Company Information

Company Name	*Lawrence Livermore National Lab*	**Date Submitted**	*09/27/2022*
Project Title	*Autonomous investigation of rivulet formation in CO_2-scrubbing column packing designs* ***(LLL_CO2)***	**Planned Starting Semester**	*Fall 2023*

Senior Design Project Description

Personnel

Typical teams will have 4-6 students, with engineering disciplines assigned based on the anticipated Scope of the Project.

Please provide your estimate of staffing in the below table. The Senior Design Committee will adjust as appropriate based on scope and discipline skills:

Discipline	**Number**	**Discipline**	**Number**
Mechanical	3	Electrical	1
Computer	1	Systems	
Other ( )			

Company and Project Overview:

For 70 years, the Lawrence Livermore National Laboratory (LLNL) has applied science and technology to address nationally important problems. Multidisciplinary teams work together to create solutions to complex technical challenges and build our understanding of fundamental science. Within the Materials Engineering Division, development and deployment of advanced manufacturing (AM) has created new research opportunities and challenges. However, the increased design flexibility comes at the cost of increased complexity, requiring new approaches to design systems and evaluate performance.

Carbon capture and utilization is one of the many tools required to reduce net emissions over the next 10

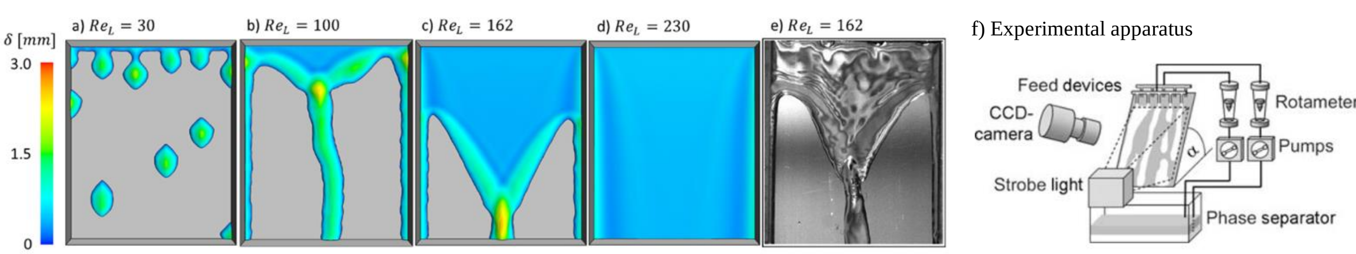

Figure 1. Simulation of transition between a) droplets, b-c) rivulets, and d) sheet flow. Experimental imaging of e) rivulet flow. Prior work established a basic f) experimental set up for measuring rivulets. [1, 2]

years [3], but the cost per ton of CO_2 mitigated must be reduced to make it effective. For industrial applications, carbon capture relies on a structured packing to mix a gas waste stream with a CO_2 absorbing liquid. Due to the dynamic, multiphase physics involved in fluid-gas transport, comprehensively studying these systems computationally and experimentally to rapidly identify key metrics affecting performance can be challenging. A key metric that has been previously identified is the effective surface area between the liquid and gas. The effective surface area can impact absorption rates and affect the transition from sheet-like flow to narrow rivulets which can compromise the performance of a structured packing design.

Experimentally and computationally, rivulet formation has been studied for flat or angular surfaces using systems such as Fig 1f [1, 2]. With a system consisting of an adjustable flat plate, camera, light source, and pump, a range of flow conditions can be produced. However, packings with smooth curves with gradual, spatial variation throughout the column may have the potential to increase performance, but there is little experimental data on such systems. Prior flat plate experiments may neglect the impact of curved surfaces on rivulet formation.

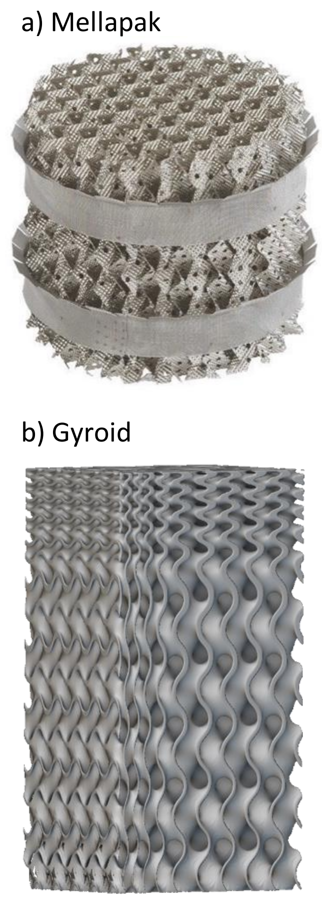

Figure 2. Examples of a) commercial Mellapak structured packing and b) a conceptual gyroid packing

While additive manufacturing (AM) can enable the creation of new packing geometries, evaluation of their performance is time intensive. Commercial packings, such as Fig 2a, feature sharp angles with uniform variation, but a gyroid design like Fig 2b features smooth curves that vary with distance along the column, creating a large range of conditions that must be understood. By building the system seen in Fig 1f and replacing the flat plate with an addressable, deformable membrane, a range of curvatures approximating a gyroid surface can be evaluated for rivulet formation. Furthermore, since the system is self-contained, the parameter space can be traversed by a machine learning agent, allowing for autonomous experimentation, the process of generating a library of information with minimal manual intervention [4]. This will help us better understand the liquid hydrodynamics and flow distribution on curved surfaces, which are building blocks of any triply periodic minimal surface packings.

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Project Requirements:

The objective is to design and assemble an apparatus for measuring rivulet formation on a deformable membrane.

1. *Enclosure requirements*
   a. Reservoir to recapture fluid
   b. Pumps with flowrate control
   c. Manifold to uniformly dispense fluid

   d. Lighting system to illuminate fluid
   e. Camera for imaging fluid on membrane surface
2. *Deformable membrane*
   a. Selection of materials with varying wettability for water
   b. Adjustable radius of curvature along and across direction of flow
   c. Adjustable radius of curvature for periodic patterns
   d. Allow both positive and negative curvatures i.e. convex or concave shaped membranes
   e. Combinations of previous curvatures into complex surfaces
   f. Adjustable tilt angle
3. *System control API should enable access to:*
   a. Camera images
   b. Light source (if included)
   c. Pump state (on/off) and flow rate
   d. Membrane deformation

<u>Expected Deliverables/Results:</u>

Physical system
- Operational prototype
- Functioning camera, pumps, reservoir, and deformable membrane

Control System
- REST API, implemented in any language, python preferred

Documentation
- Complete design narrative
- Instruction manual for API access
- Design drawings for all subsystems in 3D format
- Bill of materials for all subsystems

<u>Disposition of Deliverables at the End of the Project:</u>

The work product will be displayed at the last Expo then immediately handed over to the supporter unless arrangements are made to deliver at a later date.

<u>List here any specific skills, requirements, specific courses, knowledge needed or suggested (If none please state none):</u>

Courses (Strongly Preferred):
- Instrumentation (MEGR 3171)
- Fluid Mechanics (MEGR 3114)

Courses (Preferred):
- Thermal/Fluids Laboratory (MEGR 3251)
- Mechatronics (MEGR 7222)

ET Equivalents:
- Instrumentation - ELET 2241
- Fluid Mechanics -ETME 3133
- Thermal/Fluids Laboratory (MEGR 3251)-ETME 4244L

Other:
- Good results in Junior Design

References:

1. Olenberg, A. and E.Y. Kenig, *Numerical investigation of liquid flow morphology in structured packings.* Chemical Engineering Science, 2020. **219**.
2. Hoffmann, A., et al., *Detailed Investigation of Multiphase (Gas–Liquid and Gas–Liquid–Liquid) Flow Behaviour on Inclined Plates.* Chemical Engineering Research and Design, 2006. **84**(2): p. 147-154.
3. IPCC, *Climate Change 2022: Mitigation of Climate Change*. 2022.
4. Gongora, A.E., et al., *A Bayesian experimental autonomous researcher for mechanical design.* Sci Adv, 2020. **6**(15): p. eaaz1708.