Recirculation Effects in Sorbent Beds for Direct-Air Carbon Capture

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Abstract

This project addresses the study of CO_2 absorption using packed bed media. Packed beds are a porous media, usually made of metal foam or glass beads, and are commonly used in carbon capture experiments [1]. An existing research-grade, blow-through wind tunnel was modified into a closed-loop operation, which enables the use of Particle Image Velocimetry (PIV) to study flow through packed beds, allows for the investigation of mixing effects in returned flow and prevents contamination of the lab environment (due to olive oil seed particles). Additionally, the recirculation of air allows for a reduction in fan work, reducing operational energy requirements. The fabrication of this return-flow shell includes air ducts, 90° elbows, turning vanes and a settling chamber – all designed using SolidWorks and/or Ansys Fluent. The completed return-loop wind tunnel meets criteria for modularity, PIV use, and dimensional constraints, has been tested for health and safety, and enables velocimetry and mixing experiments while costing less than $1,600.

Introduction

Design Problem

- To design, develop and manufacture the return-flow shell of an existing research-grade open-loop wind tunnel.
- Test for flow quality at the test section.

Project Components

- Ducts, Settling Chamber, Turning Vanes, Particle Injection

Project Benefits

- Allows us to study mixing effects in returned flow, and flow through packed beds using Particle Image Velocimetry (PIV).
- Prevents harmful aerosols like olive oil seed particles from contaminating lab environment.
- Reduces fan work and thus energy requirements.

Methods

- Multiple design iterations for the return-loop were modelled in SolidWorks.
- The most important section is the settling chamber, which must allow air expansion, mixing, and improvement of flow uniformity. Settling chamber designs were implemented in Ansys Fluent and SolidWorks Flow Simulation and optimized for low total pressure loss, low turbulent kinetic energy, and outlet velocity profile uniformity.
- Turning vanes in corners were verified using CFD, and a literature review was conducted to determine their best length and spacing.
- Particle injection necessitated a transparent section to allow for visualization of the flow along with a manifold.
- Physical model was assembled using make-to-order ducts, 90° elbows, duct transitions, and a hand-built plywood settling chamber.
- Testing was conducted using a pitot tube sweep of the test section to assess flow velocity uniformity.

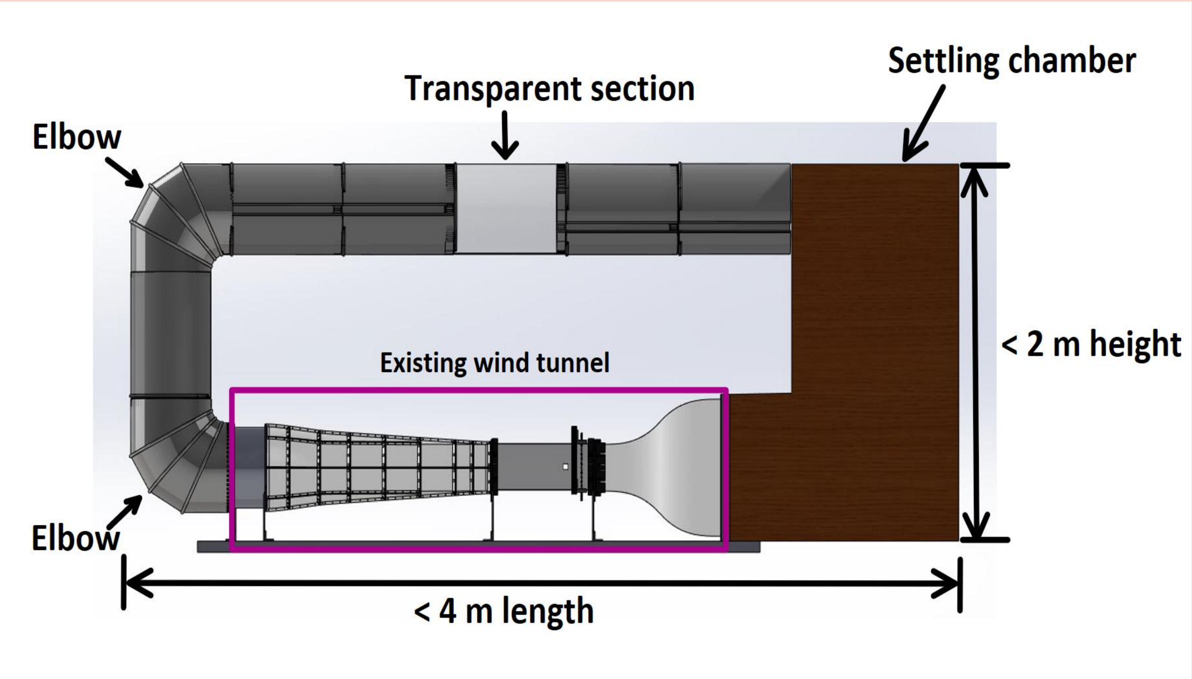
Results

- CFD Analysis was performed done on multiple proposed designs for the settling chamber section.
- The settling chamber is equipped with turning vanes to help achieve the required flow uniformity. The successful design yielded the best flow uniformity and distribution in the analysis.
- The material used for the air ducts and turning vanes was galvanized sheet metal, due to their cost, weight, and non-corrosive properties.
- Tests were performed on rpm sensor to ensure accurate readings. Leak test was performed on wind tunnel thereby eliminating contamination of the surrounding laboratory environment.

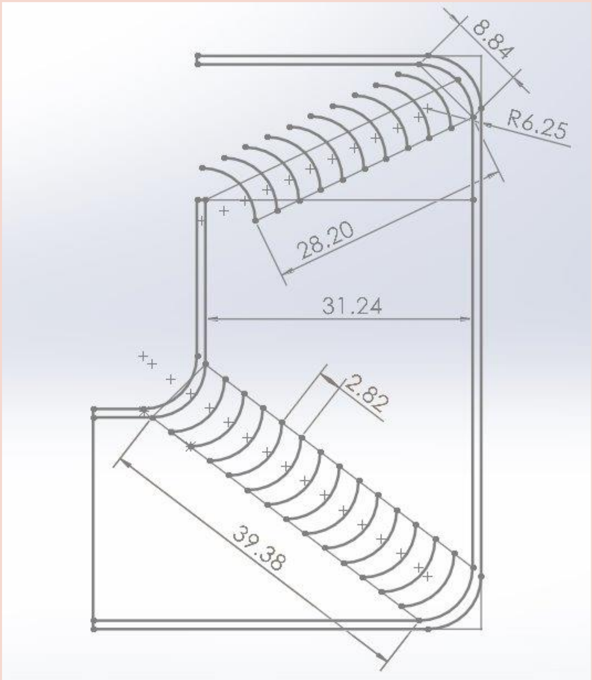
Conclusions

- The return-loop wind tunnel was built and successfully passed tests that eliminate health and safety concerns.
- The built return-loop meets sponsor requirements of being modular, having an access port to allow the introduction of particles, turning vanes, and not exceeding the dimensional constraints of 4 m length and 2 m height.
- Costs of manufacturing and implementation do not exceed $1,600.

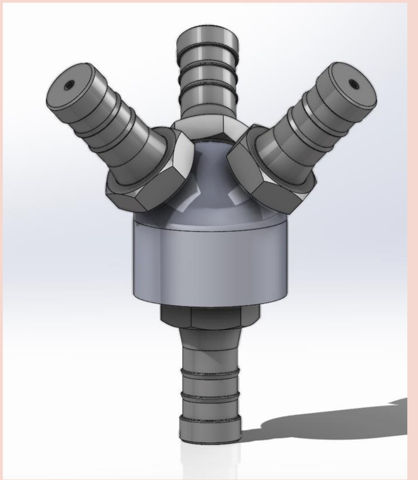
SolidWorks Assembly



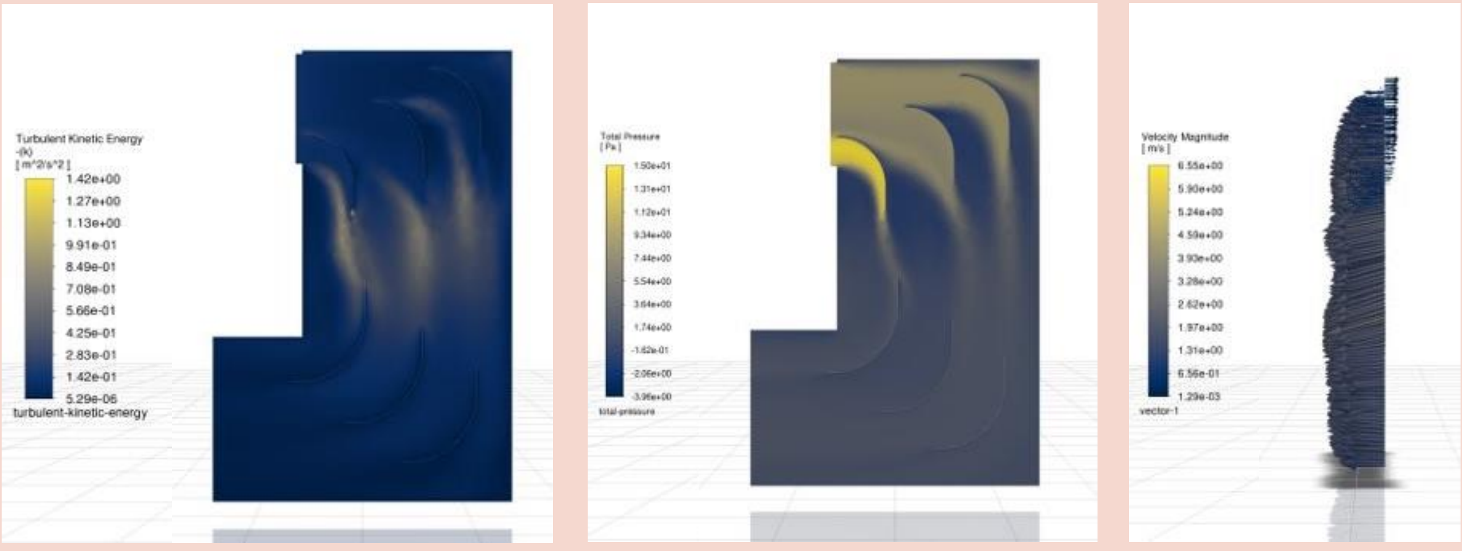
Turning Vanes



Manifold Design



CFD Airflow Simulation



References

[1] R. Martinuzzi, "Recirculation effects in sorbent beds for direct-air carbon capture," Project Proposal Form, ENME 501/502 Mechanical Engineering Capstone Design Project, Schulich School of Engineering, University of Calgary, 2023.