



Concentration plot for the numerical simulation of a dynamic case

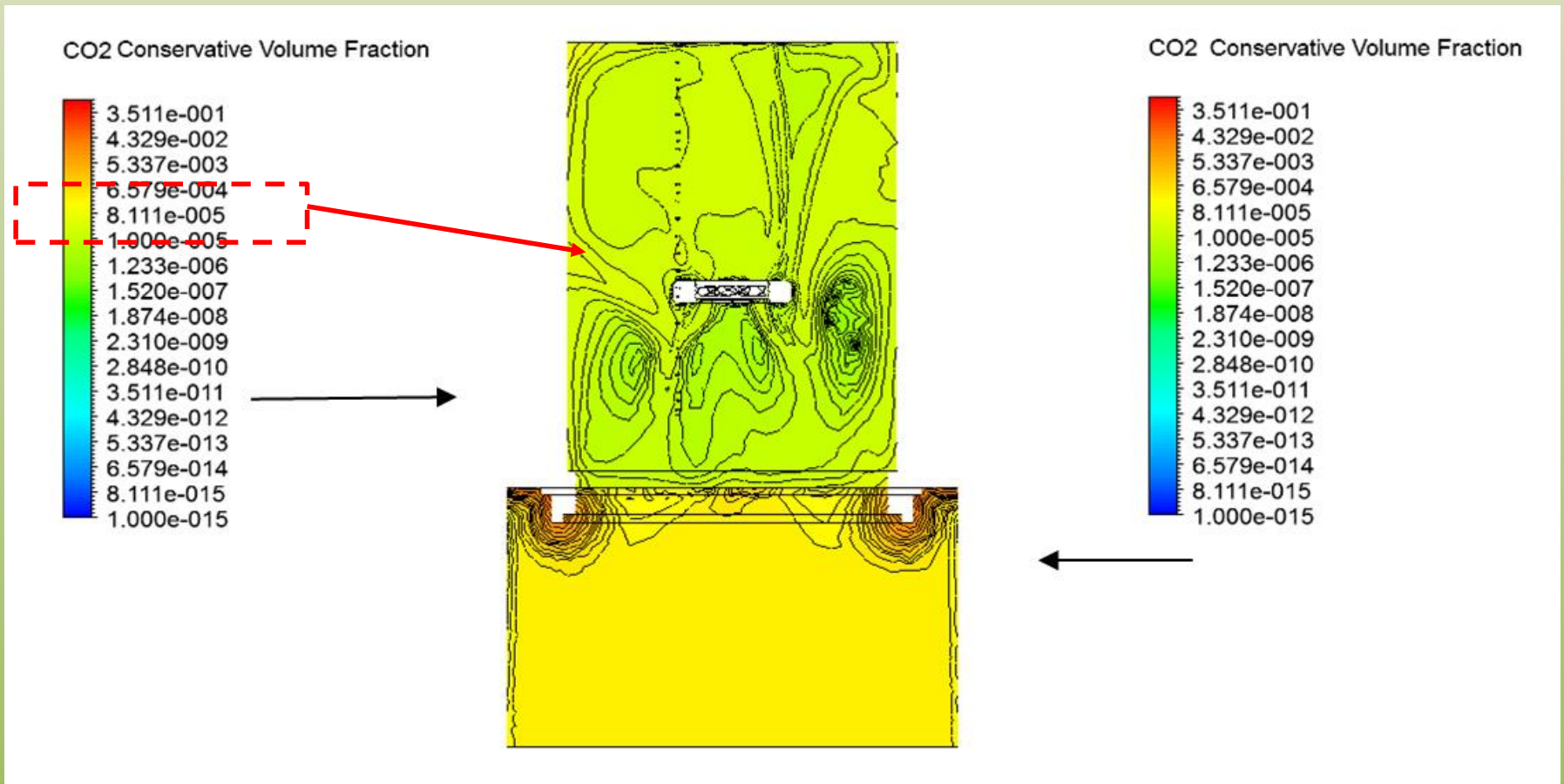


Rotating blade fan

Capturing the flow pattern within the chamber

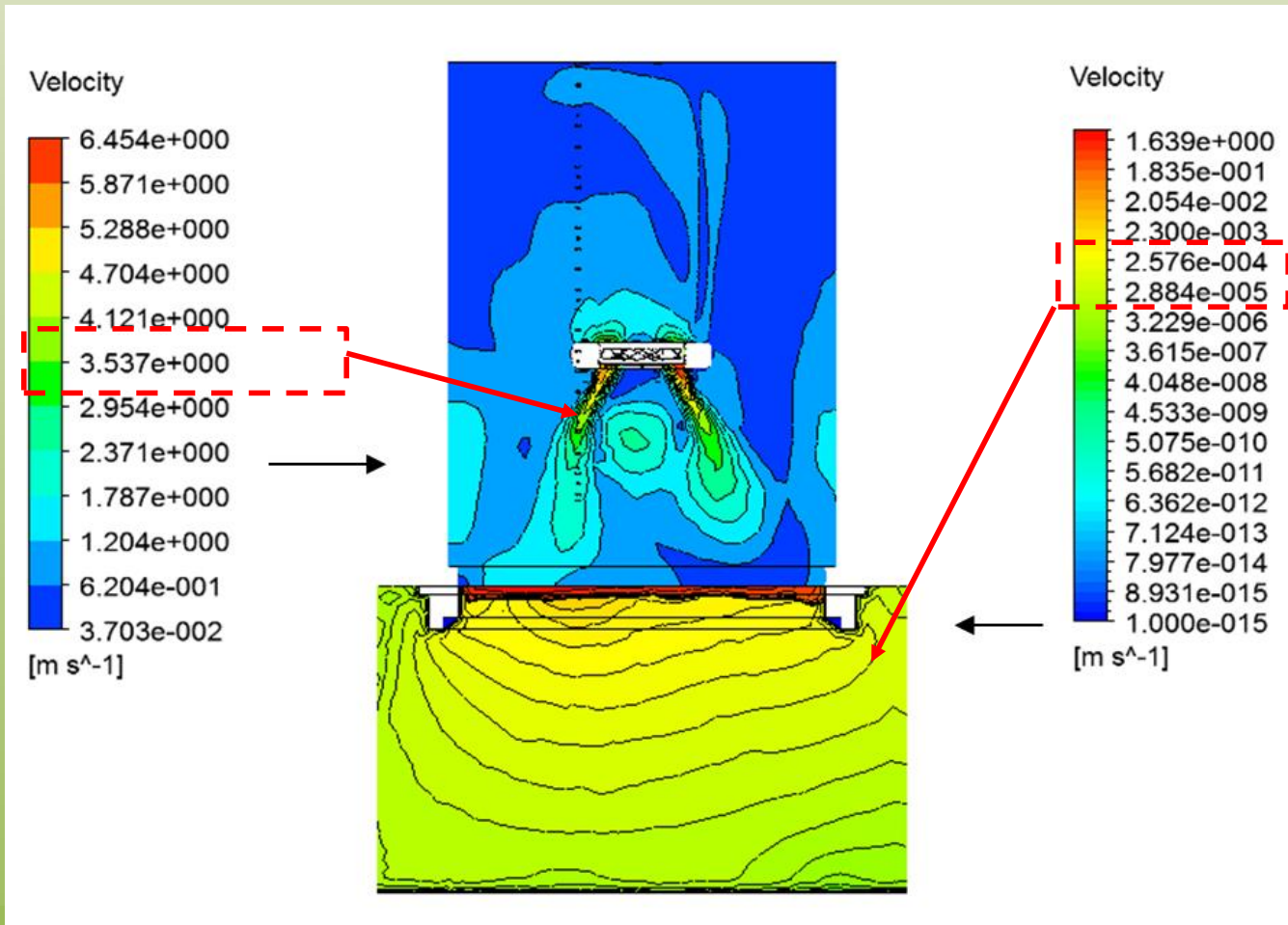
CFD Dynamic Case Simulation with a Rotating Mesh

Concentration plot for a numerical simulation of a dynamic case



CFD Dynamic Case Simulation with a Rotating Mesh

Velocity contour plot for a numerical simulation of a dynamic case



Thesis Conclusion



- Several forms of efflux equations were derived to link soil physical mechanisms, soil biological parameters and types of soil textures that affect soil biological efflux respiration.
- A new chamber design was made, tested and validated.
- The results of this project significantly contribute towards the growing research in this area. The innovations of the respiration chamber design in its operational mode whether static or dynamic delivered accurate concentration measurements to a level of ± 20 ppm for a frequency sampling period of 5 seconds by the used gas sensor.



Thesis Conclusion



- A software code using MATLAB was developed to incorporate interface windows that can assist in the data analysis stage of the project for the grass land location. Consequently this will help future testing and calibrating new sensor technologies compatibility with any developed chamber design.
- For both cases of a rotating fan mesh and without a fan mesh the K-Epsilon turbulence model proved that it can be used to model flows in closed dynamic respiration chambers.
- The Laminar flow model can be applied to model the static flow case where mass diffusion is dominant.
- The Darcy equation proved to be applicable and can be used in porous media for a grassland location.



Conference Paper

- A NUMERICAL AND EXPERIMENTAL STUDY OF A NEW DESIGN OF CLOSED DYNAMIC RESPIRATION CHAMBERS. Ahmed Al Makky, Olabi, Alaswad, Gibbson, and Shigeng Song.

Journal Paper (Submitted and Under Review)

- A NUMERICAL AND EXPERIMENTAL STUDY OF A NEW DESIGN OF CLOSED DYNAMIC RESPIRATION CHAMBER Authors: Ahmed Al Makky; A. Alaswad; D. Gibbson; A. G. Olabi. Article Type: Research Paper Environmental Pollution.
- DEVELOPMENTS ON SOIL EMISSION MEASUREMENTS PART I. Authors: Ahmed Al Makky; A. Alaswad; D. Gibbson; A. G. Olabi. Article Type: Renewable & Sustainable Energy Reviews.
- DEVELOPMENTS ON SOIL EMISSION MEASUREMENTS PART II. Authors: Ahmed Al Makky; A. Alaswad; Des Gibbson; A. G. Olabi. Article Type: Renewable & Sustainable Energy Reviews.



Thank You

