Sustainability Fee Project Grant Report Guidelines
for grants awarded during FY2015-
Due by 5pm August 1, 2015
Email pdf or word doc to cfs@georgiasouthern.edu

Please provide the following information in order to help the Center for Sustainability document the success of the Sustainability Fee Grant Program.

/Date: 7/27/2015
/Name(s): Mujibur Khan (PI) Spencer Harp (Co-PI)
Unit/Department(s): Mechanical Engineering
E-mail address: mkhan@georgiasouthern.edu; sharp@georgiasouthern.edu
Phone: 912-468-8004
Project title: Nanofiber based carbon capture technology to reduce CO_2 Emissions in GSU Campus
Amount granted: $ 30,044.00
Amount spent:$20079.75

Project Outcomes/Value
Detail the planned and actual outcomes of the project here.

Planned outcomes
The testing idea of nanofiber based CO_2 filter to capture and reduce the CO_2 emission.

The project will demonstrate the greenhouse gas emission sources exits with in the campus and enhance awareness about its impact on the long term environmental sustainability among the GSU community.

Integration of faculty, technician, graduate and undergraduate students efforts for the long term sustainability.

It also develops partnerships with existing entities on campus to help facilitate activities for environmental sustainability to make positive cultural change.

Actual outcomes

We have processed and fabricated a nanofiber membrane based filter canister (PAN (Polyacrylonitrile) Nanofiber Membranes Functionalized with MOF (Metal Organic Framework)) to test for CO_2 Capturing. We have also designed and build a small scale test bench to test the absorbance of CO_2 by the nanofiber based membrane.

The project integrated a team work involved faculty, laboratory supervisor, graduate and undergraduate students to test and implement the idea of reducing the CO_2 from our environment. It develops the partnership and awareness with students by demonstrating the project and explaining the importance to reduce the CO_2 emission even if it is smaller scale. It also developed partnership with

i^2STEM through outreach program to high school science teachers and students to make aware about our environment and the future impact of the greenhouse gases.

Project Timeline - Is your project *completed* or still *in progress*?
If not yet completed, please explain why it is delayed and provide a projected completion date.* (*Note – an amended final report will be due one month after the projected completion date).

Project Outcomes -List the *proposed* project goals/objectives and *actual* outcomes of the grant. Describe any successes, challenges and observations.

Proposed project goals

a) Fabrication of electrospun nanofiber mesh/sieves with Metal Oxide Frameworks for capturing carbon dioxide (CO_2).
b) Design and development of CO_2 filter using the electrospun nanofibers.
c) Installation and performance testing of the CO_2 filters at the CO_2 emission sites within the GSU campus.

We have designed and fabricated the electrospun nanofiber mesh/sieves with Metal Oxide Frameworks based filter canister and test bench to do the performance tests.

We have been successful to electrospun fiber mat and functionalize MOF on the fiber mat and tests its gas selectivity and absorbance capacity. The challenge was in the synthesis and fabrication of such system with very high specific surface area to absorb increased amount of gases. We were successful to produce the MOF particle in micron scale which trapped within the nanofiber mat.

The challenge is to produce the particles in nano size and uniformly distribute the fictionalize particle on the fiber surface to create more surface area to enhance the absorption of the gas.

Sustainability Improvements – clearly state how your project has improved campus or community sustainability and explain how you assessed the improvement. If funds were used to purchase products intended to reduce energy, water use, waste, labor cost, etc., please provide information and calculations that show the expected return on investment for your grant.

Based on the test we conducted the nanofiber based membrane loaded with MOF shows that it can absorb CO_2 gases. Increasing its efficiency potentially can have impact on the emission reduction. Such project shows the concern and awareness of CO_2 emission (greenhouse gases) and efforts to reduce them from our environment.

Given the proximity of the project to the students, dozens of students were informed about the nature of the project and the technology being sought for. Several of these students showed great interest in the research and will hopefully participate in continuing this work.

Outreach – how did you publicize your Sustainability Fee grant/project? Please attach copies of all publicity (news articles, web pages, fliers, newsletter, etc.) associated with your grant. If no publicity measures have been taken yet, what are your plans for publicity of your project?

The project was demonstrated and explained as part of our effort to improve sustainability through nanotechnology to the participant of the Nanotechnology professional development workshop for the school science teachers of the south east Georgia. Nanoscale Professional Development. Thirteen teachers representing 4 school districts (Burke, Candler, Bulloch, and a charter school) in Southeast Georgia attended this year's nanoscale professional development opportunity. This outreach program was organized by i^2STEM. Dr. Khan was the PI and faculties from other department (Chemistry and Biology) were also involved in the workshop.

The project has also been demonstrated to another group of teachers (approximately 24 teachers) from Bibb county, Bryan county, Burke county, Bullock and Fulton county through STEM Workshop. Both were part of the outreach to the school kids through their teachers.

Demonstration During The Nanomaterials Workshop 2015

Budget report- provide an explanation of how all funds were used and explain any deviation from the original budget.

The funds were used for student salary (graduate and undergraduate students) and the fringe benefit. Funds were also used to procure equipments, materials, chemicals and supplies (operating costs).

The students and their hours those were hired through the budget are mentioned in the next section.

Equipments:

- ThermoScientific Microcentrifuge,
- Talboys Model 134-2 Heavy Duty Constant Torque Mixer,
- NDIR CO_2 Sensors and Sensor Pump Accessories (filters, pump motors, tubes, USB ports for Data Acquisition) from CO2Meter.
- Two Mixed Calibration Gas Cylinders (1% CO_2/ 99% N_2 and 10% CO_2/ 90% N_2) from Airgas.

Chemicals:

- Polymers: Polyvinylpyrrolydine (PVP), Titania, Polyacrylonitrile (PAN)
- MOF Chemicals: Trihydrate Copper Nitrate, Trimesic Acid, Magnesium Nitrate Hexahydrate, Dihydroxybenzenecarboxylic Acid (H_4dhtp)

- Solvents: Ethanol, DMF, Deionized Water, DMAc.

Materials and supplies:

- For Electrospinning: Dispensing syringes, Needles, Luer locks, Chemically Resistant Spinning Tubes.
- For Test Setup: PVC Pipes, Pressure Gauge, Flow Regulators, Block Valves, O-rings, ABS Material for 3D Printing, Canister Materials.
- Others: Separator funnel, Buchner funnel, filter paper, Pipettes, Safety supplies, Battery, Stir bars, Media Bottles, wipes, gloves.

Student and Community Impact

Because these grant funds come directly from a $10 Student Sustainability Fee, it is important to document how they benefit students. Please provide information on the following:

#Undergraduate students employed by the grant, and length of employment (# hours/week for x weeks)

Jeffrey Neumann: 8-10 hours/week; for 18 weeks approximately. Jeffery Neumann was a senior Mechanical Engineering student and was in his final semester in spring 2015. He graduated and did not continue in the summer as he was planning to get a professional job.

#Graduate students employed by the grant, and length of employment (# hours/week for x weeks)

James Denham: Was hired in August 2014 as a graduate research assistant, However he quit from the graduate program at the beginning of October. His working hours was 20 hours/week about 8-9 weeks.

As because at that point no graduate student was possible to hire for the project until January 2015, The PI has engaged another graduate student (Wahiduzzaman) to work on the project who was hired through his start up grant as an RA

Wahiduzzaman : 20 hours/week for about 16 weeks. 12-15 hours/week for about 14 weeks. Quazi

Nahida Sultana: Was hired in January 2015 to join on the ongoing project. Hours: 20/week; 30 weeks.

volunteers involved in the project, including total # of volunteer hours

Micheal Santangelo and Christopher Gerdman, Mechanical Engineering Junior; helped in the machine shop for machining and 3D printing of few designed parts.

We also acknowledge the help from Kyle Edward (Chemistry Student who has already graduated) and Nathan Takas (Laboratory supervisor) to assist using some characterization equipment and interpretation of the spectra's involved in the characterization.

students reached through classes or other means

The project was shown to the PIs manufacturing class (approximately 38 students) as part of the nano manufacturing demonstration and how it can help our long term environmental sustainability.

community members reached

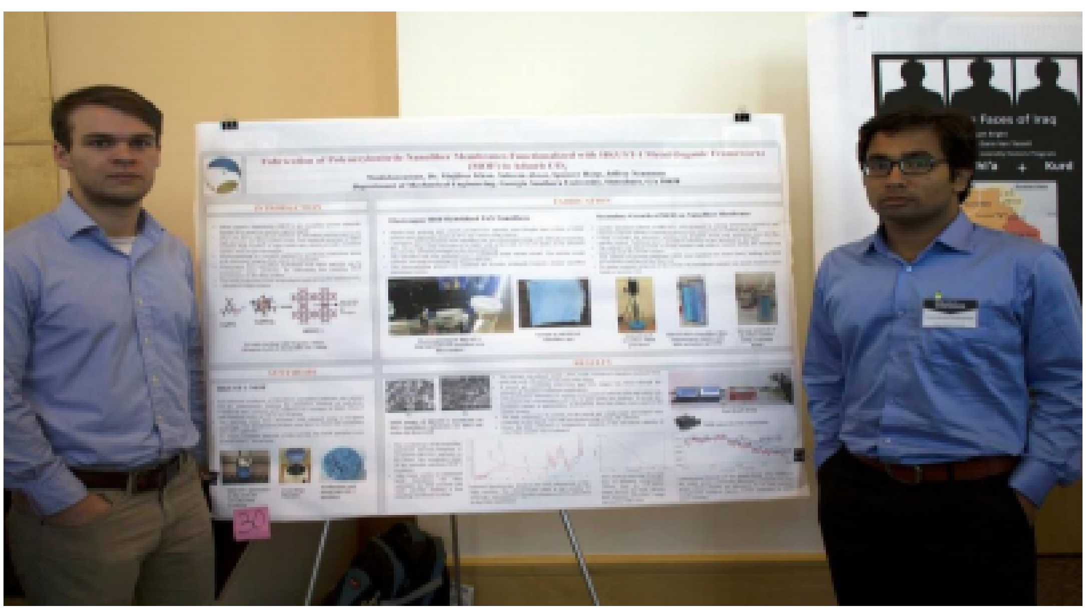
The project was demonstrated to approximately 39 school teachers through two different Workshop (Nanotechnology work shop and STEM work shop through i^2 STEM center) of different school district at south east Georgia.

Grant Leverage

Were you able to leverage your work for additional outcomes? Indicate the following if they apply.

Presentations given on grant work (indicate if local, regional, national, international, list title and conference name and date)
Papers published, in press or in preparation (indicate student authors with an asterisk)
Grants leveraged (list granting agency, amount awarded)

- An International conference paper has been accepted to present this work:
  Wahiduzzaman, Mujibur Khan*, Spencer Harp, Saheem Absar, Kyle Edwards, Nathan Takas; "Fabrication of PAN (Polyacrylonitrile) Nanofiber Membranes Functionalized with MOF (Metal Organic Framework) for CO_2 Capturing."; 2015 IMECE, International Mechanical Engineering Congress and Exposition, November 13-19, 2015, Houston, Texas.
- Poster Presentation: Research Symposium 2015, Georgia Southern University • Project Presentation: Sustainability Showcase and Earth Day Celebration, Georgia Southern University
- Journal Paper Under Preparation:
  Wahiduzzaman, Mujibur Khan, Quazi Nahida Sultana, Spencer Harp, "Electrospun PAN (Polyacrylonitrile) Nanofibers Functionalized with HKUST-1 Metal Organic Framework (MOF) Nanoparticles to Adsorb CO_2 Gas"



Poster Presentation at Research Symposium 2015

Project abstract

Provide a one paragraph abstract of the completed project and a photo (preferably including some of the people involved with the project at work) to be posted on the CfS web page.

Also include links to all web pages on which this work is discussed or displayed.

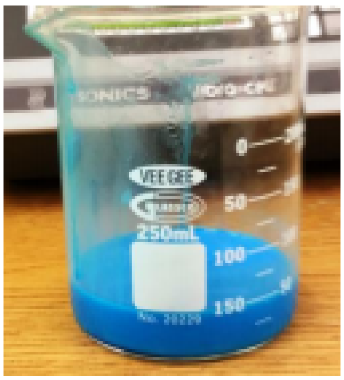
ABSTRACT

Crystalline particles known as Metal Organic Frameworks (MOF's) are known for their large surface area and high adsorption and storage capacity for CO_2 gas. Electrospun nanofibers are considered as ideal substrates for synthesizing the MOF particles on the fiber surface. Two types of MOF were considered; MOF-Mg-74 and HKUST-1. Polyvinylpyrollidine (PVP) was chosen as the precursor for nanofibers. Apparently, HKUST-1 was chosen as the working MOF because of its high adsorption and storage capacity for CO_2 and good functionality at high temperature and pressure. It's a Copper based MOF, synthesized solvothermally by mixing Copper Nitrate and an organic linker called Trimesic Acid. The end product was washed with Ethanol multiple times, and then separated by using a centrifuge. Drying the particles in room temperature gives them a crystalline octahedral porous structure. Bicomponent electrospinning of PVP and HKUST-1 was performed to observe the formation of MOF particles on the fiber. SEM images showed very little attachment of the MOF particles which is not desired to be effective at gas adsorption purpose. Therefore, another approach of electrospinning PAN polymer hybridized with HKUST-1 particles was undertaken. To achieve stronger fiber substrates, Polyacrylonitrile (PAN) was chosen as the precursor for its high strength and thermal stability. Both the polymer and particles were dissolved in Dimehtylformamide (DMF) which was used as the primary component solution for electrospinning. SEM images of the electrospun fibers showed formation and impregnation of small MOF particles which eventually forms the seed layer for the attachment of further MOF inclusion on the fiber. The fibers were electrospun in a canister model collector on a bulk scale, making it a thick fiber mat. To increase the amount of MOF on the fiber mat, a secondary solvothermal process of MOF particles growing on the fibers was then executed to increase the amount of MOF particles for effectual gas adsorption. This process consists of synthesizing a MOF gel like solution made by Ethanol where suspension of MOF particles is evident. This sol-gel was used to incorporate further MOF particles on the fiber substrates. The fiber mat was then dried and heated under vacuum oven to ensure complete removal of the solvent. This procedure was carried on at multiple cycles, leading into substantial amount of MOF accumulation on the fiber substrates. SEM images showed uniform distribution of porous MOF particles of 1-2μm in size on the fiber surface. EDS report of the fiber confirmed the presence of MOF particles through identification of characteristic Copper elemental peaks of HKUST 1.Thermogravitmetric analysis (TGA) of HKUST-1 doped PAN fiber displayed 32% of total weight loss between 180°C and 350°C thus proving the as-synthesized MOF particles are thermally stable within the mentioned temperature range. A comparative IR spectroscopic result between the gas-treated and gas untreated fiber samples showed the presence of characteristic peak in the vicinity of 2300 and 2400cm^{-1}

which corroborates the assertion of adsorption of CO_2 on the system. To test the fiber based filter system, an experimental test bench was built containing a cylindrical gas chamber and a compressed gas flow tank contains CO_2 and N_2. The inlet and outlet ports of the gas chamber were 3D printed. Two Non-dispersive Infrared (NDIR) sensors were placed into the inlet and outlet to measure the concentration of CO_2. These sensors are able to read the concentration of CO_2 in the unit of parts per million (ppm).The data collected from the sensors were plotted in the computer (concentration vs time) using GASLAB software. From the

difference between the data collection, the adsorption capacity of the filter canister was evaluated. Initial comparative data analysis from the experimentation at ambient temperature showed 13.76% reduction in CO_2 concentration at outlet for 7 minutes. Another cycle of experiment showed 6.3% reduction in CO_2 concentration for 5 mintutes. The gradual decreasing of the value of reduction signifies the fact that the CO_2 filter membrane might be reaching at its saturation point. A multi-canister housing was also built for another experiment which consists of three filter canister containing gas chambers placed in a closed container. The container is then connected to the compressed gas tank and sensors in a similar way to execute CO_2 adsorption test.

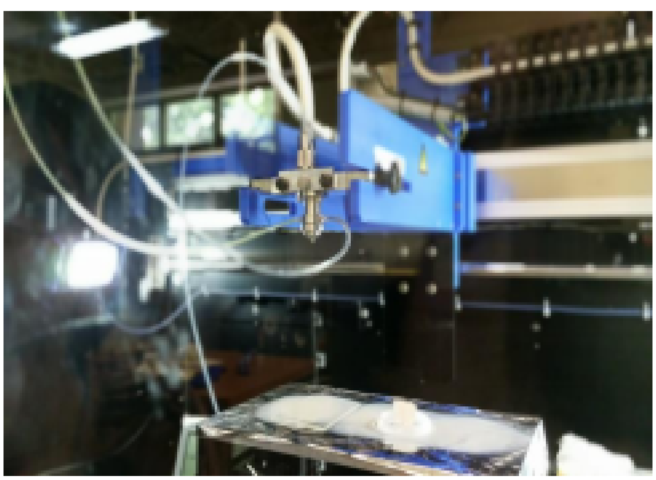
Synthesis of HKUST-1 MOF



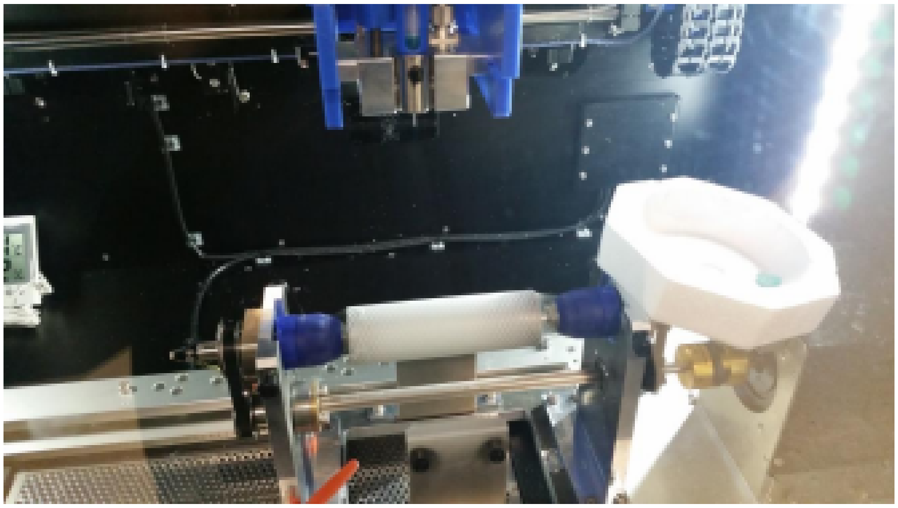
Centrifuge Unit HKUST-1 Particles

Precursor solution

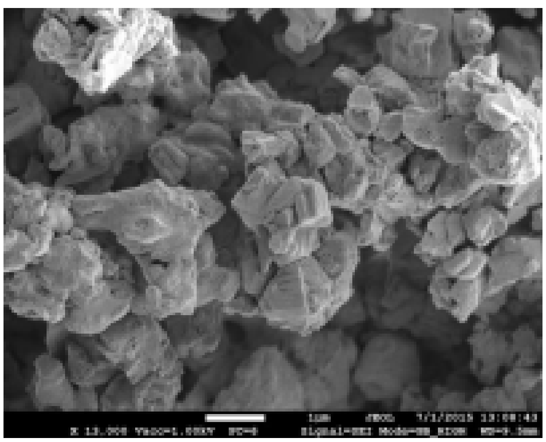
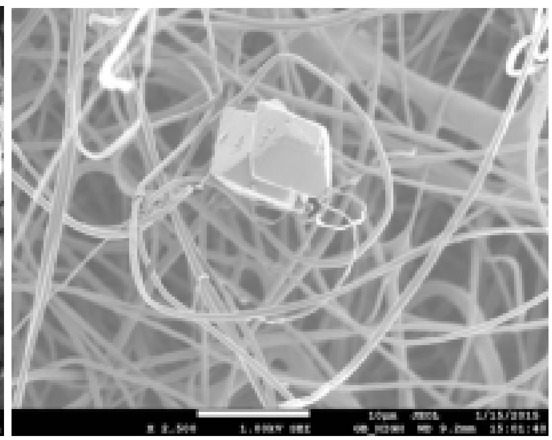
Electrospinning of PAN/HKUST-1 Nanofibrous Mat



Mixing of MOF and PAN Electrospinning of Fiber Sample



Electrospinning of MOF/PAN Hybridized Nanofiber Mat on a Canister

SEM Image of HKUST-1 Sample SEM image of Octahedral HKUST-1 on PAN Fiber Surface

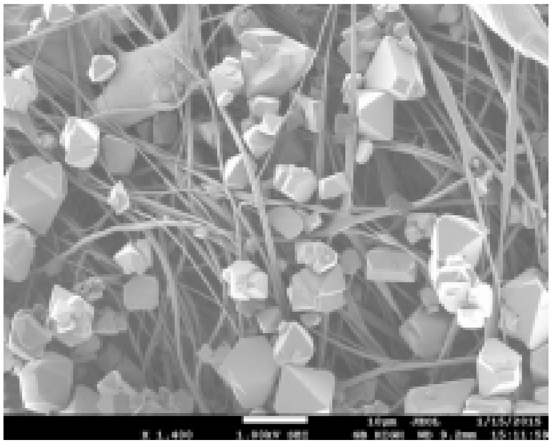
Secondary Formation of MOF Particles



Sonication of

HKUST-1 Precursor HKUST-1 Incorporated

Fiber Mat Vacuum pumping for Solvent Removal



SEM Images of Accumulated HKUST-1 Particles on the Nanofiber Substrates

Experimental Setup for Gas Adsorption

3D Printing of the Test Setup Parts CO_2 Senso

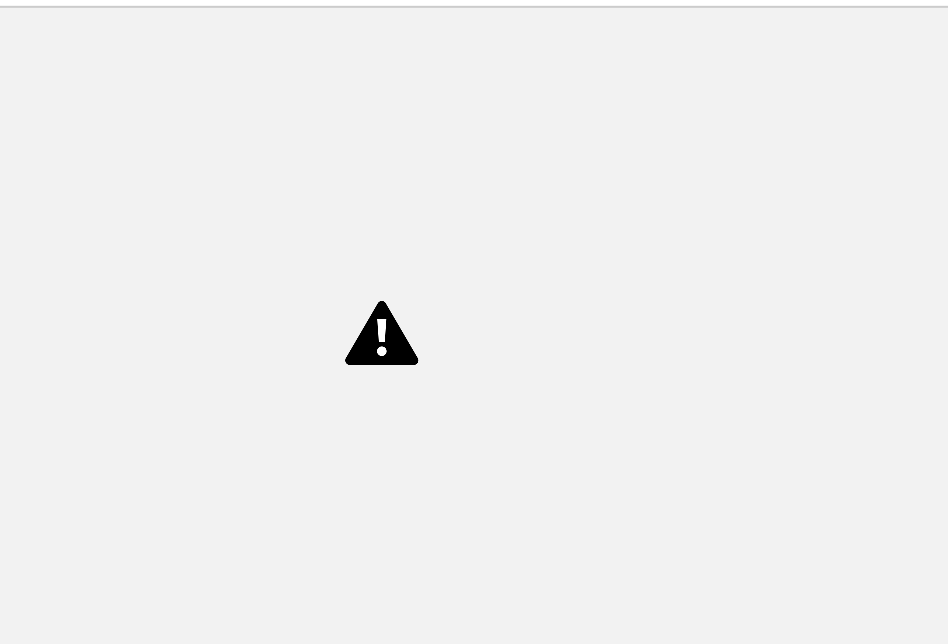
Outlet Valve CO2 Sensors

Senso
r
Filter

Gas Chamber Canister

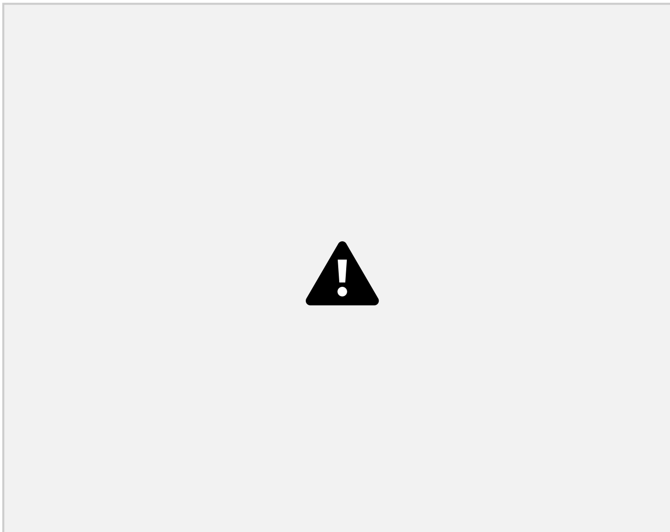
Adsorption

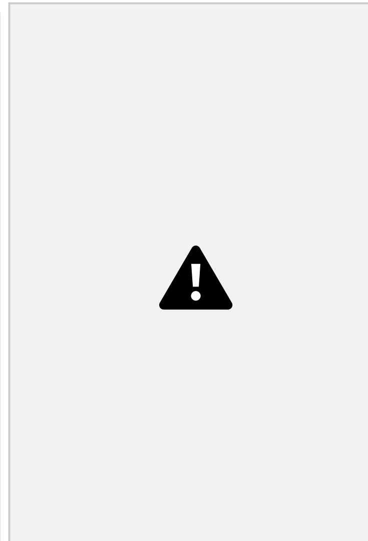
Pump Motor
Pump Kits



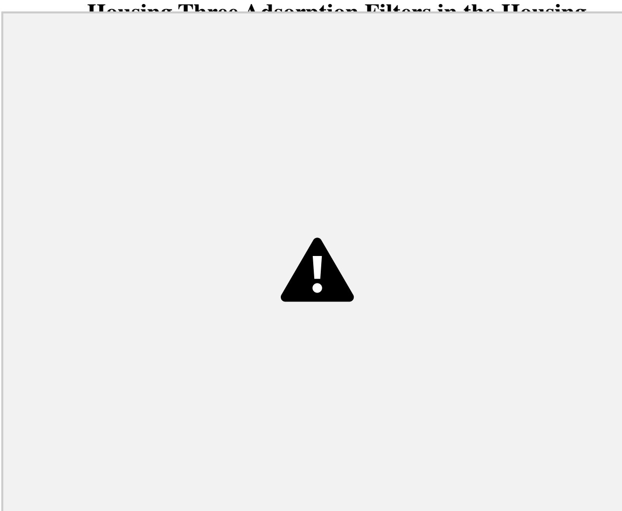
Nanofiber Filter Gas Tank
Containing Gas
Chamber

Experimental Setup for CO_2 Adsorption





Multi-canister Housing Three Adsorption Filters in the Housing



IR Spectroscopy Displaying Characteristic Peak of CO_2 at 2339 cm^{-1} is Visible for Gas Treated Sample

17:23.7 18:06.9 18:50.1 19:33.3

Inlet Sensor Outlet Sensor

205000

200000

195000

190000

185000

180000

Experimental Gas Adsorption results

Project Group Members