Contract No:

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Heat and Mass Transfer Study to Understand TCAP Scale Up

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Savannah River National Laboratory®
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

Overview & Relevance

Project start date:
10-01-2019
Project end date:
09-30-2019

Budget
FY19 funding:
- $255K

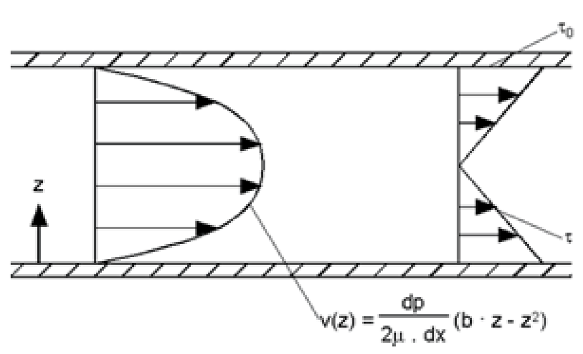
FY20 funding
- $300K requested project not selected

Partner
- Auburn University

Overall Objective:
- Understand the fundamental physics of the efficiency losses previously noted during TCAP scale up and devise means to overcome them.

First Year Objectives:
- Determine the factors affecting and affected by gas mass transfer
- Determine the factors affecting and affected by heat transfer

Technology Drivers:
- SRNL TCAP (Thermal Cycling Absorption Process) is the world's leading technology in hydrogen isotope separation
- Scale-up of TCAP is nontrivial
  - Issues with column scale up in tritium facility in 2004
- External inquiries received for TCAP at up to 1000x higher throughput
  - Demonstration fusion energy projects will require both large-scale hydrogen isotope separation and water detritiation



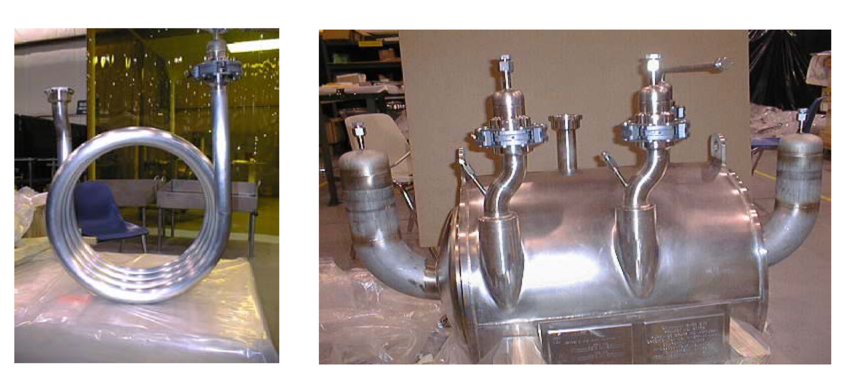
Hypothesis:
- Temperature gradients across the column diameter affect isotope separation factors in larger columns

van Deemter equation (plate height):

$$HETP = 2\frac{D_L}{u} + \frac{(uF_l/\alpha)}{(1+KF_l/(1-F_l))}$$

Navier-Stokes equation (viscous fluid):

$$\rho\frac{D\boldsymbol{u}}{Dt} = -\nabla(p - \zeta\nabla\cdot\boldsymbol{u}) + \mu\nabla^2\boldsymbol{u} + \frac{1}{3}\mu\nabla(\nabla\cdot\boldsymbol{u}) + \rho\boldsymbol{g}$$



Internal helical coil for HT-TCAP column (left) and assembled HT-TCAP unit (prior to installation)

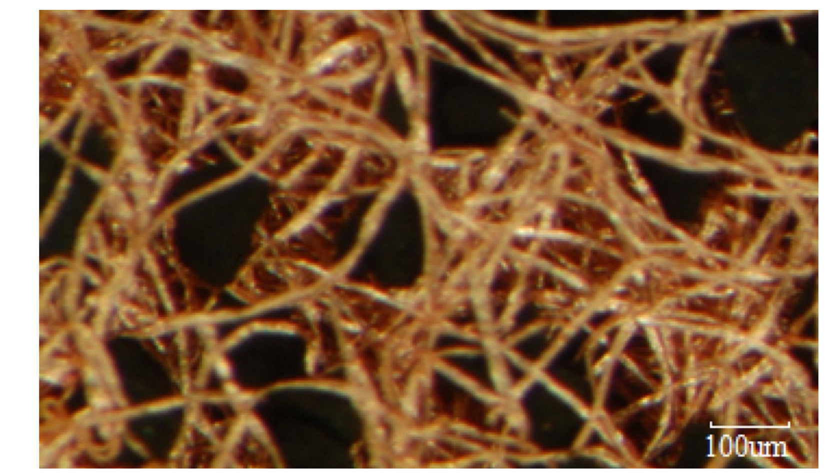
Approach

TCAP Scale-Up

- TCAP has been successfully scaled down
- Next challenge is scale-up

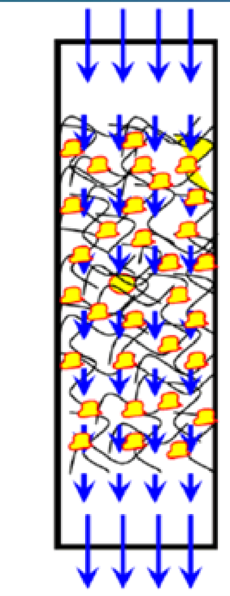
Heat and Mass Transfer

- Use of microfibrous metal packing material



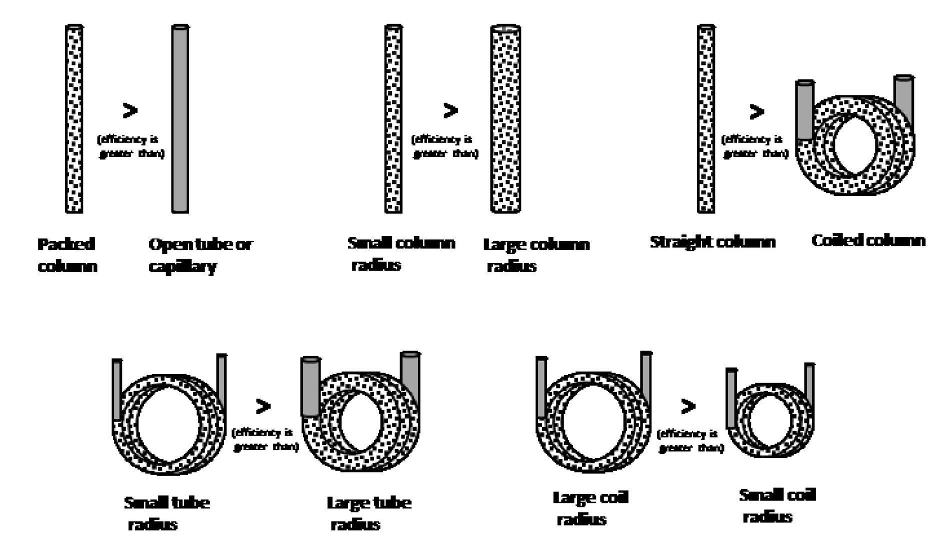
Microfibrous Matrix Benefits
(1) Uniform velocity profile
(2) Minimized channeling
(3) High thermal conductivity (M)
(4) Superior wall contacting
(5) Fast heat transfer (M)
(6) Near isothermal temperature profile (M)

(M) Metal microfibrous media only



Technical Progress (Accomplishments)

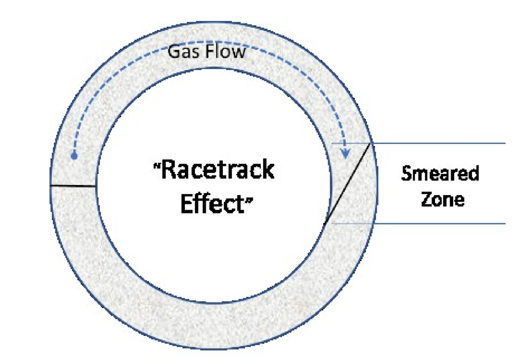
Literature Review and Model Development



- Identified previously unrecognized mathematical model to account for impact of coiled geometry in packed columns

$$H = \frac{7\,v r_0^4}{12 R_0^2\,\gamma D_g}$$

Giddings Equation



Packed Coil

$$\text{Stage Height} = \frac{7\,(\text{gas velocity})\,(\text{tube radius})^4}{12\,(\text{coil radius})^2\,(\text{packing factor})\,(\text{gas diffusivity})}$$

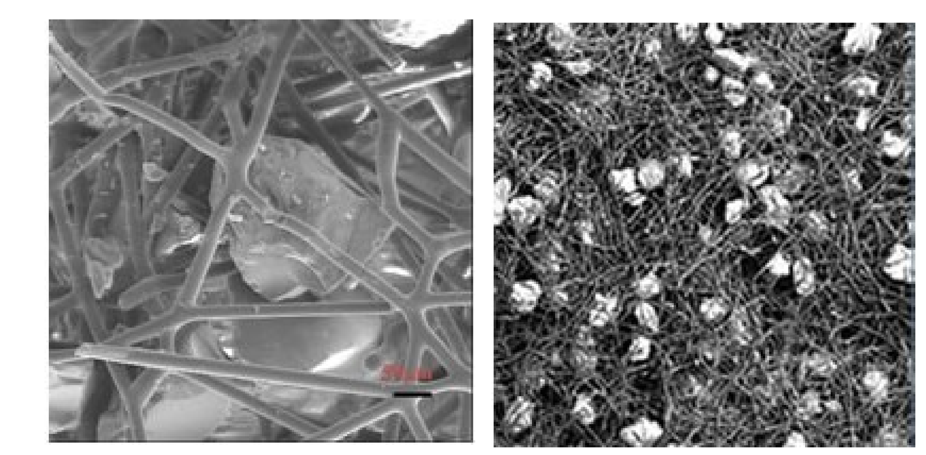
Smaller stage height → better separation efficiency

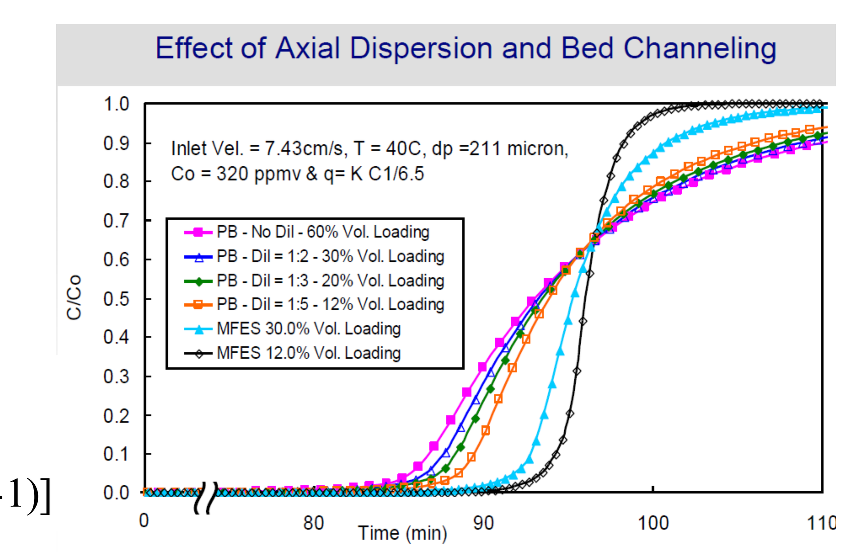
Use of a coiled packed column amplifies the negative effect of tube radius increase on column efficiency

For n stages in series Y(S)=1/[S*(1+ τ *S)^n]
Inverse Laplace transformation
Y=1-e^(-t/ τ)*[1+(1/1!)*(t/ τ)^1+(1/2!)*(t/ τ)^2+……+(1/(n-1)!)*(t/ τ)^(n-1)]

University Collaboration

- Fabrication development of microfibrous metal materials from Auburn University/IntraMicron, Inc.
- Model development for heat and mass transfer





Collaborations

Savannah River National Laboratory
- Defense Programs Technology
- National Security Studies

Auburn University
- Prof. Bruce Tatarchuk

Remaining Challenges and Barriers

- Need sustained program support for scale-up
- Need deeper scientific understanding and breakthrough discovery

Proposed Future Work

- Build prototype according to modeling results
- Validate performance of prototype

Project Summary

- Studied prior art in adsorption and isotope exchange phenomena
- Conceptualized one theory to account for possible mixing mechanism
- Experiments and model validation in progress
- Parameters to be optimized

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